Using Argument as a Bridge Between Literacy and Science: An Intervention Study in a Science Methods Course for Elementary Preservice Teachers

Rebeca Grysko
University of Central Florida

USING ARGUMENT AS A BRIDGE BETWEEN LITERACY AND SCIENCE: AN INTERVENTION STUDY IN A SCIENCE METHODS COURSE FOR ELEMENTARY PRESERVICE TEACHERS

by

REBECA A. GRYSKO
B.A. Montclair State University, 2011
M.Ed. Saint Leo University, 2014

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the School of Teacher Education
in the College of Community Innovation and Education
at the University of Central Florida
Orlando, Florida

Summer Term
2019

Major Professor: Vassiliki L. Zygouris-Coe

ABSTRACT

The purpose of this study was to investigate the impact of an intervention on teaching science as argument within a science methods course on elementary preservice teachers' (PSTs') (a) understandings of the nature of science (NOS), (b) knowledge about argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the framework for teaching science as argument to support students' literacy and science learning. This mixed-methods study utilized an embedded quasi-experimental design with a treatment (n = 20) and control group (n = 25). The treatment group instructor, who completed an eight-week professional development course, implemented the intervention protocol across a 12-week period. Throughout the intervention, emphasis was placed on three key components of teaching science as argument (i.e., argument structure, public reasoning, and the language of science). The control group instructor, who did not partake in any professional learning activities, implemented business-as-usual instruction. Results from a repeated measures MANOVA revealed that, although the intervention did not have a significant impact on PSTs' knowledge of argumentation, PSTs who received the intervention did demonstrate a significant increase in their understanding of the NOS and in the complexity of their written explanations, as compared to PSTs who did not receive the intervention. Furthermore, analysis of PSTs' written lesson plans revealed several themes (i.e., opportunities for students to collect and analyze data, use of scaffolds for helping students construct scientific explanations, emphasis on the use of text to support scientific inquiry, and attention to developing students' science vocabulary) consistent with the framework for teaching science as argument. These findings contribute to a growing body of evidence illustrating the effectiveness of intentionally designed teacher preparation

experiences for developing PSTs' knowledge, beliefs, and practices for supporting students' engagement in scientific explanation and argument.

For Matt, for your constant encouragement and support of my ambitions.

And for all "young scientists", especially Ryan. May you never lose your curiosity and wonder about how the natural world works.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my dissertation committee chair and academic advisor, Dr. Vicky Zygouris-Coe. You played an instrumental role in not just the completion of this dissertation, but also in my growth and development as a scholar. I will be forever grateful for the mentorship, guidance, and support you provided throughout my entire doctoral journey.

I also owe tremendous gratitude to the members of my dissertation committee, Dr. Haiyan Bai, Dr. Su Gao, Dr. Zihui Fang and Dr. Sherron Roberts, for their time, expertise, and guidance. Your feedback helped me to develop not only a greater understanding of the issues, theoretical frameworks, and implications surrounding the topic of my study, but also of the research process itself. Each one of you, individually and as a whole, have played a significant role in my success a doctoral student.

A sincere thank you to the course instructors who welcomed me into their classrooms and enabled this research to take place. I hope to continue this line of work with you in the future! To Courtney Lopas, my loyal research assistant, thank you for devoting countless hours to assisting me with data collection and analysis. I owe you several cups of coffee! To my editor, Dr. Mary Ann Lynn, thank you for all your support and feedback during the dissertation-writing process. I would also like to thank my peers and colleagues in the program for their camaraderie and fellowship. I am truly grateful to be a part of such an inspiring group of passionate educators!

Last, but most importantly, thank you to my family. Without the support of my husband, Matt, this academic achievement would not have been possible. Thank you for encouraging me to take the initial plunge and supporting me throughout the entire journey. And to my Ryan,

thank you for all your smiles, hugs, and giggles; you brought me much joy at the end of hard days.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE:
INTRODUCTION

Background

This study was conducted to investigate the impact of a one-semester intervention (12 weeks) focused on teaching science as argument within a science methods course on PSTs' (a) understandings of the nature of science (NOS), (b) knowledge about argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the Teaching Science as Argument Framework (TSAF) when planning for science instruction. This chapter begins with an overview of the research problem and the purpose of the study. Next, both the conceptual and theoretical frameworks are explained. Following the guiding frameworks, the research questions, null hypotheses, and significance of the study are presented. This chapter concludes with limitations, delimitations, assumptions and operational definitions.

Statement of the Problem

In the rapidly evolving world of the 21st century, the need for a scientifically literate populace is greater than ever before. According to the Science Framework for the 2015 National Assessment of Education Progress, a scientifically literate person

> …is familiar with the natural world and understands key facts, concepts, principles, laws, and theories of science, such as the motion of objects, the function of cells in living organisms, and the properties of Earth materials. Further, a scientifically literate person can connect ideas across disciplines; for example, the conservation of energy in physical, life, Earth, and space systems. Scientific literacy also encompasses understanding the use of scientific principles and ways of thinking to advance our knowledge of the natural

world as well as the use of science to solve problems in real-world contexts. (National Assessment Governing Board, 2014, p. x)

Despite the centrality of science to one's ability to thrive in the 21st century, a troubling number of students in the United States are struggling to acquire even the most basic concepts, skills, and abilities in science (National Center for Educational Statistics [NCES], 2015). The National Assessment of Educational Progress (NAEP) science assessment measures both students' science content knowledge and the understanding of science practices and is based on an understanding on what scientific literacy means. Results from the NAEP are reported as percentages of students performing at or above three achievement levels (Basic, Proficient, and Advanced). According to the descriptions of achievement levels used by the NAEP, students performing at or above Proficient "demonstrate solid academic performance and competency over challenging subject matter" (NCES, 2012). In contrast, students who fail to meet the criteria for Proficient tend to demonstrate only "partial mastery of prerequisite knowledge and skills that are fundamental for proficient work at each grade" (NCES, 2012).

According to the 2015 NAEP achievement-level results in science, 24% of fourth graders, 32% of eighth graders, and 40% of 12th graders perform below the Basic level; 38% of fourth graders, 32% of eighth graders, and 22% of 12th graders perform at or above the Proficient level; and very few students in Grades 4 (1%), 8 (2%), and 12 (2%) perform at the Advanced level (NCES, 2015).

Results from international tests, such as the Trends in International Mathematics and Science Study (TIMMS), also have indicated that students in the U.S. are performing at a "just average" level in science. Although U.S. students still score higher than students in many

countries, they continue to lag behind students in the top-performing countries, such as Singapore, the Republic of Korea, the Russian Federation, and Japan (Provasnik et al., 2016).

The troubling state of science education has serious consequences for the preparation of a highly skilled scientific workforce, threatening to leave many young Americans unprepared to thrive in a global economy and to solve problems of the future. In response to this issue, a series of reform initiatives focused on improving science teaching and learning have surfaced. Recommendations promote an inquiry-oriented approach to science teaching (National Research Council, 2012; NGSS Lead States, 2013) as well as the use of language and literacy practices to support students' engagement and learning in science (Fang, Lamme, & Pringle, 2010; Hand et al., 2003; Wellington & Osborne, 2001). Developing students' language and literacy abilities in inquiry-based science is viewed as a crucial step in creating a scientifically literate populace who can engage in conversations about local, national, and global scientific issues (Fang et al., 2010).

Two key disciplinary literacy practices in science are constructing explanations and engaging in argument from evidence (Krajcik & Sutherland, 2010; National Research Council, 2012; Osborne, 2010). Building explanations and engaging in argument are complementary discursive practices through which new and reliable scientific knowledge is constructed (Boyer, 2016). It has been suggested that engagement in explanation and argument not only helps to develop students' content learning and understandings of the nature of science, but also students' fluency in the language and discourse patterns of science (Jimenez-Aleixandre & Erduran, 2007). For these reasons, explanation and argument are considered to be central components of science education in terms of the Next Generation Science Standards (NGSS Lead States, 2013) and in

the view of various scholars (e.g., Driver, Newton, & Osborne, 2000; Osborne, 2010; Zembal-Saul, 2009).

The call to incorporate explanation and argument in science education presents new challenges for teachers, especially at the elementary level. At a time when proficiency in science is more important than ever, the average time U.S. students spend learning science in the elementary grades has dropped to an all-time low. On average, students in Grades K-2 receive only 18 minutes per day of science instruction while students in Grades 3-5 receive only 22 minutes per day of science instruction (Trygstad, 2013). Furthermore, researchers have found that the little science instruction that does occur is typically teacher-dominated, with few opportunities for students to construct, communicate, or critique evidence-based explanations (Osborne, 2010). Elementary teachers' lack of knowledge of science content and practices (Davis, Petish, & Smithey, 2006), inadequate knowledge of the NOS (R. Duschl, 2000; Lederman, 1992), and limited pedagogical skills for supporting students' construction of scientific explanations (Zembal-Saul, 2009) have all been identified as major barriers to the inclusion of scientific explanation and argument in elementary school science.

To overcome these challenges, preservice elementary teachers (PSTs) need to develop specific knowledge, beliefs, and practices for supporting students' engagement in scientific explanation and argument. This involves developing an understanding of how explanation and argument contribute to the generation of scientific knowledge, learning about the structure of scientific explanations, and acquiring pedagogical skills for using talk and writing activities to scaffold students' construction of evidence-based scientific explanations. In addition, scholars have suggested that teachers must be able to construct evidence-based explanations themselves

before they can support students' successful engagement in explanation and argument (Zohar, 2008). Although the barriers are daunting, there is promising evidence that framing teacher preparation in science around a coherent conceptual framework can assist PSTs in building initial knowledge and practices for teaching science as argument (Barreto-Espino, Avraamidou, & Zembal-Saul, 2014; Boyer, 2016; Zembal-Saul, 2009).

Very few studies have been conducted that explicitly characterized PSTs' knowledge of specific scientific practices, such as constructing evidence-based explanations (Davis et al., 2006). This is particularly true at the elementary level. Without developing sophisticated understandings of scientific explanation, prospective elementary teachers are unlikely to be able to successfully engage their students in this complex scientific practice. Therefore, investigations are needed that examine how purposefully designed teacher education experiences can help PSTs develop their own abilities for constructing evidence-based explanations and initial knowledge and practices for teaching science as argument.

Purpose of the Study

The purpose of this study was to investigate the impact of a one-semester intervention (12 weeks) focused on teaching science as argument within a science methods course on PSTs' (a) understandings of the NOS, (b) knowledge about argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the Teaching Science as Argument Framework (TSAF) when planning for science instruction.

Guiding Frameworks

The following section includes a discussion of two different frameworks that informed this study. The conceptual framework section provides an overview of the Teaching Science as

Argument Framework (TSAF) (Zembal-Saul, 2009). The TSAF was used to guide PSTs' thinking about how to support students' science and literacy learning in tandem during the 12-week intervention, as well as a lens through which to interpret the qualitative data. The theoretical framework section discusses how this study was informed by the notion of science as argument, sociocultural perspectives on human learning, and schema theory.

Conceptual Framework

The conceptual framework, shown in Figure 1, that informed this study "brings together the essential elements of scientific inquiry, in particular giving priority to evidence and explanation and communicating scientifically, with perspectives on argumentation" (Zembal-Saul, 2009, pp. 692-693).

The design of the TSAF was informed by a series of design-based research studies focused on understanding how preservice elementary teachers make sense of elementary school science as argument and on informing iterations of an elementary science methods course (Zembal-Saul, 2009). Findings from these studies suggest that the framework serves as an effective scaffold for enhancing PSTs' understanding of scientific practices associated with explanation and argument.

The three main features of the framework include (a) using an argument structure to support students' construction of scientific explanations and arguments, (b) reasoning publicly about the development of claims from evidence and the evaluation of claims on the basis of evidence, and (c) engaging authentically with the language of science (Zembal-Saul, 2009, p. 693). Each of these features are described in detail in the following sections.

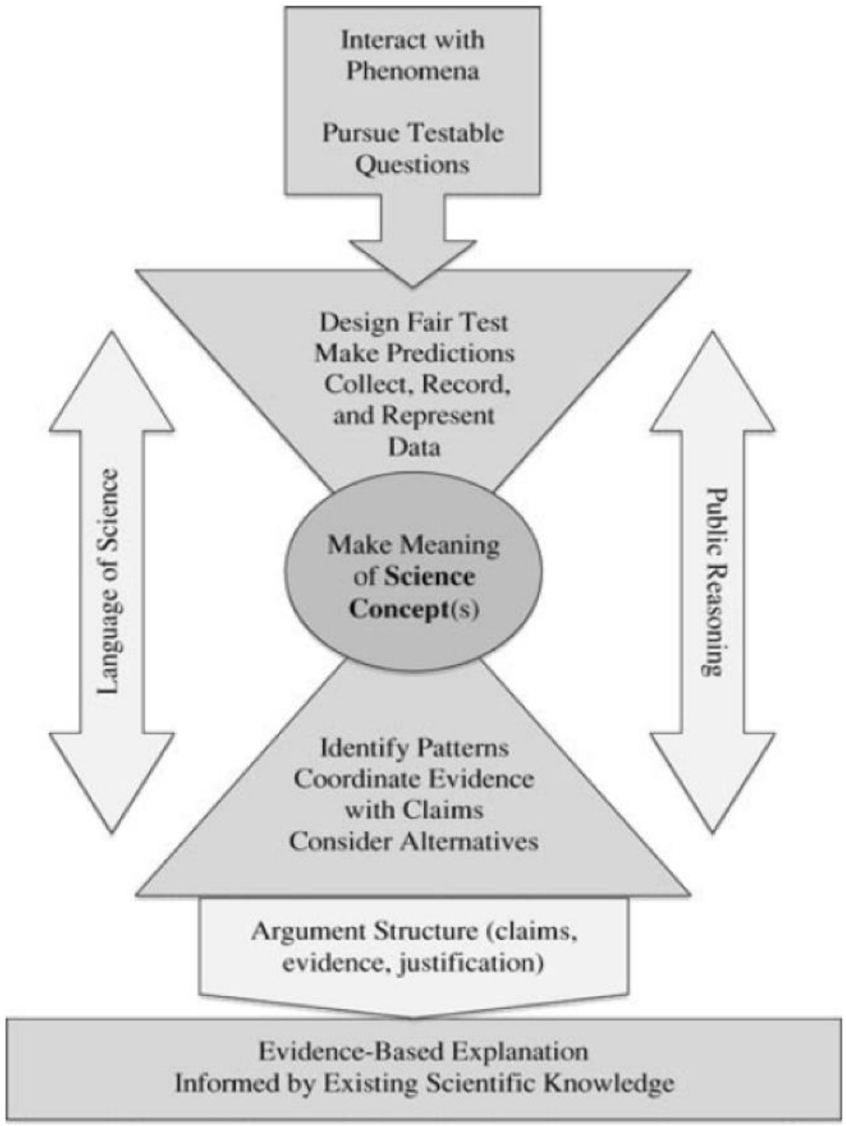


Figure 1. Teaching Science as Argument Framework (TSAF)

Source: from Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education, 93*(4), 687–719. Reproduced with permission.

Argument Structure

The first important feature of the TSAF involves using the structure of argument to support PSTs as they work to construct, communicate, and evaluate scientific explanations. This

component of the framework is intended to call PSTs' attention to important epistemological features of scientific explanations, such as the centrality of evidence in constructing and evaluating knowledge claims. The TSAF explicitly calls for teachers and students to engage in discourse using the claims, evidence, reasoning (CER) framework. The CER framework is a simplified version of Toulmin's (1958) six-part model of argumentation and can be used to provide a reasonable entry point for PSTs and elementary students to participate in argument discourse. The CER framework provides a guide for how a scientific explanation can be organized, as well as the kinds of contributions considered appropriate when participating in science talks (Zembal-Saul, 2009).

<u>Public Reasoning</u>

The second important feature of the TSAF is making thinking visible though public scientific reasoning. According to Zembal-Saul (2009), "this aspect of the framework is intended to call PSTs' attention to the role of classroom discourse and the importance of the process, as well as the product, of argument construction in science leaning" (p. 693). When students are engaged in constructing, communicating, and evaluating scientific explanations, they make their thinking public (Bell & Linn, 2000; Michaels, Shouse, & Schweingruber, 2008; Zembal-Saul, 2009). Talking about their own thinking requires students to process their understandings as they attempt to coordinate claims with evidence and negotiate meaning (Zembal-Saul, 2009). In addition to considering one's ideas in relation to those of others, making thinking visible and negotiating meaning also supports the establishment of social norms for communicating in science. For example, if a teacher consistently prompts students for evidence to support their claims, students will hopefully begin to include evidence as part of their

contributions to discussions. Lastly, when science meaning is negotiated publicly, teachers can monitor and assess student thinking and learning.

The Language of Science

The third important feature of the TSAF is authentic engagement with the language of science. According to Zembal-Saul (2009), this aspect of the framework places emphasis "on the role of language in learning science, particularly how practices such as coordinating claims with evidence and weighing alternatives, contribute to the social negotiation of meaning about science concepts" (p. 693). Language is the key tool for making meaning in science (Gee, 2004; Lemke, 1990, 2001). Scientists use language in conducting scientific inquiries and in explaining and interpreting natural phenomena. They also use language to communicate, evaluate, and challenge scientific knowledge, claims, and arguments (Fang, 2006). Becoming truly literate in science requires students to learn the specialized language used to construct and communicate scientific knowledge.

The language of science differs substantially from the language that children use in daily social interactions (Schleppegrell, 2004). Scientific writing is characterized by range of grammatical features (e.g., technical vocabulary, abstraction, impersonal authoritativeness) that present significant decoding and comprehension challenges for students (Fang, 2006). The technical vocabulary of science, in particular, is a major source of difficulty for students, especially struggling readers and English Language Learners (ELs).

Many technical words in science are polysemous, meaning they have both a science-specific meaning and a more common everyday meaning (Cervetti, Hiebert, Pearson, & McClung, 2015). The word "fault," for example, is used regularly in everyday language to

describe responsibility for a mistake or act of wrongdoing. However, in the context of science, the word, fault, refers to a break in the continuity of rock formation. Scholars (e.g., Pearson, Hiebert, & Kamil, 2007) have noted that such words have the potential to create learning obstacles for students.

In order to support students' ability to cope with the demands of scientific language, it is imperative that teachers incorporate explicit language tasks and instruction into their science teaching (Yore & Treagust, 2006). Examples of language-based strategies include using a concept of definition word map (Schwartz & Raphael, 1985) to enhance students' conceptual understanding of technical vocabulary in science and using sentence frames (Warwick, Stephenson, & Webster, 2003) to scaffold students' use of scientific language when writing and speaking. Embedding such strategies within inquiry-based science instruction can help students learn the vocabulary, functions, syntax, and discourse of scientific language.

In summary, the TSAF is not intended to encompass all discourses and practices of science or all the ways in which teachers can support students' engagement and learning in science. Instead, the TSAF serves to focus preservice elementary teachers' attention on scientific discourse and reasoning in ways that are likely to support their future students' disciplinary learning in science (Zembal-Saul, 2009).

The current study was initiated to expand upon the work of Zembal-Saul and her colleagues (2009) by exploring ways in which the TSAF can be used, not only to help elementary PSTs learn to support students' science learning, but how it can also be used to help them learn to support students' language and literacy development in the context of inquiry-oriented science. As such, the three features of the TSAF (i.e., argument structure, public

reasoning, and language of science) were used as a consistent set of concepts for shaping participants' thinking about how to support both young students' science and literacy learning during the 12-week intervention. A detailed description of how the three core components of the TSAF were emphasized throughout the intervention is included in Chapter 3.

Theoretical Framework

Several theories of learning informed the focus of this study. The contributions of the following theoretical frameworks are explained in this section:

- Science as Argument
- Sociocultural Theory of Human Learning
- Schema Theory

Science as Argument

The main goal of science is to construct new knowledge and understandings about how the natural world works. Two practices crucial to accomplishing this goal are explanation and argument (Osborne, 2010). Professional scientists routinely engage in the construction, communication, and evaluation of scientific explanations. They also engage in evidence-based discourse in which they debate scientific ideas, attempt to persuade others of their arguments, and use evidence to defend their claims. It is through these processes that new and reliable scientific knowledge is co-constructed among members of the scientific community. Furthermore, these processes aid in the revision and refinement of existing scientific knowledge in light of new evidence. For this reason, argument has been viewed as a core discursive practice in science (Kuhn, 1993; Osborne, 2010) and a number of scholars have advocated for its inclusion in the science classroom.

In addition to building students' science content knowledge, scholars (e.g., Newton, Driver, & Osborne, 1999; Osborne, 2010; Zembal-Saul, 2009) and educational reform initiatives (National Research Council, 2012; NGSS Lead States, 2013) have called for teachers to engage students in science and engineering practices, including the construction of explanations and engagement in argument from evidence. Teaching science as argument requires an instructional emphasis on: (a) the role of evidence in the construction of scientific explanations,(b) the communication of scientific ideas in both talk and writing, (c) the criteria used in science to evaluate the validity of evidence-based claims, and (d) the social negotiation of meaning among students through ongoing discussion and debate. Central to teaching science as argument is the recognition that language and literacy play a vital role in the learning, and doing, of science. Language is the primary medium through which knowledge is constructed and learning occurs as students read, write, and communicate in science-specific ways (Fang, 2004; Halliday, 1994; Schleppegrell, 2004).

Various scholars have argued that one of the greatest challenges in learning science is learning the specialized language of science itself (Fang, 2004; Lemke, 1990; Wellington & Osborne, 2001). Unlike the everyday ordinary language students are accustomed to, scientific language, especially in its written form, is overall particularly dense, technical, abstract, and authoritative (Fang, 2004). The unique grammatical features of scientific language pose a variety of comprehension and composition challenges for students. For these reasons, it has been argued that the explicit teaching of scientific language should be a part of science education for all students (Wellington & Osborne, 2001).

Given the importance of language and literacy in science learning, Schleppegrell (2004) reasoned that "Teachers need greater knowledge about the linguistic basis of what they are teaching and tools for helping students achieve greater facility with the ways language is used in creating the kinds of texts that construe specialized knowledge at school" (p. 3). Based on this need, a primary aim of this study was to help PSTs recognize the fundamental role language plays in science leaning through modeling explicit strategies for interacting with science texts and teaching the specialized vocabulary of science.

Sociocultural Theory of Human Learning

Argumentation is a fundamental discourse of science, consistent with the epistemological assumptions of Vygotsky's theory of human learning (Lave & Wenger, 1991; Vygotsky, 1978). Sociocultural perspectives describe learning as a "social and communicative process, whereby learners share knowledge and construct understandings in a social context through dialogue, conflict, and negotiation" (Aydeniz, Pabuccu, Cetin, & Kaya, 2012, p. 1303). This perspective shifts the focus of study from individual mental processes toward the study of interactions among learners in understanding how knowledge is both constructed and displayed (Lee & Smagorinsky, 2000).

An important aspect of Vygotsky's theory of human learning is the notion of the zone of proximal development. The zone of proximal development refers to the difference between what a learner can achieve independently and achieve with support from a more competent other (Vygotsky, 1978). The well-known construct of scaffolding was derived from Vygotsky's notion of the zone of proximal development. Bruner (1983) defined scaffolding as "a process of

setting up the situation to make the child's entry easy and successful and then gradually pulling back and handing the role to the child as he becomes skilled enough to manage it" (p. 60).

For young children who are new to engaging scientific explanation, science talks can serve as an important scaffold. Science talk has been defined as a "persistent evidence-based whole-class dialogue" (Benus, Yarker, Hand, & Norton-Meier, 2013, p. 239). Science talks provide a social environment in which the norms of scientific explanation (e.g., asking questions, providing reasons and evidence) can be acquired through apprenticeship by more competent others. During science talks, students and teachers can both serve as more competent others through modeling and scaffolding. Through what Croninger, Li, Cameron, and Murphy (2018) referred to as a "discourse apprenticeship," students gradually come to internalize higher cognitive functions, such as coordinating claims with evidence.

Given the important role of science talk in supporting students' engagement in scientific explanation, the current state of elementary science classrooms, in which teacher talk is often dominant and student talk is minimal, must change. Scholars (e.g., Sadler, 2006) have argued that a reasonable place to advocate and promote this kind of change is with prospective teachers within teacher preparation programs. Therefore, a primary goal of this research was to assist PSTs in recognizing the important role of science talk as a means for scaffolding elementary students' communication of scientific ideas and evidence in ways that reflect scientific discourse.

Schema Theory

Schema Theory has been a driving force in the study of reading processes, specifically in relation to reading comprehension, learning, and memory. According to Anderson and Pearson

(1984), schema Theory is “a model for representing how knowledge is stored in human memory” (p. 259). It also provides insight into how learners construct new knowledge.

A schema is an abstract mental structure of information (Anderson, 1984). Learners use schemata (the plural of schema) to organize current knowledge and provide a framework for future knowledge construction. Through schemata, existing knowledge influences new information. Theorist Jean Piaget (1969) explained that learning occurs through the modification of an individual’s schemata as they interact with their environment. Piaget referred to the processes by which schemata are changed or modified as assimilation and accommodation. In assimilation, new information is interpreted and incorporated into the learner’s pre-existing schemata. In accommodation, existing schemata are changed or new schemata are constructed as a learner has new experiences. Without a schema to which new information can be assimilated, learning is slow and difficult (Anderson, 1984).

Schema Theory is pertinent to this research in that the process of developing elementary preservice teachers’ knowledge about scientific explanation is influenced by their own prior conceptions about science teaching and learning. Researchers have found that preservice teachers generally hold naïve beliefs about the processes by which scientific knowledge is generated (Aydeniz & Ozdilek, 2015). The knowledge and beliefs that make up preservice teachers’ schemata for teaching science are often directly influenced by their own experiences as science learners (Davis et al., 2006).

Thus, preservice teachers need to develop sophisticated understandings of how scientific explanation contributes to the construction of scientific knowledge before they can help their students build similar knowledge. For this reason, the primary aim of this study was to challenge

preservice teachers' prior knowledge and experiences in order to help them develop more sophisticated understandings about scientific explanation, consistent with new views of science proficiency (National Research Council, 2012; NGSS Lead States, 2013). It is through this initial schema construction that the continued development of preservice teachers' knowledge and appreciation for the role of evidence in the teaching and learning of science can take place. Therefore, this study focused on four major research questions.

Research Questions and Null Hypotheses

This study was guided by the following research questions:

1. Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' understandings of the NOS, as measured by the Nature of Science as Argumentation Questionnaire (NSAAQ)?
   Null Hypothesis: The mean NSAAQ scores for the treatment and control group are equal to one another.
2. Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' knowledge of argumentation, as measured by The Argumentation Test (ARGTEST)?
   Null Hypothesis: The mean argumentation test scores for the treatment and control group are equal to one another.
3. Does participation in an intervention focused on teaching science as argument have an impact on the complexity of elementary PSTs' written explanations, as measured by a researcher-developed written scientific explanation assessment?

Null Hypothesis: The mean written explanation assessment scores for the treatment and control group are equal to one another.

4. How do elementary PSTs incorporate components of the Teaching Science as Argument Framework to support both students' literacy and science learning when planning for inquiry-based science instruction, as evident in their written lesson plans?

Significance

The findings of this study contribute to the emerging body of research exploring how to support the development of PSTs' knowledge, beliefs, and practices for teaching science as argument in order to support young students' literacy and science learning in tandem. Given the influence of teachers' knowledge and beliefs on their pedagogical decisions (Bandura, 1997), developing elementary PSTs' understandings and practices for teaching science as argument is critical if teachers are to effectively facilitate elementary students' engagement in scientific reasoning, as called for by recent education initiatives in both science and literacy.

It is unreasonable to expect elementary teachers to effectively support students' engagement in explanation and argument if they themselves do not develop more sophisticated understandings of these science-specific literacy practices (Aydeniz & Ozdilek, 2015; Beyer & Davis, 2008; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002). In the words of Zembal-Saul and colleagues, "Teacher education experiences must include opportunities to learn science in ways that reflect effective, reform-based pedagogies, as well as transform those experiences for the purposes of supporting students' science learning" (p. 456). Therefore, it is critical that the teacher education community takes directive initiative to help PSTs adopt ways

of thinking about science teaching that are more aligned with contemporary views of proficiency in science (National Research Council, 2012).

Limitations

The following are limitations that threatened internal and external validity of the study:

1. Participants were selected using non-probability sampling methods. The sample may or may not have accurately represented the target population, thus limiting the generalizability of the research findings (Creswell, 2003).
2. Participants were not randomly assigned to condition. Non-random assignment violates the statistical assumption of independence, inhibits the ability to establish cause and effect relationships, and reduces the generalizability of the results to the wider population (Creswell, 2003).
3. The sample sizes of PSTs in the treatment condition ($n = 20$) and control condition ($n = 25$) were small. Small sample size decreases statistical power, thereby increasing the likelihood of committing a Type II error (Lomax & Hahs-Vaughn, 2012).
4. There were some occurrences of missing pretest and posttest assessment data due to absences and/or course withdrawals. Make-up tests were attempted but not always successfully completed due to time and scheduling constraints.
5. A researcher-developed instrument was used to assess the complexity of participants' written scientific explanations. The measure was not tested for reliability or content validity, although it was developed using research-based guidelines for creating appropriate explanation assessment tasks (McNeill & Krajcik, 2012). Similar types

of researcher-developed instruments have been used in previous studies (e.g., (McNeill & Krajcik, 2008).

6. The researcher had established a professional relationship with the course instructor of the treatment group prior to the study. This had the potential to introduce researcher bias. Steps were taken to control for researcher bias by monitoring fidelity of implementation throughout the intervention.
7. The treatment group and control group were not taught by the same instructor. The treatment group instructor was an assistant professor in science education with eight years of experience teaching at the post-secondary level. The control group instructor was a first-year doctoral student in science education with less than one-year of experience teaching at the post-secondary level. Thus, differences between instructors (e.g., experience, level of competency) were possible confounding factors. In an attempt to achieve comparability between the treatment and control conditions, a graduate teaching assistant, also a first-year doctoral student in science education, facilitated all three inquiry-based model lessons with participants in the treatment condition.
8. The group structure of the lesson plan assignment did not allow for individual analysis of PSTs' application of the TSAF components when planning for inquiry-based science instruction. Furthermore, this study did not capture the rich collaborations that occurred as PSTs worked together to plan instruction.
9. This study took place within a very specific context, thus restricting the generalizability of the findings.

Delimitations

Participants were required to meet the following inclusionary criteria: (a) be enrolled in either the treatment or comparison course section of the science methods course during the spring 2019 semester, (b) agree to participate in the study, (c) complete all data collection tasks, and attend class sessions regularly (i.e., no more than two absences during the semester).

Assumptions

The study was guided by the following assumptions, which are based upon findings of existing research and theoretical perspectives on scientific explanation and argument:

1. Scientific knowledge is socially constructed (Driver et al., 2000). Therefore, talk and discourse play a central role in the collective process of making meaning in science (Lemke, 1990; Sadler, 2006).
2. Constructing explanations and forming arguments are complementary discursive practices through which scientific knowledge is constructed (Boyer, 2016).
3. Explicitly teaching the structure of scientific explanation is a vital pedagogical practice for supporting students' explanation construction (McNeill & Krajcik, 2008).

Operational Definitions

The following terms were operationally defined for the purposes of this study:

Argument – An argument examines the question of whether a scientific explanation is valid and whether it is better than competing arguments (Osborne & Patterson, 2011).

Argumentation – Argumentation refers to the discourse process in which two or more people attempt to persuade others of their explanations, defend their ideas, and revise them in light of new evidence (Osborne & Patterson, 2011).

Claim, Evidence, Reasoning (CER) Framework – The CER framework (McNeill & Krajcik, 2008) is a simplified version of Toulmin's 1958 six-part argument structure designed specifically to support younger students in constructing both oral and written scientific explanation. The framework includes three structural components of a scientific explanation: a claim, evidence, and reasoning. These three structural components were defined by McNeill & Krajcik (2008) as follows:

a. Claim – an assertion that addresses a specific question or problem.

b. Evidence – the data used to support the claim.

c. Reasoning – a justification for how the evidence supports the claim.

Disciplinary Literacy – Disciplinary literacy refers to "the specialized information and organizational patterns, language, vocabulary, syntax, text features, and ways of interpreting, evaluating, and conveying evidence and information within a particular discipline" (International Literacy Association, 2018).

Discourse – The term discourse refers to the structures of oral and written language and also how the members of a discipline act, talk, write, and engage in knowledge construction (Gee, 2004; Sadler, 2006).

Explanation - A scientific explanation attempts to explain how and why a particular scientific phenomenon occurs (Osborne & Patterson, 2011).

Literacy – Literacy is defined as "the ability to identify, understand, interpret, create, compute, and communicate using visual, audible, and digital materials across disciplines and in any context" (International Literacy Association, 2018)).

Nature of science (NOS) – NOS refers to the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992).

Scientific inquiry – According to the National Research Council (2000), scientific inquiry is…

> a multifaceted activity that involves observation; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating the results. (p. 13)

Scientific literacy – According to the Science Framework for the 2015 National Assessment of Education Progress, scientific literacy refers to the understanding of key facts, concepts, principles, laws and theories of science and the ability to use that knowledge to solve problems in real-world contexts (National Assessment Governing Board, 2014).

Summary

This chapter began with a rationale and purpose of the study. The researcher also introduced the guiding frameworks and the research questions. Lastly, the significance of the study was explained, as were limitations, delimitations, assumptions, and operational definitions.

CHAPTER TWO:
LITERATURE REVIEW

Introduction

To frame this study, multiple areas of research were reviewed. This chapter contains a brief overview of how the definition of literacy has evolved and expanded over the years, followed by a description of science as a discipline. In the third section of this chapter, reform recommendations in science and literacy education are presented, as well as a discussion of the common emphasis on disciplinary literacy. The fourth section reviews the role of language and literacy in inquiry-based science. The fifth section reviews research on explanation and argument in science education, highlighting the important role teachers play in teaching science as argument and the various challenges that teachers, especially those at the elementary level, face in giving priority to explanation and argument in their teaching. The final section synthesizes findings from previous studies focused on developing PSTs' knowledge and beliefs of effective science teaching.

Reading/Literacy in the 21st Century

In the 1985 report, *Becoming a Nation of Readers: The Report of the Commission on Reading,* Anderson, Hiebert, Scott, and Wilkinson defined reading as "the process of constructing meaning from written texts" and argued that, "It is a complex skill requiring the coordination of a number of interrelated sources of information" (p. 7). Furthermore, the authors outlined five key principles of skilled reading: (a) reading is a constructive process, (b) reading must be fluent, (c) reading must be strategic, (d) reading requires motivation, and (e) reading is a continuously developing skill. This notion of reading was mainly rooted in cognitive and psycholinguistic perspectives on reading pertaining to phonological awareness, decoding, word

recognition, and literal comprehension. Since 1985, this view of reading has continuously evolved and expanded in response to new theoretical and empirical developments in the field of reading research.

For example, in 2002, the RAND Reading Study Group defined reading as “the process of simultaneously extracting and constructing meaning through interaction and involvement with written language” (p. 11). They argued that reading comprehension occurs through an interaction between the following three elements (the reader, the text, and the activity) which includes comprehension. In contrast to Anderson and colleagues’ (1985) definition, the definition proposed by the RAND Reading Study Group (2002) reflects a greater emphasis on the important role of the text and activity in the process of meaning construction, as well as increased attention on the larger sociocultural contexts through which reading takes place.

Several scholars (e.g., Brandt & Clinton, 2002; Gee, 1999; Street, 2003) have argued that in order to address issues of access and equity in education, one must seek to understand literacy as a socially-constructed practice. Major theoretical perspectives within this paradigm include literacy as a social practice, multiliteracies, and multiple literacies (Perry, 2012). These perspectives include an emphasis on culture, activity, identity, power, and the sociocultural contexts in and through which reading occurs.

Frankel, Becker, Rowe, and Pearson (2016) argued that this expanded notion of reading requires a shift in focus from reading to literacy. As such, they revised the definition provided by Anderson and his colleagues in 1985 from a definition of reading to a definition of literacy. Their revision defines literacy as a “the process of using reading, writing, and oral language to extract, construct, integrate, and critique meaning through interaction and involvement with

multimodal texts in the context of socially situated practices" (p. 7). Using this reconstructed definition of literacy, Frankel et al. (2016) also updated the five principles of reading originally outlined by Anderson and his colleagues in 1985. Their updated principles are as follows: (1) literacy is a constructive, integrative, and critical process situated in social practices; (2) fluent reading is shaped by language processes and contexts; (3) literacy is strategic and disciplinary; (4) literacy entails motivation and engagement; and (5) literacy is a continuously developing set of practices (Frankel et al., 2016). This new conceptualization of reading/literacy encompasses several recent theoretical developments in the field, including construction-integration models of reading, sociocultural and critical theories of literacy and learning, multimodality, and disciplinary literacy.

Recent publications by the International Literacy Association (ILA), such as the *Standards for the Preparation of Literacy Professionals 2017,* also promote an expanded definition of literacy beyond reading to include a broader repertoire of skills reflective of what it means to be literate in the 21st century. These skills include writing, speaking, listening, viewing, and visually representing in both print and digital formats. As 21st century students prepare for college and career readiness, they must learn to comprehend and compose information using print and nonprint materials across disciplines and in a variety of contexts (International Literacy Association, 2012).

The Discipline of Science

At the most fundamental level, science is about investigating and explaining how the natural world works. Science is both a body of knowledge that reflects one's current understanding of the world and is also a set of practices used to construct, extend, and refine that

knowledge (National Research Council [NRC], 2012). Although the practices used to construct scientific knowledge differ from one domain of science to another, all domains share common features. Among these features is a commitment to data and evidence as the basis for developing knowledge claims (Duschl, Schweingruber, & Shouse, 2007).

Science is primarily a social endeavor, in that scientific knowledge advances in large part through cooperative effort and in the context of a social system with well-developed norms of practice and discourse (Michaels et al., 2008). Members of the scientific community work together to build a body of evidence and devise and test scientific theories.

Science is a central aspect of modern life, and knowing how to think about it, talk about it, and write about it, is essential for full democratic participation. An understanding of science and the processes of science is a prerequisite for engagement in discussions and debate about scientific issues that affect society (National Research Council, 1996). For this reason, developing proficiency in science is vital for everyone, even those who plan to pursue careers in fields other than science or engineering. As the authors of the 2008 publication, *Ready, Set, SCIENCE!: Putting Research to Work in K-8 Science Classrooms*, explained, "Generating scientific productivity requires a workforce, not only of scientists, engineers, medical and health professionals, but also of journalists, teachers, policy makers, and the broader network of people who make critical contributions to science and the scientific enterprise" (Michaels et al., 2008, p. 2).

Reform Recommendations in Science and Literacy Education

A Framework for K-12 Science Education (National Research Council [NRC], 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) set ambitious goals for K-12

students in science. At the same time, the *Common Core State Standards for English Language Arts* (CCSS-ELA) (National Governors Association [NGA] Center for Best Practices & Council of Chief State School Officers [CCSSO], 2010) set equally important ambitious goals for students' language and literacy learning in English language arts and across the disciplines. A description of these new reforms and their implications for classroom instruction are included below.

A Framework for K-12 Science Education and the Next Generation Science Standards

The new vision of proficiency in science put forward by *A Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) is based on earlier reform documents and research syntheses. These include the *National Science Education Standards* (NRC, 1996), *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAA], 1993), Taking Science to School (Duschl, et al., 2007), and *Ready, Set, Science!* (Michaels et al., 2008). The new framework advocates for positioning inquiry at the heart of the science education curriculum and is built around three major dimensions of scientific literacy: disciplinary core ideas, crosscutting concepts, and scientific practices. According to the NRC (2000), scientific inquiry is…

> a multifaceted activity that involves observation; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating the results. (p. 13)

Inquiry-oriented science shifts the focus of science education from the memorization of facts and concepts to experiences that engage students in investigating to seek answers to their own questions (Fang, et al., 2010). In this way, inquiry environments provide students with the opportunity "to experience science as a way of knowing and doing" (Beyer & Davis, 2008, p. 383). Students who participate in scientific inquiry engage in many of the same practices that professional scientists value for constructing scientific knowledge. As outlined in the *Framework*, these scientific practices include:

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

The NRC (2012) argued that focusing on science content alone threatens to leave students with naïve understandings of the nature of science. Therefore, the *Framework* intertwines both knowledge and practices in designing learning experiences in K-12 science education. Engagement in the practices of science supports not only students' knowledge of science concepts but also their understanding of the values and beliefs inherent to scientific knowledge and its development. Furthermore, the actual doing of science can pique student' curiosity and increase their interest and motivation in science. As such, inquiry-oriented science

is a powerful vehicle for preparing students as scientific literate citizens. As stated in the *Framework*:

> Seeing science as a set of practices shows that theory development, reasoning, and testing are components of a larger ensemble of activities that includes networks of participants and institutions, specialized ways of talking and writing, the development of models to represent systems or phenomena, the making of predictive inferences, construction of appropriate instrumentation, and testing of hypotheses by experiment or observation. (NRC, 2012, p. 43)

The Common Core State Standards for English Language Arts (CCC-ELA)

The CCCS-ELA (National Governors Association Center for Best Practices & Council of Chief State School Officers [NGA & CCSSO], 2010) describe equally important ambitious goals for the development of students' language and literacy learning. To build a solid foundation for college and career readiness, the standards require students to read and comprehend increasingly challenging texts, write for a variety of purposes and different audiences, communicate flexibly, and use language to effectively convey meaning. In addition to developing students' literacy knowledge and skills in ELA classrooms, the CCSS also call upon teachers to support students in developing advanced abilities to read, write, and communicate in other content areas, including science. The CCSS-ELA for Grades 6-12 includes a section entitled "Literacy in History/Social Studies, Science, and Technical Subjects" (NGA & CCSSO, 2010). The reading standards within this section detail grade-specific requirements for helping students meet the specific challenges of reading, writing, speaking, listening, and language in the disciplines. This focus on

developing language and literacy across the disciplines is one unique feature of the CCSS-ELA in comparison to earlier standard documents.

A Common Focus on Disciplinary Literacy

At the core of both the CCSS-ELA and the NGSS is a focus on disciplinary literacy. Disciplinary literacy refers to the specialized literacy practices of a given discipline, such as history, science, or mathematics (Moje, 2015; Shanahan & Shanahan, 2008; Zygouris-Coe, 2012). The integration of literacy into the content areas is not a new phenomenon. Reading strategy instruction has long been advocated as a way to help students activate and integrate prior knowledge, monitor their own comprehension processes, and organize information from texts (McKeown, Beck, & Blake, 2009; Palincsar & Brown, 1984; Pressley et al., 1992). These general reading strategies are aimed at encouraging students' use of cognitive and metacognitive skills (e.g., predicting, inferring, visualizing, questioning, synthesizing) necessary for proficient reading not only in science, but in other content areas as well. What is new, however, is the call for teachers to engage students in deep disciplinary literacy learning (Moje, 2015), as opposed to simply applying general reading strategies across the content areas. Engaging in disciplinary literacy learning involves students not only developing content knowledge in a particular discipline but also participating in and understanding how knowledge is created and shared in the discipline (Moje, 2008; Shanahan & Shanahan, 2008). Thus, disciplinary literacy teaching and learning focuses on how members of disciplines read, write, think, reason, and communicate knowledge (Shanahan & Shanahan, 2008). Various scholars (e.g., Gillis, 2014; Moje, 2015; Zygouris-Coe, 2015) have argued that disciplinary literacy instruction is needed in order to adequately prepare students to meet the literacy demands unique to each academic discipline.

As students advance grade levels, they must develop more sophisticated but less generalizable literacy skills and strategies. Figure 2 was developed by Shanahan and Shanahan (2008) to illustrate how the development of literacy progresses. The base of the pyramid represents the highly generalizable basic skills that underlie virtually all reading and writing tasks, such as word decoding, recognition of high-frequency words, and basic knowledge of writing conventions and text organization. Ideally, these skills are developed during the primary grades and serve as the foundation for future reading success. As students move beyond these foundational aspects of literacy, usually by the intermediate elementary grades (Grades 3-5), they begin to develop a more sophisticated repertoire of literacy skills and strategies, represented by the middle level of the pyramid. These include becoming more fluent and automatic when reading and gaining knowledge of more complex forms of text organization (e.g., problem-solution, cause-effect), as well as other generic literacy skills and strategies that can be applied across various content areas.

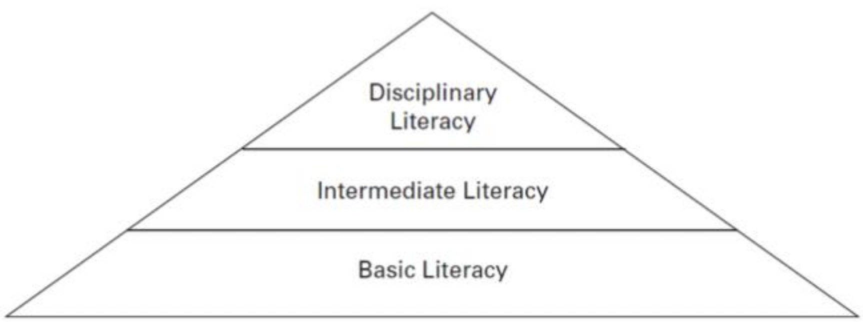


Figure 2. The Increasing Specialization as Argument Framework (TSAF)
Source: Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents:

Rethinking content- area literacy. *Harvard Educational Review, 78*(1), 40–59. Reproduced with permission.

The apex of the pyramid represents disciplinary literacy, meaning the skills and strategies specialized to history, science, mathematics, or other content areas. These include knowledge of "specialized language conventions, disciplinary norms of precision and accuracy, and higher-level interpretive processes" (Shanahan & Shanahan, 2008, p. 43). Without developing such knowledge, students are left ill-prepared to handle the sophisticated and specialized nature of reading in the disciplines and also limited in the depth of content knowledge they can attain.

Although disciplinary literacy is generally not a focus for students until middle and high school, many scholars have argued for its introduction in the elementary grades. As Shanahan and Shanahan (2014) argued, although the CCCS-ELA does not outline specific disciplinary goals for students in grades K-5, elementary teachers still have an important role to play if their students are to eventually reach college- and career-readiness. This role for elementary teachers includes providing students with scaffolded opportunities to participate in disciplinary ways of reading, writing, communicating, doing, and thinking. In the context of science, this includes engaging young students in practices that reflect those engaged in by professional scientists, including reading scientific texts, using the norms and conventions of science, forming scientific explanations, and engaging in argument from evidence.

The Role of Language and Literacy in Science

There has been broad acknowledgement in the research community that literacy practices such as reading, writing, and oral discourse are an integral part of scientific inquiry (Hand et al., 2003; Phillips & Norris, 2009; Wellington & Osborne, 2001). *A Framework for K-12 Science Education* (NRC, 2012) highlights this relationship, noting that "reading, interpreting, and

producing text are fundamental practices of science, and they constitute at least half of engineers' and scientists' total working time" (p. 3-19).

On one hand, science is an organized human activity that aims to develop a more complete understanding of the natural world through the gathering and analyzing of evidence. On the other hand, science is also a form of discourse involving the use of language (Fang & Wei, 2010). Language is fundamental to the practices of science (Norris & Phillips, 2003; 2009). Scientists use language in science-specific ways when conducting scientific inquiries, constructing evidence-based explanations of natural phenomena, and communicating their ideas to others.

Scholars have argued that in addition to embracing inquiry as the cornerstone of science, school science instruction should also focus on teaching the specialized language used to construct and communicate scientific knowledge (Fang & Wei, 2010; Norris & Phillips, 2003; Wellington & Osborne, 2001). Norris and Phillips (2003) captured this duality of science literacy by arguing that students need not only to develop knowledge of science concepts (i.e., the "derived" sense of science literacy), but also become fluent in the language and discourse patterns of science (i.e., the "fundamental" sense of science literacy). In this new view of scientific literacy, "Reading and writing are inextricably tied to the very nature and fabric of science, and by extension, to learning science" (Norris & Phillips, 2003, p. 226).

In the science classroom, literacy is a powerful vehicle for engaging students' minds, for developing conceptual understanding, and for supporting scientific inquiry (Fang et al., 2010; Pearson, Moje, & Greenleaf, 2010). When literacy is positioned as a tool for investigating phenomena, students develop science and literacy knowledge and skills in tandem. For example,

through the construction of scientific explanations and engagement in argument, students will learn appropriate language and norms for productive participation in the discourses of science, while simultaneously developing scientific knowledge. Reading and interacting with scientific texts enables students to develop rich content knowledge about science and gain familiarity with the nature of scientific language, while also stimulating students' interest in conducting scientific inquiries of their own. A disciplinary literacy approach to science instruction provides an opportunity for students to not only develop knowledge about the natural world but also to learn about the specialized literacy practices of science (Pearson et al., 2010). Thus, an early focus on supporting students' disciplinary literacy in inquiry-oriented science is vital for building a solid foundation from which future science and literacy learning can be built.

The current emphasis on making literacy and language vital parts of science education has led to the development of several instructional models that aim to integrate literacy and inquiry-based science. Following is a brief description of four longstanding approaches that have demonstrated promise of developing elementary students' science and literacy learning in tandem.

Concept-Oriented Reading Instruction (CORI)

Concept-oriented Reading Instruction (CORI), developed by Guthrie and Wigfield, is an instructional framework for students in Grades 3-9 that strives to improve students' reading comprehension of scientific texts, support students' conceptual knowledge building and development of scientific inquiry skills, as well as increase student motivation. It is one of the longest-existing programs of literacy and science integration at the elementary level. The program aims to improve students' reading comprehension by providing explicit reading strategy

instruction, such as activating prior knowledge, questioning, searching for information, summarizing, and organizing graphically. In addition to explicit reading strategy instruction, CORI involves hands-on investigations, text-based inquiries, working in collaborative groups, and writing to share scientific ideas and findings. Across several studies conducted with students in the upper elementary grades, the CORI intervention has been shown to increase students' conceptual understanding in science, motivation, use of reading strategies, and text comprehension when compared to students in control classrooms (Guthrie et al., 2004; Guthrie, Anderson, Alao, & Reinhart, 1999). A major focus in the CORI research is the central role that motivation plays in learning both science and literacy.

Guided Inquiry supporting Multiple Literacies (GIsML)

Guided Inquiry supporting Multiple Literacies (GIsML) is another well-studied approach to science and literacy integrated instruction. In this approach, teachers in grades K-6 learn to engage their students in multiple cycles of investigation framed around a guiding question. The primary goal of GIsML instruction is to not only support students' understanding of science concepts, but to "enable students to experience, understand, and appreciate the ways in which these understandings have evolved by using tools, language and ways of reasoning that are characteristic of scientific literacy" (Palincsar, Collins, Marano, & Magnusson, 2000, p. 242). During GIsML instruction, students participate in both firsthand investigations (during which students conduct direct investigations of the physical world) and secondhand investigations (during which students use text-based information to advance their thinking about the physical world). GIsML promotes the interplay between these firsthand and secondhand experiences through the use of simulated scientist notebooks, referred to as notebook texts. Notebook texts

are modeled after the type of notebooks professional scientists use to record their investigative activities and findings. The notebook text models for students how data can be represented (e.g., figures, tables, graphs) and how knowledge is refined in response to additional and more precise data. After students engage in direct investigation, they consult the notebook text to explore how the fictitious scientist has interpreted similar data. Thus, the notebook text also provides an opportunity for a shared inquiry experience. The GIsML approach has been shown to advance students' development of conceptual understanding and scientific reasoning.

For example, during a 10-day instructional unit on motion, second-grade students participated in both firsthand and secondhand investigations to develop their understandings of the relationship between mass and speed. As part of this unit, students read and discussed two notebook texts, written in the voice of a fictitious scientist. The notebooks were intended to serve as a model for the way professional scientists document their research questions, record observations and data, and construct claims from evidence. The teacher guided students in reading these texts through a critical lens by discussing whether the investigative methods the scientists used were appropriate, what patterns they identified in her data, and if there was sufficient evidence to support her claims. Additionally, the students engaged in related firsthand investigations about the motion of objects traveling down inclined planes. Similar to the fictitious scientist, they tried to find patterns in their data and develop evidence-based claims to explain phenomena, such as how the mass of a ball affects its speed going down a ramp.

Analysis of pretest and posttest data revealed a significant increase in students' conceptual understanding about motion. Additionally, analysis of students' writing revealed that, by the end of the program of study, nearly all students became more adept at their ability to

generate knowledge claims supported by evidence and use data tables to organize their findings (Hapgood, Magnusson, & Palincsar, 2004).

In-depth Expanded Application of Science (Science IDEAS)

The In-depth Expanded Applications of Science (Science IDEAS) is also known for its longevity and impact on student learning in both science and literacy. Developed by Romance and Vitale, Science IDEAS is a cognitive-oriented model that replaces traditional language arts instruction in Grades 3-5 with a daily two-hour instructional block focused on in-depth science instruction integrated with reading comprehension and writing. The model engages students in a variety of inquiry-oriented hands-on, reading comprehension, writing/journaling, and prepositional concept-mapping activities, all of which aim to develop students' in-depth understanding of core science concepts.

A series of multi-year studies have demonstrated that students who receive Science IDEAS instruction outperform comparison students on standardized measures of science and reading achievement, as well as display more positive attitudes and self-efficacy toward science (Romance & Vitale, 1992, 2001). Additionally, Romance and Vitale (2017) found that schoolwide implementation of the model across Grades 3-5 resulted in not only direct effects on student academic achievement in science and reading comprehension, but also complementary transfer effects in Grades 6-7.

Seeds of Science/Roots of Reading

Seeds of Science/Roots of Reading, developed by the Lawrence Hall of Science at the University of California in Berkeley, is an integrated science and literacy program for students in Grades 2-5. The program originated as an attempt to embed authentic uses of reading, writing,

and language within an earlier K-8 hands-on science program known as GEMS (Great Explorations in Math and Science). The program strives to increase students' understanding of science concepts, while explicitly teaching students to read, write, and communicate in science-specific ways. In the Seeds of Science/Roots of Reading approach, literacy activities support the acquisition of conceptual knowledge and inquiry skills, and inquiry-oriented science serves as an engaging and authentic context for literacy development.

Researchers have demonstrated the effectiveness of Seeds of Science/Roots of Reading in increasing student achievement in both science and literacy. For example, across two external evaluations comparing Seeds of Science/Roots of Reading instruction with content-comparable instruction, Seeds and Roots showed consistently positive effects on elementary students' science vocabulary, writing fluency and science content knowledge (Goldschmidt & Jung, 2011; Wang & Herman, 2005).

These four instructional models share several key ingredients. First, they have involved students in scientific inquiry. That is, their focus has not been on the accumulation of science facts, but instead, on science as a process of exploration and discovery. Second, they have engaged students in text-based inquiries along with hands-on science investigation. Third, they were developed through collaboration among experts in both literacy and science.

Overall, the research findings surrounding these instructional models have demonstrated the promise of integrated approaches to literacy and science instruction. Specifically, these efforts have shown how literacy can be used to support rather than replace content learning in science. In the words of Fang and Wei (2010), literacy is "a powerful vehicle for engaging

students' minds, fostering the construction of conceptual understanding, supporting inquiry, and cultivating scientific habits of mind" (p. 263).

Explanation and Argument in Science Education

Two key disciplinary literacy practices in science are constructing explanations and engaging in argument from evidence (Bell & Linn, 2000; Jimenez-Aleixandre & Erduran, 2007; NRC, 2012; Osborne, 2010). There are key differences between these two constructs. Explanations use evidence to explain how or why a scientific phenomenon occurs (Osborne & Patterson, 2011). Though similar to explanations, arguments, in contrast, examine whether a scientific explanation is valid and if it is better than competing accounts (Osborne & Patterson, 2011). Explanations and arguments can exist in different modalities, including both oral and written forms (Osborne, 2010). Although there is a clear distinction between the two, explanation and argument can be viewed as complementary discursive practices, because argument is essential to the process of validating a scientific explanation. Lastly, argumentation refers to the discourse process in which two or more people attempt to persuade others of their explanations (Osborne & Patterson, 2011). The ability to engage in argumentation is an important disposition of professional scientists. Argumentation is directly related to explanation and argument, because the construction of a scientific explanation is a prerequisite for engagement in argumentation. In the classroom, teachers can promote argumentation by facilitating rich science talk that focuses on constructing, communicating, and evaluating scientific explanations (National Research Council, 2012; NGSS Lead States, 2013).

Several researchers have supported students and teachers in structuring explanations and arguments by drawing upon Toulmin's (1958) argumentation framework (e.g., Bell & Linn,

2000; Erduran, Simon, & Osborne, 2004; McNeill & Knight, 2013; Sandoval, 2003; Zohar & Nemet, 2002). The structural definition of an explanation utilized in this study was based on the work of McNeill and Krajcik (2012), who have simplified Toulmin's six-part model of argumentation to create an instructional framework designed to support younger students in constructing both oral and written scientific explanations. The framework includes three structural components of a scientific explanation: a claim, evidence, and reasoning, which is why it is often referred to as the CER framework. The claim is an assertion that addresses the specific question or problem. The evidence is the data used to support the claim. Lastly, reasoning articulates the justification for how the evidence supports the claim using scientific principles.

Researchers have identified several reasons for engaging elementary students in scientific explanation and argument that are consistent with current views on proficiency in science. First, the construction of evidence-based explanations requires students to design and conduct investigations, and to collect, organize, and analyze data – all essential scientific practices outlined by the *Framework for K-12 Science Education* (NRC, 2012). Second, when students construct, communicate, and critique evidence-based explanations, they participate in the norms of science and develop fluency in the language and discourse patterns of scientific language – what Norris and Phillips (2003) have referred to as the "fundamental" sense of science literacy. Finally, teaching science as explanation has been shown to not only have a positive impact on student learning of science content (Bell & Linn, 2000; Zohar & Nemet, 2002), but it also helps students learn about the NOS (Bell & Linn, 2000; Driver et al., 2000; Sandoval, 2003; Sandoval & Reiser, 2004). NOS refers to the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992). Beyer and Davis (2008) illustrated the relationship between

engaging in explanation and learning about the NOS by explaining that, “When students connect new science ideas with evidence and to reasoning, they not only learn *that* something is so but also *how* and *why* it is so” (p. 383). Thus, constructing scientific explanations can help students develop several skills and abilities that are necessary for scientific literacy and evidence-based decision making in a democratic society (Driver et al., 2000; Duschl & Osborne, 2002; Osborne & Patterson, 2011).

Despite these benefits to student learning, explanation and argument are nearly absent from science education (Osborne, 2010). Previous researchers (e.g., Cavagnetto, 2010; Driver et al., 2000; Sadler, 2004) have found that current classroom practices provide few opportunities for students to develop their ability to construct scientific explanations or engage in argument from evidence. Though social interaction plays a prominent role in the lives of professional scientists, students is science classrooms often work independently with little opportunity to share ideas, findings, or interpretations (Cavagnetto, 2010).

A number of reasons may contribute to this de-emphasis on explanation and the role of evidence in teaching science. Research on teachers’ knowledge and understanding of scientific explanation suggests that teachers generally possess an inadequate understanding of the NOS (Abd-El-Khalick & Lederman, 2000), hold naïve conceptions about how explanations are developed and evaluated (Beyer & Davis, 2008; Sampson & Blanchard, 2012), and lack pedagogical skills needed to support students in constructing explanations (Sampson, 2009; Simon, Erduran, & Osborne, 2006). Additionally, some teachers do not view the practices of constructing scientific explanations or engaging in argument based on evidence as important teaching outcomes (Beyer & Davis, 2008).

Although giving priority to explanation and evidence in science instruction proves challenging for all teachers, preservice and early career elementary teachers face particular barriers due to their inadequate knowledge of science content, unsophisticated understandings of inquiry and related skills, little pedagogical knowledge for teaching science, and lack of teaching experience (Davis et al., 2006). As a result, new elementary teachers tend to place a greater emphasis on fun, hands-on activities during science instruction rather than on the role of evidence in developing scientific knowledge (Trygstad, 2013).

Although it has traditionally been believed that young children are not yet capable of the sophisticated reasoning skills required to engage in complex scientific practices and discourse, recent researchers have shown that even students in the elementary grades can construct and debate evidence-based explanations when provided with adequate support (Duschl et al., 2007). The authors of the 2007 National Research Council report, *Taking Science to School,* have argued that "All children bring basic reasoning skills, personal knowledge of the natural world, and curiosity, which can be built on to achieve proficiency in science" (Duschl et al., 2007, p. 4).

Therefore, elementary teachers play an essential role in supporting young students' explanation construction (McNeill & Pimentel, 2010). Elementary teachers can help students develop an understanding of what counts as evidence in science, locate patterns in their data, develop evidence-based claims, and consider alternative explanations. For example, providing explicit instruction in the components of explanation (i.e., claim, evidence, and reasoning) can support elementary students' ability to construct scientific explanations in both talk and writing (McNeill & Krajcik, 2008). Elementary teachers can also use specific talk moves during class discussion to establish argumentative discourse (Chen, Hand, & Norton-Meier, 2017; Chin,

2007) and use writing scaffolds and visual representations to assist students in appropriately justifying their claims in writing (Nelson, 2010).

Therefore, the successful integration of scientific explanation into the teaching and learning of science places new expectations on elementary teachers. Elementary teachers, for example, need to develop a better understanding of the nature of scientific knowledge and the purposes for scientific investigations (Aydeniz & Ozdilek, 2015). They need to develop robust disciplinary understandings of science so that they can see the value of disciplinary literacy practices such as constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information (Davis & Bricker, 2011). They need ample practice in constructing, critiquing and debating explanations so that they can develop an understanding of what counts as strong claims, evidence, and reasoning (Beyer & Davis, 2008). They need to learn how to use effective supports such as the CER framework (McNeill & Krajcik, 2008) to scaffold young students' engagement in explanation and argument. They also need to recognize the vital role classroom discussion plays in promoting elementary students' communication of scientific ideas and evidence in ways that reflect scientific discourse (Driver et al., 2000; Sadler, 2006). Most importantly, elementary teachers need opportunities to engage in inquiry as learners and experience science as argument for themselves (Beyer & Davis, 2008; Boyer, 2016).

Teacher Preparation for Teaching Science as Argument

Because teachers' pedagogical decisions in science are inextricably tied to their beliefs about the nature of scientific knowledge and how it is acquired, researchers within the science education community have recognized the need for preservice teacher education programs to influence PSTs' knowledge and beliefs of the fundamental practices essential for science

learning. These scholars have investigated a variety of approaches aimed at accomplishing this goal, including the potential of science methods courses for developing PSTs' knowledge beliefs, and abilities surrounding scientific explanation and argument. Findings from this body of research highlight the effectiveness of explicit focus on explanation and argument, within the context of science methods courses, for improving PSTs' conceptual understanding in science (Aydeniz et al., 2012), views of the NOS (McDonald, 2010), and their ability to produce sound and logical arguments (Robertshaw & Campbell, 2013; Sadler, 2006).

For example, Sadler (2006) documented PSTs' argumentation skills as they participated in a methods course, with an explicit focus on scientific discourse and argumentation. Participants included 17 secondary science PSTs, all enrolled in the same science methods course at a large university in the Midwestern region of the United States. Throughout the course, Sadler, who also served as instructor of the course, provided explicit instruction in argument structure using the Toulmin Argumentation Protocol [TAP] (Toulmin, 1958). Qualitative analysis of participants' pre-instruction and post-instruction written arguments revealed that the majority of participants improved the structure of their arguments (e.g., by incorporating counter positions and rebuttals) over the course of the semester.

In a similar study, Robertshaw and Campbell (2013) also found that explicit instruction in argumentation using the TAP had a positive impact on the quality of PSTs' written scientific arguments over the course of a one-semester science methods course. Participants included seven PSTs, all enrolled in the same science methods course within the secondary science education program at a university in the Rocky Mountain Region of the United States. Quantitative analyses showed a general trend of improvement in scores from pre- to post-

argumentation instruction. These findings were further supported by participants' self-reflections about how their arguments had changed from the beginning to the end of the course. Findings from both studies illuminated the potential of explicit instruction in argument structure for improving PSTs' argumentation skills.

The growing body of research on PSTs' knowledge, beliefs, and abilities surrounding scientific explanation and argument also suggests that participation in a teacher education program built around a comprehensive conceptual framework can support PSTs' ability to successfully engage elementary students in scientific discourse and practices for evidence-based explanation building (Barreto-Espino et al., 2014; Boyer, 2016; Zembal-Saul, 2009). For example, Zembal-Saul conducted a series of three related design-based studies that examined elementary PSTs' developing understandings and practices for teaching science as argument within the context of a science methods course and teacher education program. Within the science methods course, PSTs engaged in argumentation practices within the context of inquiry-based science. The TSAF (described in Chapter 1) was used to inform the organization of methods course content.

Findings across all three studies have suggested that the use of the TSAF can help PSTs improve their science teaching in various ways, such as greater focus on classroom discourse and increased attention to monitoring and assessing students' thinking. Zembal-Saul's (2009) work revealed the potential for PSTs to "adopt ways of thinking about science that are more aligned with reform-based views of science, as opposed to the more superficial, activity-based perspectives that dominate the literature on elementary science teaching" (p. 711).

Similarly, Barreto-Espino and colleagues (2014) found the TSAF effective in supporting PSTs' development of the understandings and abilities necessary for supporting students in meaningful science learning. Participants included three elementary PSTs, all of whom were members of a larger cohort of prospective elementary teachers, enrolled in the same science methods course at a large university in the northeastern United States. Using the TSAF (Zembal-Saul, 2009) as a guiding framework, the course content placed emphasis on evidence-based explanation, reasoning, and discourse in science. Qualitative analysis of participants' pre-course interviews, continuous weekly reflections, and post-course interviews led the researchers to make the following three assertions: (1) the existence of opportunities for interacting with phenomena and collecting firsthand data through physical experimentation helped participants increase their emphasis on evidence-based explanations; (2) participants came to view scientific discourse as an essential tool for meaning making in science; and (3) participants demonstrated attention to scientific content, from both students' and teachers' perspectives, during instruction rather than solely focusing on inquiry processes (Barreto-Espino et al., 2014). Overall, findings contributed to the body of research, suggesting that using a coherent, research-based framework in science methods courses can help positively shape PSTs' thinking about science teaching and learning, as well as the role of literacy in science.

Most recently, Boyer (2016), in an attempt to counter the deficit narrative associated with the teaching and learning of science in the elementary grades, explored how a coherent teacher education preparation program helped two PSTs plan for and enact science instruction that aligns with reform-based views of science. Boyer followed two elementary PSTs from their science methods course into their field placement experiences. The TSAF (Zembal-Saul, 2009) was

used to inform the design of course experiences and served a model for lesson planning and a teaching heuristic for the study participants. Following the semester-long science methods course, PSTs participated in a scaffolded cycle of planning, teaching, and reflection enacted in their field placement classrooms. Audio-recordings of lesson planning conferences between the methods course instructors and PSTs, videos of the PSTs' enacted practice, and self-analysis videos compiled by the PSTs served as the primary data for the study. Qualitative data analysis revealed that although neither participant reached the level of competency of veteran elementary science teachers, they were able to engage their students in scientific discourse and practices for evidence-based explanation building. Boyer asserted that the participants were able to achieve such successes due to their participation in a teacher education program and field placement, designed using a comprehensive conceptual framework. As Boyer explained, exemplars such as those described in her work "are important to examine because they provide insight into what is possible to achieve through initial teacher training when traditional barriers, such as the lack of coherence between course work and field experiences, are ameliorated" (p. 1013).

Overall, this body of research suggests that intentionally-designed teacher preparation experiences can help PSTs shift from traditional conceptions of science teaching to beliefs and understandings better aligned with new views of science proficiency and the call for disciplinary literacy in science. Though it may never be possible for teacher educators to fully equip PSTs with all the knowledge and abilities needed for effective disciplinary literacy teaching in science, teacher preparation experiences, such as those highlighted in this review, may hold much promise for laying the groundwork upon which future progress can be made.

Summary

In the first section of this chapter, a brief description of how the definition of literacy has evolved and expanded over the years was provided, followed by a description of science as a discipline. In the next section, an overview of reform recommendations in science and literacy education was presented, as well as a discussion of the common emphasis on disciplinary literacy. The fourth section reviewed the role of language and literacy in inquiry-based science. The fifth section explained the role of explanation and argument in science, highlighting the important role of teachers in teaching science as argument and the various challenges that teachers, especially those at the elementary level, face in giving priority to explanation and argument in their teaching. The chapter concludes with a synthesis of research findings from previous studies focused on developing PSTs' knowledge and beliefs of effective science teaching.

CHAPTER THREE:
METHODS

This chapter begins with a restatement of the purpose of the study and the guiding research questions. This is followed by a detailed description of the following methods: (a) research design, (b) context, (c) participants, (d) sampling and assignment procedures, (e) intervention procedures, (f) data collection procedures, and (g) data analysis.

Purpose

Very few studies have explicitly characterized preservice teachers' knowledge of specific scientific practices, such as constructing evidence-based explanations (Davis et al., 2006). This is particularly true at the elementary level. Without developing sophisticated understandings of scientific explanation, prospective elementary teachers are unlikely to be able to successfully engage their students in this complex scientific practice. Therefore, investigations are needed that examine how purposefully designed teacher education experiences can help PSTs develop their own abilities for constructing evidence-based explanations and initial knowledge and practices for teaching science as argument.

Thus, the purpose of this study was to investigate the impact of a one-semester intervention (12 weeks) for PSTs focused on teaching science as argument within a science methods course on (a) understandings of the NOS, (b) knowledge about argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the Teaching Science as Argument Framework (TSAF) when planning for science instruction.

Research Questions

1. Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' understandings of the NOS, as measured by the Nature of Science as Argumentation Questionnaire (NSAAQ)?

   Null Hypothesis: The mean NSAAQ scores for the treatment and control group are equal to one another.

2. Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' knowledge of argumentation, as measured by The Argumentation Test (ARGTEST)?

   Null Hypothesis: The mean argumentation test scores for the treatment and control group are equal to one another.

3. Does participation in an intervention focused on teaching science as argument have an impact on the complexity of elementary PSTs' written explanations, as measured by a researcher-developed written scientific explanation assessment?

   Null Hypothesis: The mean written explanation assessment scores for the treatment and control group are equal to one another.

4. How do elementary PSTs incorporate components of the Teaching Science as Argument Framework to support both students' literacy and science learning when planning for inquiry-based science instruction, as evident in their written lesson plans?

Pilot Study

A pilot study, "Learning to Teach ALL Students Including English Language Learners through an Integrated Disciplinary Literacy Science Methods Course: Examinations of Preservice Teachers' Lesson Plans and Reflections" (Appendix A) was conducted during the spring of 2018. The purpose of this qualitative exploratory case study was to examine PSTs' understanding of the role of literacy in science teaching to support all students' learning, especially English Language Learners (ELs). Specifically, this study focused on answering the following research questions:

1. What science-specific literacy strategies did elementary PSTs include in their lesson plans about using science-specific literacy strategies to teach science for all, including ELs?
2. What challenges did elementary PSTs report in their reflections about including science-specific literacy strategies to teach science for all, including ELs?
3. What instructional accommodations did elementary PSTs include in their science lesson plans to support ELs' learning needs?
4. What challenges did elementary PSTs report in their reflections about developing instructional accommodations for ELs in their science lesson plan?

Participants included 31 elementary education PSTs (8 juniors and 23 seniors) enrolled in a science methods course during the spring semester of 2018. The primary focus of the science methods course was preparing PSTs to implement state science teaching standards for all students in elementary science classroom settings. A majority of course time was also dedicated to teaching PSTs how to incorporate disciplinary literacy in science. Starting from the fourth

week of the course, a professor of disciplinary literacy and a doctoral student in literacy education (i.e., the researcher of the current study) co-taught with the course instructor of the science methods course to integrate science-specific literacy teaching and practices within the content of the methods course. The co-teaching took place for 12 consecutive weeks and included presentations on disciplinary literacy in science, engaging PSTs in the process of interacting with scientific text, demonstration of three inquiry-based science lessons with specific disciplinary literacy practices (e.g., engaging students in scientific explanation and argumentation using the CER framework), resources for selecting scientific texts, as well as literacy strategies to support all students' science learning.

Data analyzed included PSTs' written inquiry-based science lesson plans and PSTs' written reflections about the lesson planning process. The inquiry-based science lesson plans, developed by PSTs in groups of three to four, included eight components: (a) state science standards (b) content and language learning objectives, (c) possible student misconceptions, (d) detailed procedures following the 5E instructional model, (e) accommodations/modifications within each E phase to support ELs at varying levels of English proficiency (i.e., Beginning, Intermediate, and Advanced), (f) science practices, (g) a materials list, and (h) safety precautions. After submitting their written lesson plans, PSTs were asked to reflect upon the lesson planning process by responding to the following questions:

1. Were your content and language objectives clearly defined? How did you assess students' learning based on the objectives?
2. What did you do well for each E phase? What challenges did you encounter in each E phase?

3. What science-specific literacy practices did you try to incorporate in your inquiry-based lesson? What did you do well and what challenges did you encounter?
4. How did you plan the accommodations to meet the language objectives of this lesson, especially for ELs? What challenges did you encounter?

Although PSTs developed their lesson plans in cooperative groups, they were each required to submit an individual reflection about the lesson planning process.

Findings from both data sources indicated that PSTs showed evidence of a developing understanding of the role of literacy in science teaching and learning as well as what accommodations might look like for supporting ELs' engagement in scientific inquiry. All eight groups incorporated at least one science-specific literacy strategy into their lesson plans. These strategies included defining science-specific vocabulary terms, engaging students in science-specific writing supported by evidence, engaging students in written evidence-based explanation using the CER framework, providing sentence frames for scaffolding students' science writing, and using science notebooks to help students record and organize information. Of the different science-specific literacy strategies PSTs included in their science lesson plans, using strategies to support students' evidence-based explanation building was the most common. This is an important finding, because scientific explanation has been considered a central component of science inquiry (Driver et al., 2000) and has been advocated in recent reform efforts in both science and literacy (NGA & CCSSO, 2010; NGSS Lead States, 2013). Instructional supports incorporated by PSTs to scaffold students' ability to construct and communicate scientific explanations included the use of the CER framework and sentence frames, both of which were modeled throughout the semester in the science methods course. Although these supports can

assist all students in the explanation building process, they are especially helpful for ELs who can experience difficulties in communicating their scientific ideas (Fang, 2004; Fang & Schleppegrell, 2010).

Although analysis of PSTs' lesson plans and reflections revealed evidence of PSTs' emerging understandings about the role of literacy in science teaching to support all students' learning, several areas in need of further attention were also identified by the researcher. First, all eight participant groups included a list of related science vocabulary terms at the beginning of their lesson plan, but very few groups included appropriate strategies for building students' science-specific vocabulary beyond the definitional level. This finding indicated a need to better support PSTs in developing strategies for supporting students' vocabulary development in science.

Second, though several groups incorporated strategies for helping students write in science-specific ways (e.g., CER framework, sentence frames), only one group provided a description of how the teacher would encourage students to talk about their scientific ideas. Facilitating scientific talk was also commonly reported as a challenge in participants' written reflections. This is important to note because researchers have highlighted the critical role of classroom discussion in supporting students' conceptual knowledge building in science (Chen et al., 2017; Chin, 2007). In order to effectively encourage scientific talk in the classroom, PSTs must learn how to use questioning techniques and discourse moves to scaffold students' scientific sense making and reasoning abilities. Examples of these include re-voicing students' contributions, prompting students to provide evidence to support their claims, and asking students to compare their reasoning to that of others.

Third, although several groups incorporated a science text within their inquiry-based science lesson, very few PSTs specified how the read-aloud would be used to support the teaching of science as inquiry, nor did they include specific strategies for improving students' comprehension of scientific text. Due to the complex nature of scientific text, it has been argued that students need ample support when interacting with these types of texts (Wellington & Osborne, 2001). To help students become skillful readers in science, teachers must engage them in the wide reading of scientific texts, equip them with tools that can be used to cope with the language demands of science reading, and scaffold their comprehension of scientific texts through strategy instruction. Thus, this finding indicated the need to better support PSTs in developing specific strategies for supporting students' interaction with science texts.

The pilot study examining PSTs' understanding of the role of literacy in science teaching informed the current study in the following ways:

1. PSTs need to acquire strategies for building students' knowledge of science vocabulary beyond the definitional level.
2. PSTs need support in learning how to facilitate science talk in the classroom. This includes developing questioning techniques and discourse moves to scaffold students' communication of scientific ideas and evidence in ways that reflect scientific discourse.
3. PSTs need to learn how scientific text can be used to support the teaching of science as inquiry. This includes learning how to select quality scientific texts, learning how to read texts through a science-specific lens, as well as learning to use reading

strategies to help students activate and integrate prior knowledge, monitor their own reading processes, and organize information from text.

Research Design of Current Study

This mixed-methods study utilized an embedded quasi-experimental design. According to Creswell and Clark (2011), one major rationale for using mixed methods is that "The combination of quantitative and qualitative data provides a more complete understanding of the research problem than either approach by itself" (p. 11). In the present study, the qualitative component was embedded within the primary quasi-experimental methodology to provide an enhanced understanding of the intervention's influence on PSTs' understandings about teaching science as argument. Because the qualitative data were collected during the intervention, a one-phase approach to the embedded quasi-experimental design (see Figure 3) was used (Edmonds & Kennedy, 2013).

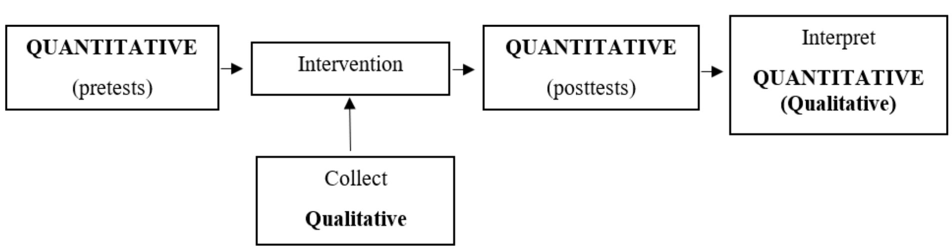


Figure 3. Embedded Quasi-experimental Design (One Phase)

Due to the nature of the science methods course, random assignment of participants to groups was not be feasible. To account for selection bias inherent in the nonequivalent nature of quasi-experimental research, the design incorporated both pretest and posttest measures (see Table 1). Pretest measures serve multiple purposes, such as allowing the researcher to test for group equivalency (i.e., homogeneity between groups) and for providing a baseline against which to compare the treatment effects (Edmonds & Kennedy, 2013).

Table 1

Pretest and Posttest Control Group Design

Assignment	*Group*	*Pretest*	*Treatment*	*Posttest*
NR	1	O_1	X	O_2
NR	2	O_1	___	O_2
		Time →		

Note. Design notations: NR = Nonrandom; O = Observation, also known as measurement; X = Treatment.

An Institutional Review Board (IRB) application was submitted in fall 2018 requesting permission to conduct research in the spring of 2019. Documentation of approval from the IRB committee for this study can be found in Appendix B.

The intervention period spanned a total of 12 consecutive weeks from January to April 2019. PSTs assigned to the control group participated only in the pretest and posttest phases of the study. The course instructor of the control group did not receive any training or implement the intervention. The treatment group instructor, however, engaged in multiple preparation activities prior to the start of the intervention, including the completion of five online professional learning modules. During the beginning of the Spring 2019 semester (weeks 1-3 of the course), the pretests were administered in both conditions. The consecutive intervention

weeks (weeks 4-15 of the course) immediately followed the pretests. The posttests were administered during the final weeks of the course.

Context

This research study was conducted at a large, Southeastern university. The science methods course that served as the context for the study was a required course for PSTs enrolled in the elementary education (K-6) program. The overall course focus was on organizing for instruction, teaching strategies, and assessment procedures for effective science teaching in the elementary grades. The course met weekly (approximately three hours per week) during the 16-week semester in spring of 2019. The treatment group course section met every Wednesday afternoon from 1:30 – 4:20 pm, and the control group course section met every Thursday evening from 6:00 – 8:50 pm.

The course typically provides an overview of national and state science teaching standards, science practices and inquiry process skills, technology to enhance science instruction, procedures for assessing student learning in science, and adapting the science curriculum for students with unique learning needs. In addition to these topics, a series of course components were specifically embedded within the treatment section to provide PSTs with opportunities to develop and apply their epistemological understandings of the NOS, develop their understandings of argumentation, and to engage in both oral and written scientific explanation as learners. In particular, emphasis was placed on the three features of the TSAF (argument structure, public reasoning, and language of science) throughout the entire course (Zembal-Saul, 2009). An in-depth description of the intervention is included later in this chapter.

Participants, Sampling, and Assignment Procedures

In this study, participants were considered both a purposive and convenience sample (Martella, Nelson, Morgan, & Marchand-Martella, 2013). Both convenience sampling and purposive sampling are types of non-probability sampling techniques. When using convenience sampling, participants are drawn from a population that is easily accessible to the researcher. When using purposive sampling, participants are selected based on a set of shared characteristics as well as the objectives of the study. In this study, the sample consisted of participants who matched the target population (i.e., elementary PSTs enrolled in a science methods course) and to whom the researcher had access. The researcher's access depended on the number of course sections being taught in the spring 2019 semester and instructors' willingness to participate in the study.

The total sample included 45 elementary PSTs (treatment = 20, control = 25) drawn from two sections of a science methods course during the spring 2019 semester. The two course sections of students were non-randomly assigned to groups. One instructor indicated a special interest in improving PSTs' understanding of science-specific literacy instruction, including the construction of scientific explanations. Therefore, she requested that her course section be automatically assigned to the treatment condition. Participants enrolled in the remaining section served as the control group.

The course instructor of the treatment group was an Assistant Professor of Science Education who had previously collaborated on a grant-funded research project with the researcher during a previous semester (see earlier description of Pilot Study). The course instructor of the control group was a first-year doctoral student in science education.

Demographic and background information were collected from the course instructor of the treatment group and the course instructor of the control group, as well as a first-year doctoral student in science education who served as a graduate teaching assistant (GTA) in the treatment section of the course. Table 2 contains a summary of the instructors' self-reported demographics and background information, including gender, race, highest degree earned, years of teaching experience at the K-12 level, subjects taught at the K-12 level, and years of teaching experience at the post-secondary level.

Table 2

Instructor Demographics and Background Information

Descriptors	Treatment Group Course Instructor	Treatment Group GTA	Control Group Course Instructor
Gender	Female	Female	Female
Race	Asian/Pacific Islander	Black or African American	Hispanic
Highest Degree Earned	Doctorate Degree	Education Specialist Degree	Master's Degree
Years Teaching K-12	8	13	14
Grades Levels Taught	6-8, 9-12	6-8, 9-12	6-8
Subject(s) Taught at K-12	Chemistry	Life Science, Earth Science, Physical Science, & Environmental Science	Biology
Years Teaching at the Post-Secondary Level	8	< 1	< 1

All PSTs enrolled in the two course sections were eligible to participate in the study. During Week 1 of the semester, instructors distributed the Explanation of Research form (Appendix C) to all PSTs enrolled in both course sections. This form explained the purpose and nature of the study and served as informed consent. As shown in Appendix B, the university's

IRB determined the study to be exempt educational research. Thus, the researcher was not required to obtain written consent from participants. The course instructors emphasized that the decision to participate in the study was voluntary and would not have an impact on final course grades. No financial or academic incentives were offered to participants for participation in the study. All PSTs enrolled in the treatment and control sections agreed to take part in the study.

Intervention Procedures

Intervention procedures for the treatment condition involved professional learning for, and the implementation of, the intervention focused on teaching science as argument. Procedures for the control condition involved the course instructor utilizing instructional methods typical to their usual instruction.

Treatment Condition

The intervention consisted of three phases and was developed using the gradual release of responsibility model to scaffold participants' knowledge and practices for teaching science as argument over the course of the semester (See Figure 4). Phase 1 provided focused instruction, as PSTs were introduced to what it means to develop a scientific explanation, how engaging students in this complex scientific practice supports both students' science and literacy learning, as well as the three core components of the TSAF. Phase 2 provided guided practice, as PSTs engaged in scientific practices and discourse associated with the TSAF. Lastly, Phase 3 provided independent practice, as PSTs worked to apply their developing understandings of the TSAF to plan an inquiry-based science lesson for elementary students.

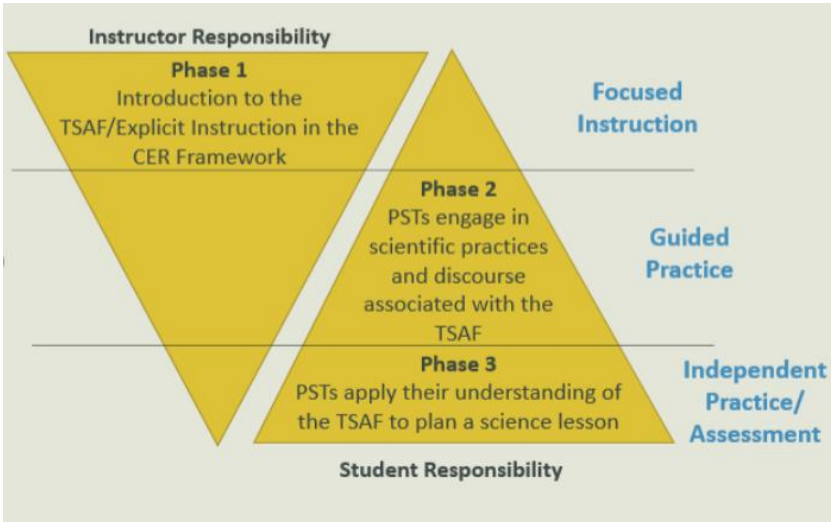


Figure 4. Scaffolding PSTs' Understanding Through a Gradual Release of Responsibility

A separate protocol was developed for each phase of the intervention. These protocols served as the blueprint for the intervention as well as the guiding steps to facilitate the instructor's fidelity of implementation. The development of the intervention protocols were informed by the TSAF (Zembal-Saul, 2009) and the findings from the Pilot Study (previously described) that explored PSTs' knowledge about science and literacy learning in an elementary science methods course. The TSAF consists of three components (i.e., argument structure, public reasoning, and language of science). Each of the protocols (Phases 1-3) consisted of three sections: "Materials, Cue, Do, and Review." The Cue, Do, and Review sequence is a research-validated technique for providing responsive instruction that activates prior knowledge and promotes meta-cognitive thinking (Bulgren & Lenz, 1996).

For each protocol, the Cue section provided specific steps for the course instructor to "cue" PSTs by bridging from the previous class session, orienting PSTs to the current lesson, and sharing the current session's learning goal(s)/objective(s). The Do section of each protocol

provided specific steps for the course instructor to follow to help develop PSTs' knowledge and practices for teaching science as argument. The Review section for each protocol prompts the course instructor to summarize the class session (e.g., "Today, we learned about a framework that can be used to help elementary students construct scientific explanations; let's review the main components of that framework") and bridge to the next lesson (e.g., "Next week, you will engage in a model inquiry-based science lesson and practice constructing your own scientific explanation using data you collected through firsthand investigation"). The Materials section of each protocol provided a complete materials list for that specific phase of the intervention. The researcher provided the course instructor of the treatment group with all necessary materials for the 12-week intervention. The researcher met face-to-face with the treatment group instructor prior to each week's class session to review key points related to the intervention protocol and share related materials (e.g., PowerPoints, handouts). A detailed summary of each phase of the intervention follows.

Phase 1 (Weeks 4-5 of the course)

The overall goal of Phase 1 of the intervention was to build PSTs' knowledge about what it means to develop a scientific explanation and why engaging students in this complex scientific practice is vital to both their science and literacy learning. Furthermore, Phase 1 focused on providing PSTs with a framework for explanation-driven science that could be applied throughout the semester when engaging in both written and oral explanation tasks. The protocol for Phase 1 of the intervention is included in Appendix D1.

During Week 4 of the course, the first week of the intervention, the course instructor delivered a presentation to the treatment group participants on the importance of engaging

elementary students in explanation-driven science instruction. During this presentation, the course instructor discussed contemporary reform-based views of science teaching and learning, the connections between literacy and science, and the benefits of engaging students in scientific explanation. This presentation also provided an overview of the three components of the TSAF (Zembal-Saul, 2009), including examples of how each component can be employed during classroom instruction. The instructor distributed a handout (Figure 5) displaying three fundamentals for teaching science as argument and instructed PSTs to preserve the visual in their science notebooks to refer to throughout the remainder of the semester.

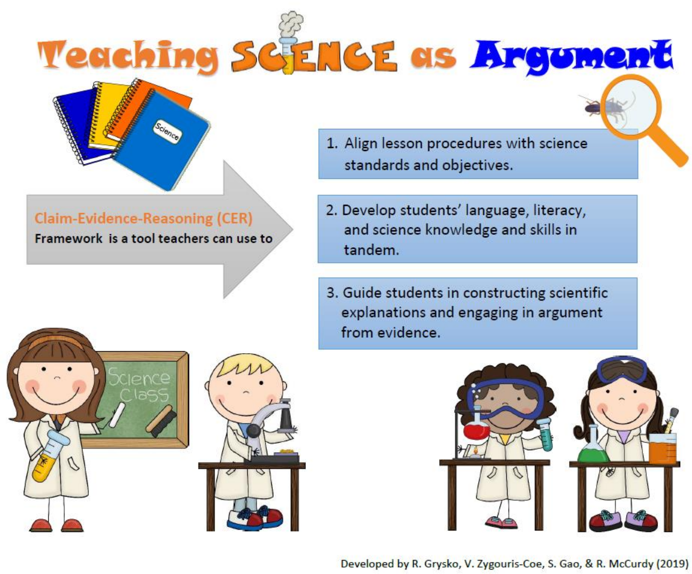


Figure 5. Fundamentals for Teaching Science as Argument

This visual was co-developed by the researcher, the researcher's academic advisor, the course instructor of the treatment section, and a doctoral student in science education prior to the start of the semester during the final face-to-face PL meeting. The visual was enlarged to poster

size and hung in the university classroom for reference purposes all semester long. The purpose of the visual was to emphasize and reiterate how the CER framework can be used as a tool to enhance inquiry-based science instruction, develop students' language, literacy and science knowledge and skills in tandem, and to guide students in constructing evidence-based explanations.

During Week 5 of the course, the participants in the treatment group were introduced to the CER framework. The instructor reviewed each component of the framework and distributed a handout (Figure 6) with definitions and examples of each component. PSTs were instructed to preserve the handout in their science notebooks so it could be used as a reference when talking and writing scientific explanations for the remainder of the semester.

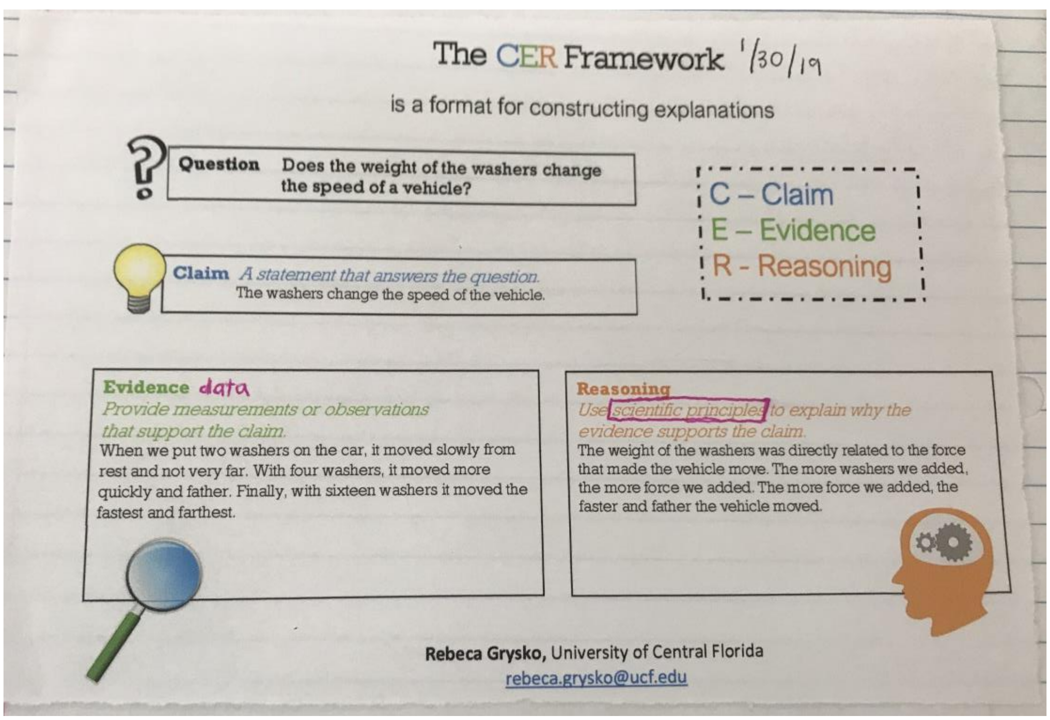


Figure 6. CER Framework Handout

Beyer and Davis (2008) suggested that PSTs need ample practice in constructing, critiquing and debating explanations so that they can develop an understanding of what counts as strong claims, evidence, and reasoning. Therefore, during Week 5, PSTs were also provided with five samples of written scientific explanations ranging in complexity. These sample explanations are included in Appendix E. The PSTs worked in pairs to underline the claim, number the evidence, and circle the reasoning within each sample. The instructor also led the class during a discussion on how the samples ranged in complexity, from simple (claim + evidence) to complex (claim + evidence + reasoning + rebuttal).

During this phase, PSTs were also assigned several intervention-related tasks to be completed during out-of-class time. These assignments predominantly focused on helping PSTs learn how to incorporate language-based activities into science inquiry instruction. For example, PSTs were asked to read a research article on the semantic feature analysis strategy and how it can be used to help students make connections, generate predictions, and develop important concepts. After reading the article, PSTs were required to submit a response providing a specific example of how the semantic feature analysis strategy can be used during science instruction to support students' conceptual understanding. Similarly, PSTs were also asked to read an article explaining how to use a concept of definition word map to develop elementary students' knowledge of science-specific vocabulary terms. Again, after reading, PSTs were required to submit a response providing a specific example of how a concept of definition map can be used during science instruction to enhance students' science and literacy learning.

Phase 2 (Weeks 5-12 of the course)

During the second phase of the intervention, participants in the treatment group engaged in a series of three model inquiry-based science lessons. Scholars, such as Zohar (2008), have suggested that PSTs need opportunities to engage in explanation and argumentation themselves before they can support students' successful engagement in these complex scientific practices. Thus, the rationale for the inclusion of the model inquiry-based science lessons was to provide PSTs with opportunities to experience engaging in scientific practices and discourse associated with the TSAF. The protocol for Phase 2 of the intervention is included in Appendix D2.

All three lessons were co-developed by the researcher and the course instructor of the treatment group during the professional learning (PL) phase of the study. The following steps were taken in developing each lesson:

1. The topic of the lesson was identified along with related science and literacy state standards.
2. A standards-based essential question was developed and ways to provide PSTs with opportunities to construct, communicate, and critique scientific explanations was discussed (e.g., What data will PSTs collect?; What evidence will they use to support their claims; What opportunities will they have to share their evidence and reasoning with others?).
3. A list of science vocabulary words related to the topic was generated. A and how PSTs' conceptual understanding of these words would be developed was discussed.
4. A related scientific text was selected for the purpose of expanding PSTs' content knowledge and supporting firsthand exploration. Each text was selected from

Newsela (https://newsela.com/), consisted of expository structures using the language of science, and was written on an upper elementary grade level.

5. An appropriate strategy was selected to scaffold PSTs' reading comprehension and to assist them in organizing information they learned from the text.

Each lesson plan was designed using the 5 E's instructional model (Biological Sciences Curriculum Study [BSCS], 1989) and provided opportunities for PSTs to engage in authentic reading, writing, and communicating in the context of inquiry science. Throughout each lesson, PSTs engaged in both text-based inquiry and hands-on science investigation.

Each inquiry-based lesson also incorporated all three components of the Teaching Science as Argument Framework (TSAF). For example, the first important feature of the TSAF involves using the structure of argument to guide students in constructing, communicating, and evaluating scientific explanations. To illustrate this component, writing scaffolds and visual representations based on the CER argument structure were used to assist PSTs in appropriately justifying their evidence-based claims, both in writing and orally.

The second important feature of the TSAF is making thinking visible though public scientific reasoning. To illustrate this component, each lesson provided opportunities for PSTs to engage in authentic science talk in which they were encouraged to communicate their explanations and critique the claims of their peers. During these whole-class science talks, the course instructor utilized a series of talk moves and questioning techniques (e.g., "Would someone like to add to that?") to make PSTs' thinking visible while also fostering peer-to-peer interactions. These science talks also provided PSTs with an opportunity to engage in classroom science discussion that does not follow a traditional turn-taking format.

The third important feature of the TSAF is authentic engagement with the language of science. As discussed in Chapter 1, science includes specialized ways of communicating, distinct from students' everyday ways of talking and writing (Fang, 2006; Schleppegrell, 2004). To help students tackle the language demands of science, teachers must incorporate language-based instruction into their science lessons. To illustrate this feature of the TSAF, each lesson provided PSTs with an opportunity to read and interact with expository texts in science, as well as develop their knowledge of science-specific vocabulary through engagement in language-based tasks (e.g., Concept of Definition Map, Frayer Model, Semantic Feature Analysis).

All three of the model inquiry-based science lessons were taught by the treatment course instructor's GTA, who was a first-year doctoral student in science education. The decision to have the GTA lead all three lessons with participants in the treatment section was made in an attempt to achieve comparability between the treatment and control condition, as the course instructor of the control group and GTA had similar backgrounds and experiences. Both were former middle school science teachers and first-year doctoral students in science education. Neither had any prior experience teaching at the higher education level.

After engaging in each lesson as learners, PSTs were provided the opportunity to unpack the lesson plan from the perspective of the teacher, using the three core components of the TSAF as a heuristic. PSTs were provided with a hard copy of the lesson plan and a lesson plan rubric (Appendix F). The lesson plan rubric was modified by the course instructor and researcher during the PL phase of the study to encompass all the three core components of the TSAF (i.e., argument structure, public reasoning, and the language of science). In pairs, PSTs scored the lesson according to the criteria specified in the rubric and were encouraged to provide evidence

from the lesson plan to justify their scores. After PSTs scored the lesson plan with the provided rubric, the instructor led a whole-group discussion in which PSTs discussed how the lesson incorporated the three components of the TSAF to promote both science and literacy learning for all students.

Following is a brief summary of each lesson.

Lesson 1: Oobleck: Solid or Liquid?

This physical science lesson was developed to engage PSTs in comparing objects and materials based on their physical properties. PSTs first read an informational text about the properties of matter. While reading in pairs, PSTs were instructed to underline any properties and examples of solids in red and underline any properties and examples of liquids in green. Next, PSTs used their color-coded text to create two Frayer Models, one for "solids" and one for "liquids" (See Figure 7 for example).

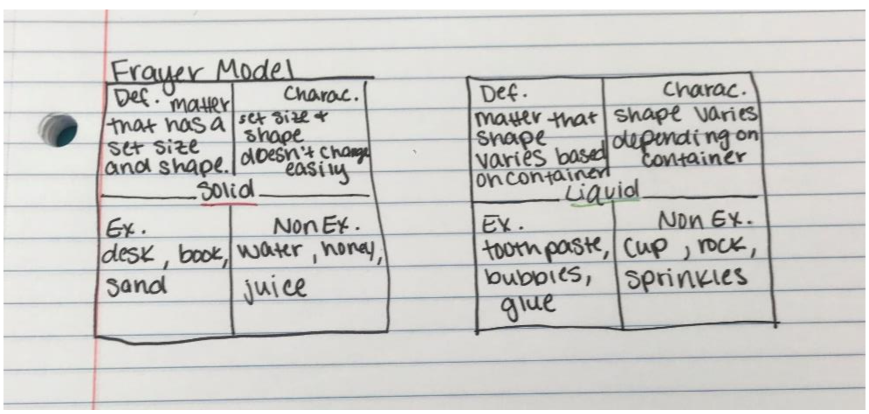


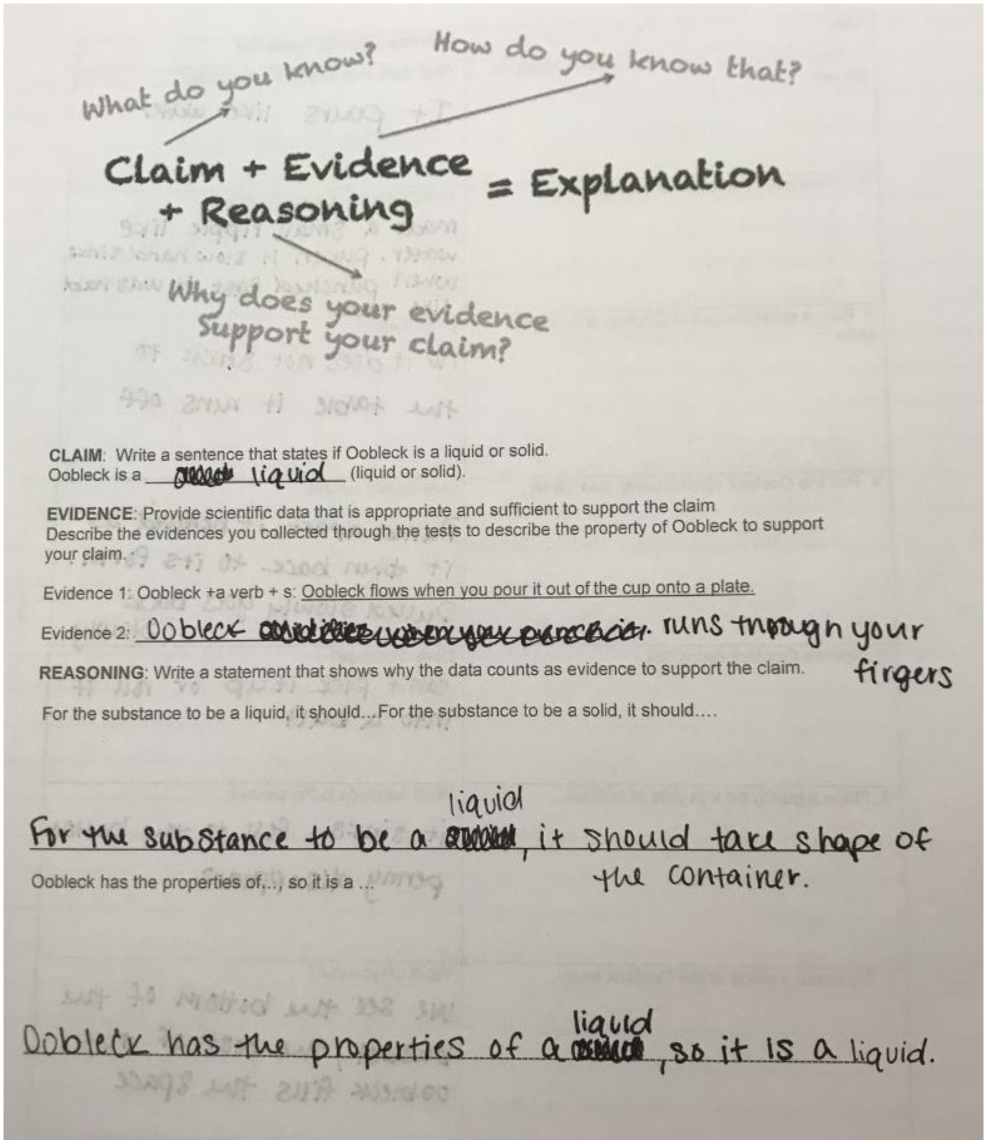
Figure 7. Example of Frayer Model

PSTs then engaged in a hands-on investigation in which they followed a recipe to create "Oobleck" and conducted a series of tests (e.g., hit the puddle of Oobleck with your fist, place a penny on a puddle of Oobleck, try to cut a piece of the Oobleck away) to determine if the

substance was a solid or a liquid. PSTs recorded their procedures and observations in their science notebooks (See Figure 8).

Figure 8. Hands-on Inquiry During Oobleck Lesson

The lesson concluded with PSTs using information from the text and their observations as evidence to construct a scientific explanation to address whether Oobleck was a solid or a liquid. Figure 9 shows an example of a scientific explanation one PST constructed. The complete lesson plan is included in Appendix G.



What do you know? How do you know that?

Claim + Evidence + Reasoning = Explanation

Why does your evidence support your claim?

CLAIM: Write a sentence that states if Oobleck is a liquid or solid.
Oobleck is a liquid (liquid or solid).

EVIDENCE: Provide scientific data that is appropriate and sufficient to support the claim
Describe the evidences you collected through the tests to describe the property of Oobleck to support your claim.

Evidence 1: Oobleck +a verb + s: Oobleck flows when you pour it out of the cup onto a plate.

Evidence 2: Oobleck runs through your fingers

REASONING: Write a statement that shows why the data counts as evidence to support the claim.

For the substance to be a liquid, it should...For the substance to be a solid, it should....

For the substance to be a liquid, it should take shape of the container.

Oobleck has the properties of..., so it is a ...

Oobleck has the properties of a liquid, so it is a liquid.

Figure 9. Scientific Explanation Constructed by PST During Oobleck Lesson

Lesson 2: Muscles, Bones, and the Body

This life science lesson was intended to help PSTs explore how the muscular and skeletal system interact to help the human body work. PSTs first read an informational science text to build background knowledge about the muscular and the skeletal systems. They then organized

what they learned from the text by developing two Concept of Definition maps: one on the muscular system and one on the skeletal system (See Figures 10 and 11 for examples).

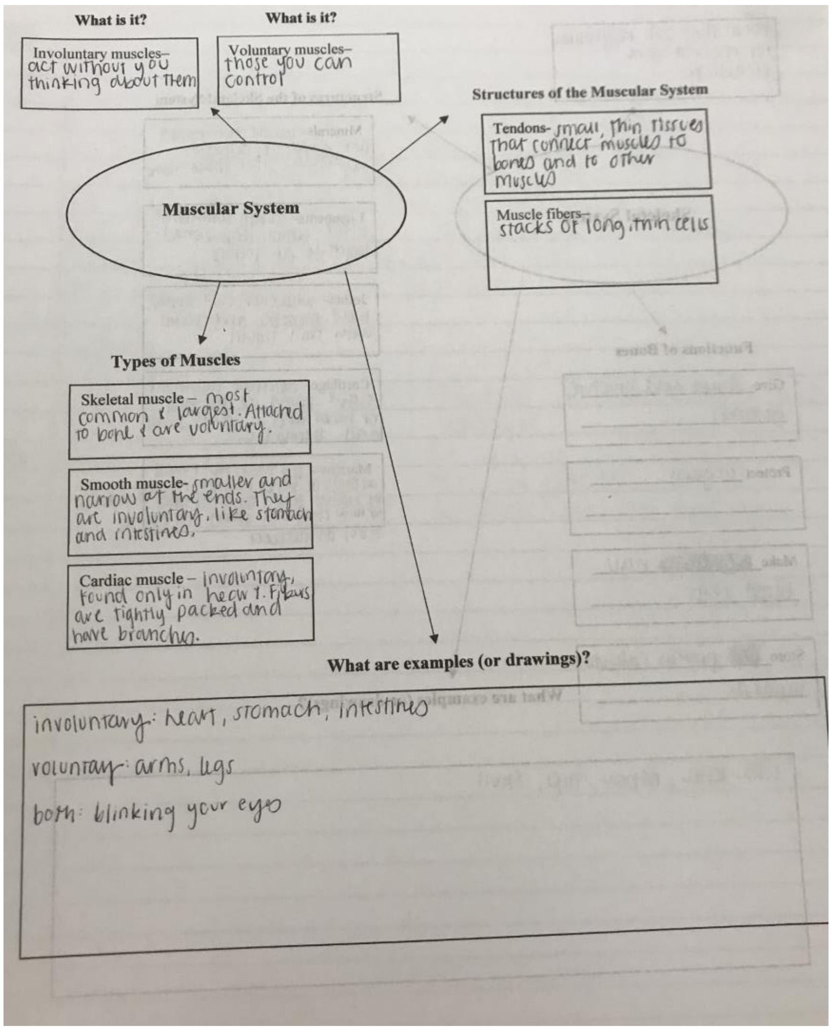


Figure 10. Concept of Definition Map A: The Muscular System

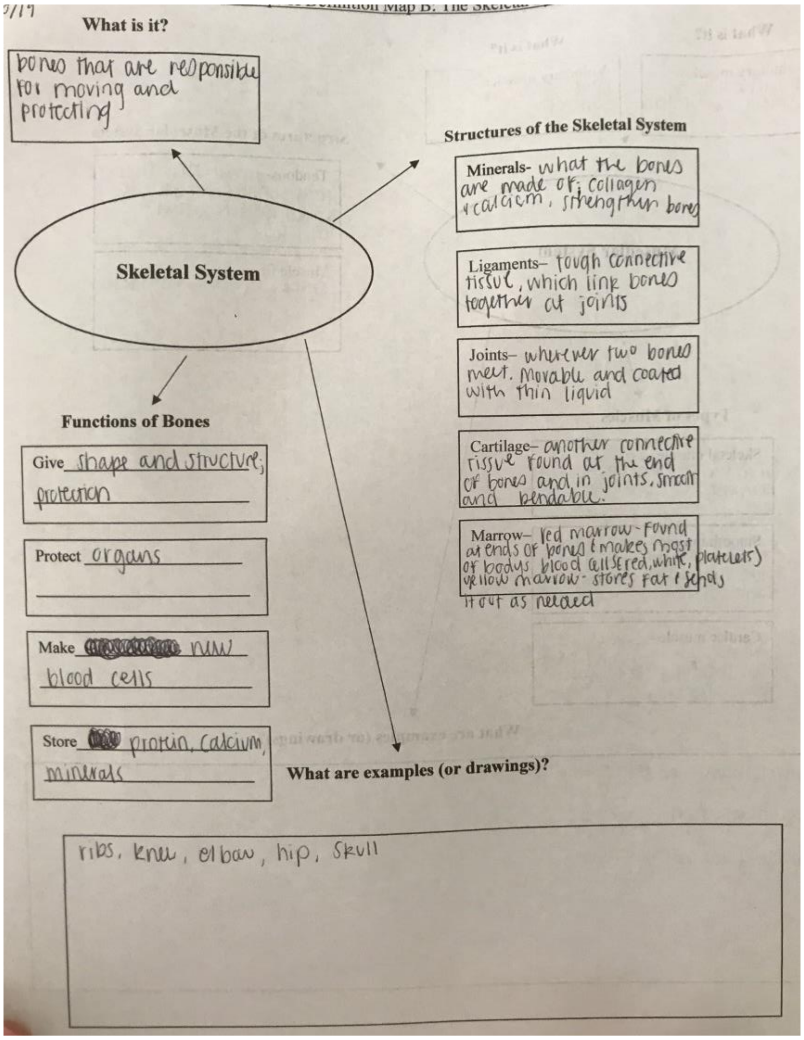


Figure 11. Concept of Defintion Map B: The Skeletal System

Next, PSTs worked in teams to build a three-dimensional (3-D) physical model of an arm, using only the following materials: rubber bands, straws, pipe cleaners, balloons, Ziploc bags, and tape. Figure 12 shows an example of one team's 3-D physical model.

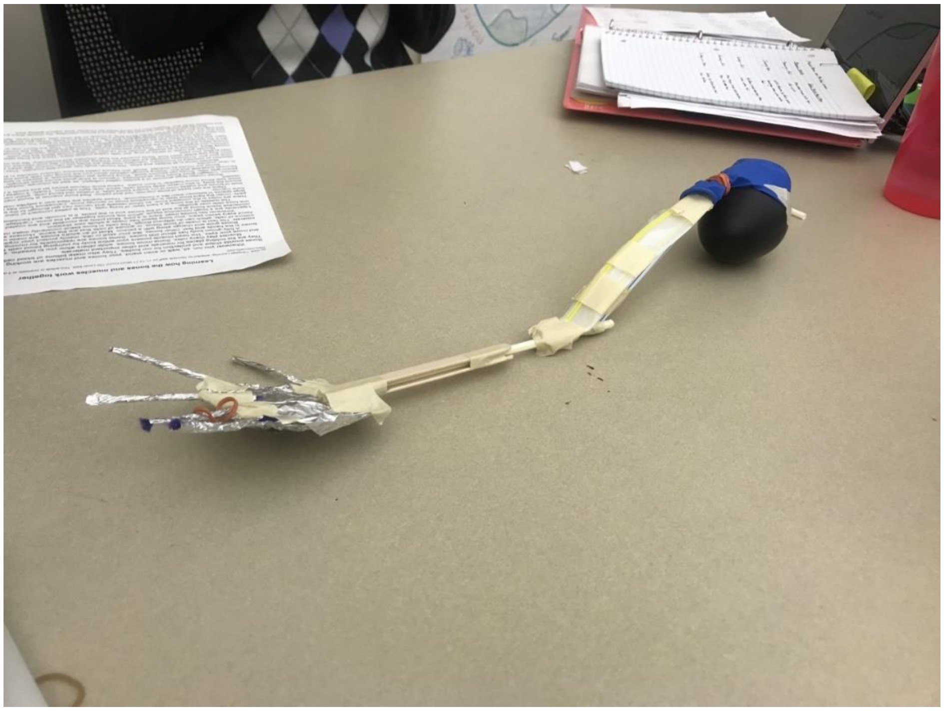


Figure 12. Physical Model of an Arm

PSTs were asked to share their models with the class, explain the materials they used to represent each part of the arm (i.e., joints, ligaments, tendons, voluntary muscle, and skeletal muscle), and to discuss how the muscular and skeletal system worked together in their model to enable the arm to extend and flex.

Finally, PSTs were asked to construct a scientific explanation to address the following question: “What would happen to the human body if the muscular system or skeletal system did not function?” PSTs were instructed to use information from the science text, as well as examples from their physical models as evidence to support their claims. Figure 13 shows an example of a scientific explanation one PST constructed.

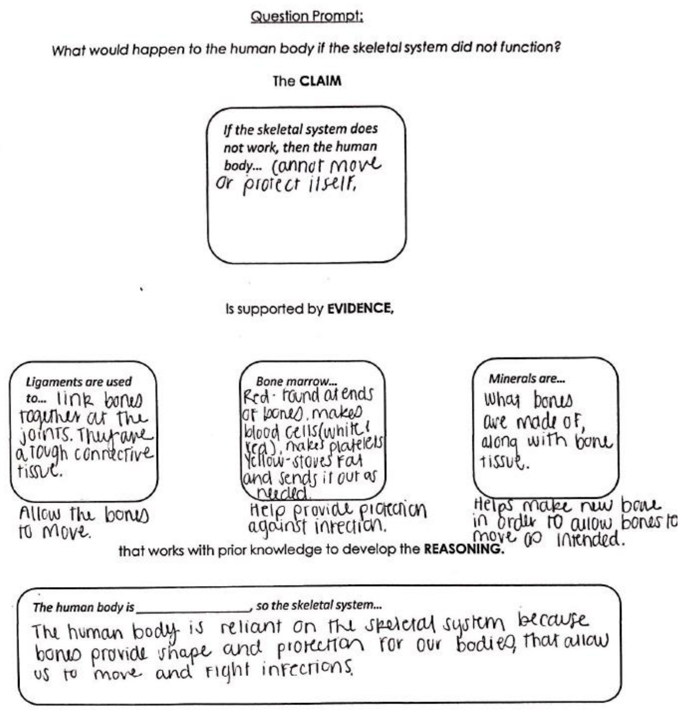


Figure 13. Scientific Explanation Constructed by PST During Human Body Lesson

After writing their scientific explanations in their science notebooks, the GTA led the PSTs through the process of sharing their explanations and critiquing others' evidence and reasoning. The complete lesson plan is included in Appendix H.

Lesson 3: Preventing Soil Erosion

This Earth science lesson was developed to help PSTs learn about the differences between physical weathering (breaking down of rock by wind, water, ice, temperature change, and plants) and erosion (movement of rock by gravity, wind, water, and ice) and the effects these processes have on the Earth's surfaces. PSTs first read an informational article about the processes of weathering and erosion. They were instructed to highlight any differences and similarities between the processes of weathering and erosion as they read. After reading,

PSTs were guided in using information from the text to complete a Sematic Feature Analysis Relationship Chart identifying similarities and differences between weathering and erosion (See Figure 14 for completed example).

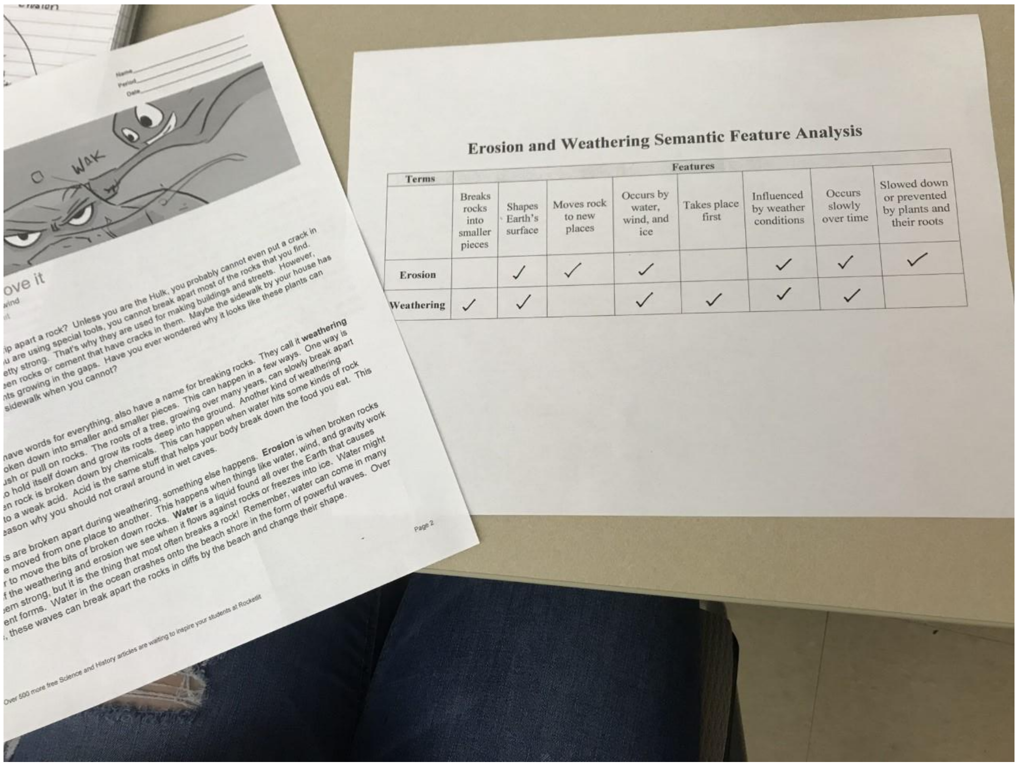


Figure 14. Comparing Weathering and Erosion using Semantic Feature Analysis

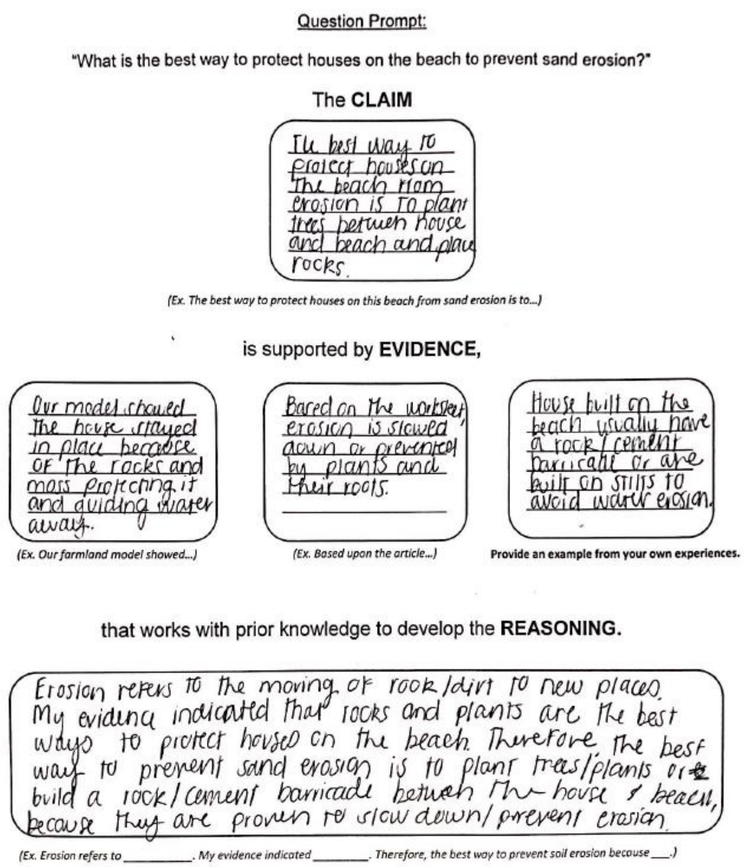
In the next phase of the lesson, PSTs worked in groups to design and build a model farmstead to explore the effects of water erosion on land. When designing their farmstead, PSTs were encouraged to think about how they could protect the buildings and crops on the farm from the effects of water erosion. After building their farmstead model, each group was asked to simulate a rain shower by pouring a cup of water over their model and to describe the effects of

water erosion on their buildings and crops. Figure 15 contains an example of one group's farmstead model after their rain simulation.

Figure 15. Farmstead Model

Following the hands-on investigation, PSTs were challenged to use observations from their simulations as well as information from the informational text to explain how to best

protect houses on the beach from sand erosion. Figure 16 presents an example of a scientific explanation one PST constructed.



Question Prompt:

"What is the best way to protect houses on the beach to prevent sand erosion?"

The **CLAIM**

Th best way to protect houses on the beach from erosion is to plant trees between house and beach and place rocks.

(Ex. The best way to protect houses on this beach from sand erosion is to...)

is supported by **EVIDENCE,**

Our model showed the house stayed in place because of the rocks and moss protecting it and dividing water away.

(Ex. Our farmland model showed...)

Based on the worksheet erosion is slowed down or prevented by plants and their roots.

(Ex. Based upon the article...)

House built on the beach usually have a rock/cement barricade or are built on stilts to avoid water erosion.

Provide an example from your own experiences.

that works with prior knowledge to develop the **REASONING.**

Erosion refers to the moving of rock/dirt to new places. My evidence indicated that rocks and plants are the best ways to protect houses on the beach. Therefore the best way to prevent sand erosion is to plant trees/plants or build a rock/cement barricade between the house & beach, because they are proven to slow down/prevent erosion.

(Ex. Erosion refers to __________. My evidence indicated ________. Therefore, the best way to prevent soil erosion because ____.)

Figure 16. Scientific Explanation Constructed by PST During Weathering/Erosion Lesson

The GTA led the PSTs through the process of sharing their explanations and critiquing others' evidence and reasoning after they had written their scientific explanations in their science notebooks. The complete lesson plan is included in Appendix I.

Phase 3 (Weeks 12-15 of the course)

In the final stage of the intervention, participants worked in groups of three to five students to develop an inquiry-based science lesson plan. The rationale for the inclusion of the lesson plan assignment was to provide PSTs an opportunity to apply their developing understandings of the TSAF when planning a science lesson for elementary students. Groups were instructed to design a lesson focused on teaching a specific life, physical, or earth/space science concept, utilizing the 5E instructional model. A lesson plan rubric (Appendix F), constructed from the three fundamentals for teaching science as argument, was used to outline required components and expectations for the assignment, to facilitate peer-review and self-assessment, and to grade PSTs' final lesson plan submissions. PSTs were required to include the following components within their lesson plans: (a) science teaching standards and content objectives, (b) detailed procedures structured by a 5E instructional model, and (c) appropriate accommodations to assist all students in developing scientific language and content knowledge within each phase. Within their lesson plans, PSTs were also encouraged to select and utilize a related scientific text to pique students' interest and build scientific background knowledge as well as incorporate at least one appropriate strategy to help students develop academic vocabulary in science. As such, the lesson plan rubric was used as a scaffolding tool to help PSTs implement knowledge gained from the intervention to design a lesson plan supportive of both elementary students' science and literacy learning.

A list of planning questions related to the framework for teaching science as argument is presented in Table 3. PSTs were encouraged to use these questions as a guide during the lesson planning process.

Table 3

Questions Used by PSTs When Planning for Inquiry-Based Science Instruction

Framework Foci	Planning Questions
Science concept Overarching explanation	What is the scientific explanation that students will construct during the lesson?
Prior knowledge/misconceptions	What do students already know about the phenomena under study? How might these understandings assist them (or interfere) with the development of the scientific explanation?
Text-based inquiry	What opportunities will students have to read about the phenomena under study?
Hands-on inquiry Data collection	What opportunities will students have to engage firsthand with the phenomena and collect data about it that will help them construct claims?
Data representation Data analysis	How can the data be organized and represented in such a way as to promote the recognition of patterns from which claims can be generated?
Coordinating claims and evidence	During the discussion(s) in which students are constructing arguments from evidence: • What questions will you ask to get students to recognize important trends/patterns in the data? • What questions will you ask to assist students in weighing claims against one another? • What questions will you ask to assist students in negotiating a scientifically accurate argument from evidence?
Testable questions	What opportunities will students have to pursue new questions that arise from their investigation?
Predictions	How can students use their developing explanation to “predict” and test related interactions with the phenomena?

Note. Adapted with permission from “Learning to Teach Elementary School Science as Argument,” by C. Zembal-Saul, 2009, *Science Education, 93,* p. 687-719.

Participant groups utilized both in-class and out-of-class time to work on the creation of their lessons. During Weeks 12 and 13 of the course, the instructor reviewed PSTs' initial lesson plan drafts and provided targeted feedback and suggestions for improvement. PSTs were also given the opportunity to evaluate each other's lesson plan drafts (using the TSAF as a guide) and to offer constructive criticism. PSTs were encouraged to revise their inquiry-based lesson plans based on feedback provided by the course instructor as well as their peers.

During Weeks 14 and 15 of the course, each participant group presented their inquiry-based science lesson to their peers using a microteaching technique. Microteaching is a teacher training technique aimed at helping teacher candidates develop and enhance their pedagogical skills in a low-risk, simulated classroom environment (Brent, Wheatley, & Thomson, 1996). Microteaching provides PSTs opportunities for both self-reflection and peer feedback.

Each group was allotted 40 minutes for their microteaching session. Participant groups began their microteaching sessions with a brief description of the context of their lesson, teaching standards addressed, and learning goals/objectives. Participant groups then carried out the procedures of their lesson plans, with their teacher candidate peers serving as elementary-age students. After each group's microteaching session, PSTs were guided in providing peer-to-peer feedback, including both strengths and weaknesses, using the Group Teaching Observation Sheet (Appendix J). Finally, all PSTs were asked to submit an individual written reflection of the lesson planning/microteaching process using the following questions as a guide:

1. How do learning objectives help to create your lesson plan? What challenges did you have?

2. What expectations do you have for all your students, including ELLs, to develop their knowledge and skills in literacy and/or science through your lesson? What is the relationship between literacy and science in your lesson?
3. Is the CER framework effective in guiding your lesson planning in order to engage students in constructing scientific explanations and argument from evidence? Please answer this question using the evidences from your lesson. What challenges did you have when you implement this tool into your lesson?
4. What other questions do you have related to lesson planning?

The protocol for Phase 3 of the intervention is included in Appendix D3.

Control Condition

The course instructor assigned to the control group was asked to cover similar science topics (i.e., properties of matter, interactions between human body systems, and weathering and erosion) during the spring 2019 semester in a manner consistent with her typical instructional approach. The control group instructor did not partake in any professional learning activities prior to the start of the semester, nor did the researcher discuss any information pertaining to the intervention with the control group instructor.

<u>Professional Learning Procedures</u>

The course instructor of the treatment section completed five researcher-designed online professional learning (PL) modules and attended three face-to-face sessions prior to the start of the intervention. The PL spanned across a total of eight consecutive weeks, beginning in October of 2018 and ending in December of 2018. The overall goal of the PL was for the

researcher and course instructor of the intervention section to co-develop knowledge on the topic of helping PSTs learn how to teach science as argument.

In September of 2018, the researcher led a one-hour introductory meeting with the course instructor of SCE AAAA to provide an overview of the online modules and format for the PL. At this meeting, the researcher and the course instructor also agreed upon a PL schedule. A detailed schedule of the PL tasks completed by the course instructor can be found in Appendix K. The course instructor began the PL in October of 2018 in preparation to implement the intervention during the spring 2019 semester.

Each online PL module included narrated PowerPoints, related readings, and demonstration videos. The five modules covered the following topics: (a) integrating disciplinary literacy and science, (b) connecting science and literacy through scientific explanation and argument, (c) supports for writing scientific explanations, (d) scaffolds for supporting scientific talk during class discussion, and (e) intervention materials, sequence, and timeline. An overview guide of each of the online modules is presented in Appendix L. These online modules were made available to the course instructor through Webcourses. Only the researcher, the researcher's academic advisor, and the course instructor of the treatment section had access to the five online modules.

Each module included a check-for-understanding task, which was completed by the course instructor after completing each online PL module. These check-for-understanding tasks provided the course instructor an opportunity to reflect on module content, demonstrate understanding of intervention procedures and fidelity expectations, and ask questions. The completed check-for-understanding tasks were emailed to the researcher and used to guide the

face-to-face sessions. A summary of the course instructor's responses to each of the check-for-understanding tasks is included in Appendix M. The face-to-face sessions provided an opportunity for the researcher to discuss the instructor's reflections and questions, clarify any information, and provide additional learning opportunities, as needed. The following section details the three face-to-face sessions held between the course instructor and the researcher.

Face-to-Face PL Meeting One

The first face-to-face session took place on Monday, October 1, 2019. This meeting served as the kick-off for the eight-week PL and lasted approximately 1.5 hours. The researcher's academic advisor attended the meeting to take notes. At this meeting, the researcher discussed the three features of the TSAF (i.e., argument structure, public reasoning, and the language of science) and how they would be used to inform the intervention for PSTs. The researcher and the course instructor also discussed the development of the three model inquiry-based science lessons that were taught as part of the intervention. Together, the researcher and course instructor decided on the topics of each of the three inquiry-based lessons (i.e., properties of matter, human body systems, and weathering and erosion). These topics were selected because they each represented a different body of knowledge in science (physical science, life science, and earth and space science) and were topics that the course instructor had already taught during previous semesters of her science methods course. Finally, the researcher shared plans about how the TSAF would be used as a heuristic to analyze preservice teachers' written lesson plans at the end of the intervention. A summary of this meeting is included in Appendix N.

Face-to-Face PL Meeting Two

The second face-to-face session took place on Monday, November 4, 2019. This meeting lasted approximately 1 hour. The researcher's academic advisor was unable to attend due to her attendance at a state-wide literacy conference at the time of the meeting. Thus, only the researcher and course instructor attended the meeting.

Prior to this meeting, the course instructor had completed online Modules 1-3. The course instructor been asked to review one of the three researcher-developed model inquiry-based lesson plans prior to the second face-to-face meeting. At this meeting, the researcher responded to the course instructor's questions that were posed in the check-for-understanding tasks from Modules 1-3. For example, the researcher provided a more concise definition of disciplinary literacy, clarified the distinction between the three features of the TSAF, and provided some additional examples of what the three features look like in practice. The researcher and course instructor also devised a plan for engaging PSTs in reflection after they participated in each model inquiry-based lesson during the intervention. See Appendix O for a complete summary of this meeting.

Face-to-Face PL Meeting Three

The third face-to-face session took place on Tuesday, December 4, 2018. This meeting also lasted approximately 1 hour and served as the wrap-up of the eight-week PL. The researcher's academic advisor attended the meeting via Skype to take notes. A summary of this meeting is included in Appendix P. The course instructor had completed online Modules 4-5 and was asked to review the remaining two researcher-developed model inquiry-based lesson plans prior to this meeting. At this meeting, the researcher responded to the course instructor's

questions that were posed in the check-for-understanding tasks from Modules 4-5. Second, the researcher reviewed pretest administration protocols and how fidelity of implementation would be calculated during the intervention period. Third, together the researcher and course instructor developed a list of three fundamentals for teaching science as argument (described earlier in this chapter) and discussed how to integrate these principles into the lesson plan rubric to be used by PSTs when developing their own inquiry-based science lesson plans. Lastly, a course schedule for the spring 2019 semester of the science methods course was agreed upon. This schedule (Appendix Q) provides the timeline for all three phases of the intervention.

Evaluation of Professional Learning

In order to evaluate the effectiveness of the PL, four critical levels of information (Guskey, 2000) were collected and analyzed:

1. Participant (course instructor) reaction
2. Participant (course instructor) learning
3. Participant (course instructor) use of new knowledge and skills
4. Student learning outcomes

Due to the limited scope of the study, the fifth level of evaluation (i.e., organization support and change) suggested by Guskey (2000) was not considered. The course instructor's reaction to the provided PL was evaluated using the TSAF Instructor Satisfaction Survey (TSAF ISS) which is contained in Appendix R1. The TSAF ISS, which was developed using evidence-based principles for survey development (Dillman, Smyth, & Christian, 2014), consists of 12 four-point Likert scale questions and a comment section. The questions on the TSAF ISS are focused on measuring the participant's (in this case, the course instructor) initial satisfaction with

the PL experience. In addition, social validity of the TSAF protocol was explored using the TSAF Social Validity Questionnaire (TSAF SVQ) which can be found in Appendix R2. Social validity refers to the social acceptability of and satisfaction with intervention goals, procedures, and outcomes (Wolf, 1978). The TSAF SVQ, also developed using evidence-based principles for survey development (Dillman et al., 2014), includes two sections: 12 questions (ten 5-point Likert scale questions and two open-ended questions) and a comment area. Both the TSAF ISS and TSAF SVQ were completed by the course instructor of the treatment group at the conclusion of the eight-week PL.

The course instructor's learning and use of the TSAF protocol were evaluated using direct observations and the TSAF Fidelity Checklist. To demonstrate the overall impact of the PL, student learning outcomes were evaluated with pre- and post-intervention measures (discussed later in this chapter).

Data Collection Procedures

Instrumentation

This section contains detailed information about the instrumentation used to conduct the study. Dependent variable measures for PSTs' outcomes are explained along with the tool used to collect participants' demographic information

Demographic Information Survey

A short researcher-developed survey entitled Demographic Information Survey was distributed to study participants in both the treatment and control groups during the first class of the methods course in January 2019. The purpose of this survey was to collect participants'

demographic and background information, including gender, race, primary language spoken, and university major. The survey can be found in Appendix S1.

The Nature of Science as Argumentation Questionnaire

The Nature of Science as Argumentation Questionnaire (NSAAQ), developed by Sampson and Clark (2006) was used to determine participants' epistemological understanding of NOS both at the beginning and end of the intervention (RQ1). Permission to use the NSAAQ was granted by Dr. Victor Sampson (see Appendix W2). The NSAAQ (Appendix S2) contains 26 items and a 5-point Likert-type scale with a Cronbach's Alpha reliability coefficient of 0.79, calculated in a pilot study with 254 PSTs in five different universities (Kutluca & Aydin, 2017). The NSAAQ consists of four subscales: nature of scientific knowledge (6 items); methods that can be used to generate scientific knowledge (6 items); what counts as reliable and valid scientific knowledge (7 items); and the role scientists play in the generation of scientific knowledge (7 items). Each item presents two contrasting statements (one of the statements demonstrates a view of science as a process of explanation and argument, and the other demonstrates more naïve understandings about NOS). Participants are asked to read the pair of statements and select a number on a continuum that best describes their position on the issue described. When computing participants' NSAAQ scores, negatively-phrased items are reversed to have higher scores reflect a more consistent view of science as a process of explanation and argument. An overall high score on the NSAAQ is accepted as evidence of the participant having a more informed understanding of NOS.

The Argumentation Test

The Argumentation Test (ARGTEST), developed by Clark and Sampson (2006), was used to determine participants' understanding of argumentation both at the beginning and end of the intervention (RQ2). Permission to use the measure was granted by Dr. Victor Sampson (see Appendix W2). The ARGTEST (Appendix S3) is comprised of two separate tasks. In the first task, participants are presented with a claim, followed by six different arguments. Participants are asked to rank the arguments in order from least convincing to most convincing. This task is designed to determine what participants believe counts as a quality scientific argument. In the second task, participants are presented with an argument followed by six different challenges. Participants are asked to rank the challenges in order, from the weakest to the strongest challenge. This task is designed to determine what participants perceive to be a good challenge to a scientific argument. The ARGTEST has a Cronbach's Alpha reliability coefficient of 0.68, calculated in a pilot study with 447 students.

Written Scientific Explanation Assessment

To measure the effect of the intervention on the quality of participants' written explanations (RQ3), an identical pre- and post-intervention Written Scientific Explanation Assessment (WSEA) was administered to participants in both the treatment and control groups (See Appendix S4). The researcher-developed assessment required participants to write a scientific explanation using secondhand data (i.e., data that has already been collected). The assessment asked participants to examine a bar graph comparing soil loss among different types of crops and to write a scientific explanation to explain which crop is the most resistant to the

effects of erosion. This particular task was chosen because participants learned about the process of erosion and its effects on land during one of the three model inquiry-based lessons.

Participants' explanations were scored by adapting a base explanation rubric (Appendix S5). The base explanation rubric includes the three components of the CER Framework: claim, evidence, and reasoning and is a general rubric that can be used across content areas (McNeill, Lizotte, Krajcik, & Marx, 2006a). However, because constructing a scientific explanation requires both an understanding of science content and an understanding of the structure of scientific explanation, assessment should combine analysis of both content and structure (McNeill et al., 2006; Sandoval & Millwood, 2005). Therefore, the base rubric was used to develop a specific scientific explanation rubric that outlined explicit expectations for participants' explanations in terms of both the CER Framework and the science content. The specific rubric that was used to score PSTs' pre- and post-intervention WSEA measures is included in Appendix S6.

Each component was scored on a three-point (0-2) scale. The scores earned on each component were then combined to assign an overall score. As a result, overall scores for the WSEA ranged from 0 to 6, with higher scores representing a higher quality explanation.

Assessment Procedures

The researcher administered the pretests and posttests to PSTs in both conditions. The testing schedule is displayed in Table 4.

Table 4

Pretest and Posttest Administration Schedule

Testing Event	Course Week
Collection of Demographic Information Survey Data	Week 1
NAASQ - Pretest	Week 1
ARGTEST - Pretest	Week 2
WSEA - Pretest	Week 3
NSAAQ - Posttest	Week 14
ARGTEST- Posttest	Week 15
WSEA - Posttest	Week 15

Pretest Administration

Pretest administration took place in both conditions during the three-week period prior to the start of the intervention phase of the study. Pretest measures were administered in a whole-group format, with 20 minutes allotted for each measure. PSTs were assured that their responses and performance on the pretests would not affect their course grades. During pretest administration, course instructors were present but were asked not to view the content of the pretest measures.

Appendices T1 – T3 contain the scripts used for each of the three pretests, as well as the Demographic Information Survey. The Demographic Information Survey and the NSAAQ were distributed as a single packet during Week 1 of the course. The ARGTEST was administered during Week 2 of the course, and the WSEA was administered during Week 3 of the course. The pretests were administered during each course section's regularly scheduled meeting times. The treatment group course met on Wednesday afternoons from 1:30 – 4:20 pm. The control group course met on Thursday evenings from 6:00 – 8:50 pm. During test administration weeks, the last 30 minutes of class was set aside for assessment purposes. Make-up pretests were

administered during Week 4 at the beginning of class time, prior to the start of any intervention activities.

After the pretests were administered and collected, the researcher assigned numeric codes to participants' tests and blacked-out participants' names. A numeric code range was used for each condition. The codes were assigned based on the order in which the papers were stacked. Codes were assigned to PSTs who were absent during pretesting to account for their participation in the study.

Posttest Administration

The administration of posttests took place during the final two weeks of the semester. The researcher arranged the posttesting schedule to accommodate instructors' preferences, and as a result, posttesting in the treatment condition took place over the final two face-to-face class sessions (Weeks 14 and 15 of the course) for a total of 60 minutes. The NSAAQ was administered during Week 14 and the ARGTEST and the WSEA were administered together during Week 15.

Posttesting in the control condition occurred over one class session (Week 15) for a total of 60 minutes; all three tasks were administered at once. Because several PSTs were absent in the control condition on the posttesting day, the researcher arranged with the course instructor to return the following week, final examination week, to administer any make-up tests. Make-up tests were administered to PSTs in a one-on-one setting with the researcher after completing their final examination.

As with the pretests, posttests (except for make-ups) were administered in a whole group format, with 20 minutes allotted for each measure to be completed. The same scripts and

procedures were used for the posttests as the pretests. Again, the researcher assured PSTs that their responses and performance on the posttests would not affect their course grades. After the posttests were administered and collected, the researcher matched the numeric code to the participants' tests, removed participants' names, and wrote the corresponding codes on participants' tests.

Data Analysis

Quantitative Data Analysis

A multivariate repeated measures MANOVA (RM-MANOVA) was conducted to answer Research Questions 1-3. Table 5 provides a visual model of the research design used in analyzing data to respond to these questions.

Research Question 1: Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' understandings of the NOS, as measured by the Nature of Science as Argumentation Questionnaire (NSAAQ)?

Research Question 2: Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' knowledge of argumentation, as measured by The Argumentation Test (ARGTEST)?

Research Question 3: Does participation in an intervention focused on teaching science as argument have an impact on the complexity of elementary PSTs' written explanations, as measured by a researcher-developed written scientific explanation assessment?

Table 5

Research Design for Research Questions 1-3

Assignment	Group	Pretest	Treatment	Posttest
NR	1	O_1	X	O_2
NR	2	O_1	___	O_2
		Time →		

Note. Design notations: NR = Nonrandom; O = Observation, also known as measurement; X = Treatment.

The RM-MANOVA was used to investigate main effects of a within-group factor, a between-group factor, and the interaction between time and group. In contrast to an RM-ANOVA, which is appropriate in situations where there is only one dependent variable, an RM-MANOVA is used when two or more dependent variables are present (Tabachnick & Fidell, 2014). The within-group factor was time (pretest to posttest) in both conditions. The between-group factor was the condition (treatment or control). The interaction referred to the interaction between time (pretest and posttest) and group (treatment and control conditions). The dependent variables, which were all interval in scale, were the scores on each of the three measures: NSAAQ, ARGTEST, and WSEA. The test was conducted using an alpha of .05. The RM-MANOVA was followed by a series of univariate ANOVAs and appropriate post-hoc tests.

Statistical assumptions were tested for each measure (pretest and posttest), and violations were examined to determine if they were in acceptable limits. Statistical procedures were conducted using SPSS (Version 25.0).

Qualitative Data Analysis

Qualitative data analysis was used to respond to Research Question 4: How do elementary PSTs incorporate components of the Teaching Science as Argument Framework to support both students' literacy and science learning when planning for inquiry-based science instruction, as evident in their written lesson plans?

Table 6 provides a visual model of the research designed used to respond to Research Question 4.

Table 6

Research Design for Research Question 4

			Collection Method	
Assignment	Group	Treatment	Pre	Post
NR	1	X		✓
NR	2	___	___	___
		Time →		

Note. Design notations: NR = Nonrandom; X = Treatment.

As part of the intervention, participants in the treatment group worked in groups of three to five to develop an inquiry-based science lesson plan. Groups were instructed to design a lesson focused on teaching a specific life, physical, or earth/space science concept utilizing the 5E instructional model. PSTs were provided with a lesson plan template that they used to construct their lessons. Required lesson plan components included: (a) science teaching standards and content objectives, (b) detailed procedures structured by a 5E instructional model,

and (c) appropriate accommodations to assist all students in developing scientific language and content knowledge within each E phase.

A lesson plan can serve as an indicator of a teacher's content and pedagogical knowledge (Shulman, 1986). For this reason, PSTs' lesson plans were collected and analyzed as an additional layer of data to explore how elementary PSTs who participated in the intervention applied their developing knowledge of the Teaching Science as Argument Framework (Zembal-Saul, 2009) when planning for science instruction (RQ4).

The lesson plans were analyzed using a constant comparative approach (Glaser & Strauss, 1967). The constant comparative method involves dividing the data into discrete "incidents" (Glaser & Strauss, 1967) and coding them to categories. Initial coding involved coding each incident in the data using a priori codes based on the three features of the TSAF (Zembal-Saul, 2009) which are displayed in Table 7. The initial coding phase was proceeded by two additional rounds, resulting in the addition of six new codes that emerged during analysis.

The final codebook, shown in Table 8, consisted of three categories (argument structure, public reasoning, and language of science) to align with the three main features of the TSAF, as well as a fourth category focused on negative instances. The codes within the first three categories encompass different aspects of the three main features of the TSAF and assisted in defining how those features were incorporated by the participants when planning for science instruction. In an attempt to minimize the effects of researcher bias, negative instances were also examined, rather than merely searching for confirmatory data (Kolb, 2012). The codes within this final category identified instances within PSTs' lesson plans that did not align with the TSAF.

Table 7

A Priori Codes Based on the TSAF

Category	Codes	Definition
Argument structure	Data collection	Providing opportunities for students to collect and record data that will help them construct claims.
	Identify patterns	Prompting students to examine data in order to categorize it into repeatable patterns.
	Claims and evidence	Prompting students to form claims based on the available evidence.
	Consider alternatives	Encouraging students to consider additional potential explanations for the patterns in the evidence.
	Constructing explanations	Asking students to form explanations for the patterns that they have seen in the evidence.
Public reasoning	Explicate reasoning	Asking students to explain their thinking.
	Reasoning	Asking students to apply their own reasoning to someone else's statement.
	Attention focusing	A question asked to prompt the student to examine some aspect of the phenomena.
	Comparison	Prompt for students to consider the similarities and/or differences between two or more things.
	Student talk	Discussion and questions initiated by the student.
Language of science	Language of science	Words and phrases used to indicate participation in the scientific community.

Note. Adapted from "Preservice Elementary Teachers' Instructional Practices and the Teaching Science as Argument Framework," by E. Boyer, 2016, *Science and Education, 25,* p. 1040 – 1042.

Table 8

Final Code Book

Category	Codes	Definition
Argument structure	Collecting data*	Providing opportunities for students to collect and record data that will help them construct claims.
	Identify patterns	Prompting students to examine data in order to categorize it into repeatable patterns.
	Claims and evidence	Prompting students to form claims based on the available evidence.
	Consider alternatives	Encouraging students to consider additional potential explanations for the patterns in the evidence.
	Constructing explanations	Asking students to form explanations for the patterns that they have seen in the evidence.
Public reasoning	Explicate reasoning	Asking students to explain their thinking.
	Apply reasoning	Asking students to apply their own reasoning to someone else's statement.
	Attention focusing	A question asked to prompt the student to examine some aspect of the phenomena.
	Comparison	Prompt for students to consider the similarities and/or differences between two or more things.
	Student talk	Discussion and questions initiated by the student.
Language of science	Scientific texts*	Exposing students to the language of science through reading and discussing science texts
	Vocabulary knowledge*	Engaging students in tasks for building knowledge of science vocabulary.
	Discourse*	Providing supports that assist students in organizing and communicating their scientific ideas in ways that reflect scientific discourse.
Negative instances	Recall*	Posing factual questions that require simple recall of facts
	Lecture*	Direct instruction of science content through teacher lecture with limited opportunities for student interaction

Note. * Denotes codes that emerged during data analysis

Furthermore, triangulation of data sources was used to enhance the credibility of the research findings. Triangulation involves the use of multiple sources of data in order to produce a more complete understanding of the phenomena (Creswell, 2003). Thus, findings from the

lesson plan analysis was validated through cross verification with insights gleaned through ongoing fidelity of implementation checks as well as participants' pre and post written scientific explanations.

Fidelity of Implementation

The collection and assessment of implementation data is critical in evaluating the internal and external validity of an intervention (Durlak & DuPre, 2008). For the purpose of this study, fidelity of implementation (FOI) was defined as the level to which the instructor in the treatment condition implemented the intervention protocols as intended by the researcher.

The final module completed by the treatment group instructor during the professional learning phase provided an in-depth overview of the components of the TSAF Protocols, TSAF Fidelity Checklists (FCs), the TSAF Instructor Fidelity Worksheet (IFW). The course instructor discussed her understanding of the treatment fidelity expectations and had an opportunity to ask questions during the third and final face-to-face meeting, prior to the implementation of the intervention. The researcher also discussed possible threats to validity and the importance of preventing contamination. The course instructor verified that she understood that she was not permitted to discuss the study with others.

TSAF Fidelity Checklists

To track fidelity of implementation, three fidelity checklists (FCs) were developed, one for each of the three phases of the intervention. As with the TSAF Protocol, each checklist followed the Cue, Do, Review format. Each component was worth 1 point in the Cue, Do, and Review sections. Each FC also included a Salient Features and Essential Components section. Components in this section were also worth 1 point. Presence or absence of the component was

noted by the researcher with a checkmark in either the Yes or No column. Scores for each section were then tallied and recorded as a section score. The end of each checklist also included an additional information section for the reviewer to note instructional time as well as any additional comments (if applicable). The researcher attended each course session of the treatment group to take detailed field notes and complete fidelity checks. A Phase Fidelity Score (PFS) was calculated for each phase of the intervention by adding scores for each section (Cue, Do, Review/Reflect, and Salient Features) and recording them in the additional information section. A phase fidelity percentage (PF%) was calculated for each phase of the intervention by dividing the PFS by the total maximum point value possible. The researcher provided feedback to the instructor after each week of instruction to inform her about whether she was meeting fidelity expectations.

Phase 1: Fidelity Checklist

The Phase 1 Fidelity Checklist (P1FC) had a maximum PFS of 17 (See Appendix U1). The Cue section of P1FC had a total point value of 3 (bridge from previous class session, orient PSTs to current lesson, and share learning goals and/or objectives). The Do section of the P1FC had a total point value of 3 (provide overview of importance/benefits of scientific explanation, discuss connections between literacy and science, provide overview of the TSAF, introduce the CER framework, distribute CER handout, distribute and review scientific explanation base rubric, guide PSTs in the process of critiquing sample explanations using the base rubric, and discuss how the samples range in complexity). The Review/Reflect section of the P1FC had a total point value of 3 (review three features of the TSAF, review all components of the CER framework, and review the role of explanation in science). The total score of the P1FC Salient

Features section was based on the presence or absence of three essential components: explicit connections between literacy and science, explicit connections to elementary students and/or classroom practice, and emphasis on the NOS (i.e., what real scientist do and why). A PFS for Phase 1 was calculated by adding the scores earned for each section (Cue, Do, Review/Reflect, and Salient Features). A PF% for Phase 1 was calculated by dividing the PFS by 17 and multiplying by 100.

Phase 2 Fidelity Checklist

The Phase 2 Fidelity Checklist (P2FC), displayed in Appendix U2, had a maximum fidelity score of 25. Three separate P2FC were completed, one for each of the three inquiry-based science investigations. The Cue section of P2FC had a total point value of 3 (bridge from previous class session, orient PSTs to current lesson, and share learning goals and/or objectives). The Do section of the P2FC had a total point value of 11 (encourage PSTs to pursue testable questions, provide opportunities for PSTs to read about the phenomena under study, engage PSTs in an academic vocabulary building strategy, provide opportunities for PSTs to engage firsthand with the phenomena under study, engage PSTs in the process of collecting, recording, and representing data, encourage PSTs to identify patterns in their data, review the three components of scientific explanation, display visual representation of the CER framework, provide writing scaffold to assist PSTs in constructing a scientific explanation, use a series of talk moves to make PSTs' thinking visible, use productive questioning techniques to scaffold PSTs' communication of scientific ideas, and lastly, make connections to be big idea/science concept). The Review/Reflect section of the P2FC had a total point value of 4 (provide PSTs with an opportunity to unpack the lesson from the perspective of the teacher, discuss how the

lesson supports all students in engaging in scientific explanation, review the components of the CER framework, and reiterate the role of explanation in science). The total score of the P1FC Salient Features section was based on the presence or absence of six essential components: explicit connections between literacy and science, explicit connections to elementary students and/or classroom practice, and emphasis on the NOS (i.e., what real scientist do and why), attention on developing academic vocabulary, engagement in science reading, writing, and talk, and peer-to-peer talk during whole-group discussion. A fidelity score for each investigation was calculated by adding the scores earned for each section (Cue, Do, Review/Reflect, and Salient Features). A fidelity percentage for each investigation was calculated by dividing the fidelity score by 25 and multiplying by 100.

Phase 3 Fidelity Checklist

The Phase 3 Fidelity Checklist (P3FC), which appears in Appendix U3, had a maximum fidelity score of 15. The Cue section of P3FC had a total point value of 3 (share rationale for lesson plan assignment, distribute and discuss planning questions related to the TSAF, and review/discuss lesson plan rubric). The Do section of the P3FC had a total point value of 5 (provide in-class time for PSTs to work on their group lesson plans, provide instructor support during the planning process, engage PSTs in peer-review, allow PSTs to revise their group lessons based on instructor and peer suggestions, and provide in-class time for each group to present/microteach their final inquiry-based science lesson). The Review/Reflect section of the P3FC had a total point value of 3 (engage PSTs in self-reflection of their own lesson plan, encourage PSTs to reflect upon how their lesson supports all students in constructing, communicating, and debating evidence-based scientific claims, and review the role of

explanation in science). The total score of the P3FC Salient Features section was based on the presence or absence of four essential components: explicit connections between literacy and science, explicit connections to elementary students and/or classroom practice, emphasis on the NOS (i.e., what real scientist do and why), and targeted feedback provided to each collaborative group. A PFS for Phase 3 was calculated by adding the scores earned for each section (Cue, Do, Review/Reflect, and Salient Features). A PF% for Phase 3 was calculated by dividing the PFS by 15 and multiplying by 100.

<u>TSAF Instructor Fidelity Worksheet</u>

The TSAF Instructor Fidelity Worksheet (IFW), shown in Appendix U4, served as a companion to the FCs and was used to assign the course instructor in the treatment condition a total fidelity score (TFS) and a total fidelity percentage (TF%) at the end of the 12-week intervention. The IFW provided a section for the reviewer to note and calculate a PFS and PF% for each phase of the intervention. Phase 1 had a maximum PFS of 17. Phase 2 had a maximum PFS of 75 because a separate P2FC was completed for each of the three inquiry-based science investigations. To calculate a total PFS for Phase 2, the fidelity scores from all three investigations (Investigation 1 + Investigation 2 + Investigation 3) were combined. Phase 3 had a maximum PFS of 15. The maximum TFS was 107 (Phase 1 + Phase 2 + Phase 3 PFS). A TF% was calculated by dividing the TFS by 107 and multiplying by 100. FOI results for the course instructor of the treatment group are presented in Chapter 4.

Interrater Reliability

Interrater reliability was calculated in four areas: assessment scoring, Fidelity Checklist (FC) scores, Instructor Fidelity Worksheet (IFW) scores, and qualitative coding. The point-by-

point formula (agreements/agreements + disagreements x 100) was used to calculate interrater reliability (Gast, 2010).

Assessment Scoring

A CITI certified graduate student research assistant (RA) conducted interrater reliability checks for 100% of the pre and post measures. The researcher reviewed the scoring criteria and provided the RA with the necessary answer key or rubric for each assessment. Using the Assessment Interrater Reliability Worksheet (IRW), shown in Appendix V1, the RA rescored all pre- and post-assessments (NSAAQ, ARGTEST, and WSEA). The researcher compared the scoring results she recorded with the scoring results of the RA. Every item and the total score were reviewed. Most of the differences in recorded scores were a result of scorer error and were corrected.

Fidelity Checklist Scores

The RA also conducted interrater reliability checks for the FC scores. To prepare the RA for the inter-rater reliability task, the researcher and RA first listened to a practice recording together and the RA completed the FC with support. During this practice session, the researcher provided feedback about any inaccuracies and clarified any confusion. The RA then reviewed recordings from each weekly session and independently completed the FCs for all three phases of the intervention.

Instructor Fidelity Worksheet

Lastly, the RA conducted interrater reliability checks for scores recorded on the IFW. The RA recalculated 100% of scores and percentages for the IFW and noted the results on the Interrater Reliability Instructor Fidelity Worksheet [IR-IFW] (Appendix V2).

Lesson Plan Analysis

In order to establish inter-rater reliability, the RA, who is experienced in document analysis, independently coded all five lesson plans using the final codebook (See Table 8). Inter-rater agreement was reached through a process of initial coding, discussion, additional rounds of coding, resolution of discrepancies, and final agreement.

Chapter Summary

In this chapter, the methodology used to conduct this study was explained. This mixed-methods study utilized an embedded quasi-experimental design to investigate the impact of a one-semester intervention (12 weeks) focused on teaching science as argument within a science methods course on elementary PSTs' (a) understandings of the NOS, (b) knowledge of argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the Teaching Science as Argument Framework when planning for science instruction. The following methods and procedures were detailed: (a) research design (b) context, (c) participants, (d) sampling and assignment, (e) intervention, (f) data collection, and (g) data analysis.

CHAPTER FOUR:
RESULTS

Introduction

The current study was conducted to investigate the impact of a one-semester intervention (12 weeks) focused on teaching science as argument within a science methods course on PSTs' (a) understandings of the NOS, (b) knowledge about argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the Teaching Science as Argument Framework when planning for science instruction. This mixed-methods study employed an embedded quasi-experimental design with a control condition and pretest and posttest measures (Edmonds & Kennedy, 2013). A repeated measures MANOVA was used to answer the first three research questions. To answer the fourth research question, PSTs' science lesson plans were analyzed using a constant comparative approach.

This chapter begins by describing procedures for missing data and descriptive statistics by condition. Following the missing data procedures and descriptive statistics by condition, statistical assumptions of the RM-MANOVA are presented, as are the results of the analysis for Research Questions 1-3. Next, four emergent themes, regarding PSTs' enactment of the TSAF components (i.e., argument structure, public reasoning, and the language of science) when planning for inquiry-based science instruction, are presented to answer the fourth research question. This chapter concludes with an overview of the effectiveness of professional learning, fidelity of implementation and inter-rater reliability.

Missing Data

There were some occurrences of missing pretest and posttest assessment data due to absences and/or course withdrawals. Participants' pretest and posttest scores for each measure are presented in Figures 17 and 18; the missing points in the graphs represent the missing data. The points along the dotted line represent each participant's pretest score. The dots along the solid line represent each participant's posttest score. The order of participants is the same in all of the graphs displayed in Figures 17 and 18.

A total of 42 participants (treatment, $n = 20$; control, $n = 22$) had valid NSAAQ pretest and posttest scores; a total of 39 participants (treatment, $n = 19$; control, $n = 20$) had valid ARGTEST pretest and posttest scores; and a total of 37 participants (treatment, $n = 19$; control, $n = 18$) had valid WSEA pretest and posttest scores. Only participants with valid pretest and posttest scores were included in the RM-MANOVA. During the data analysis, SPSS (Version 25.0) removed the participants with missing pretest or posttest scores from the data analysis using listwise deletion.

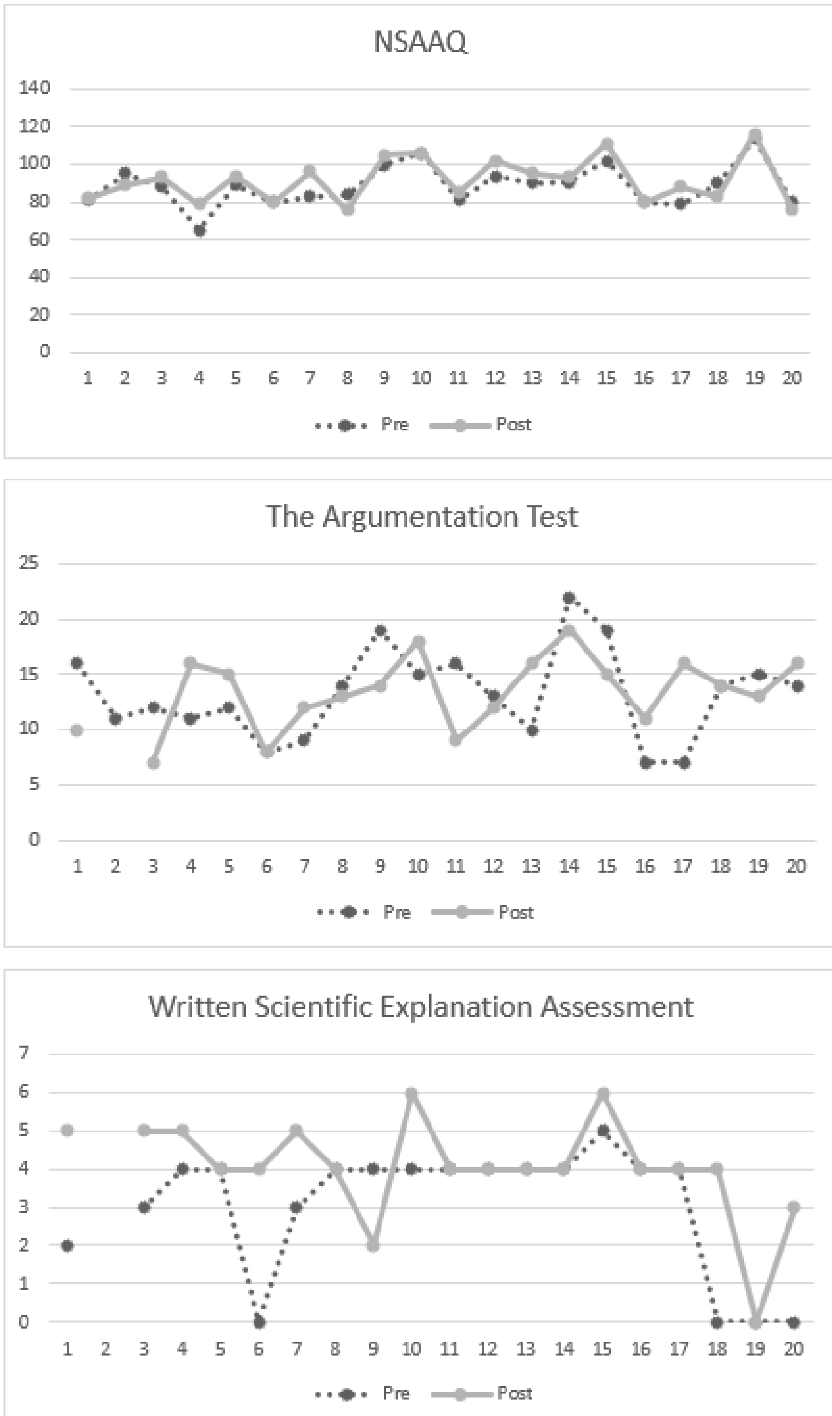


Figure 17. Treatment Condition Pretest and Posttest Scores

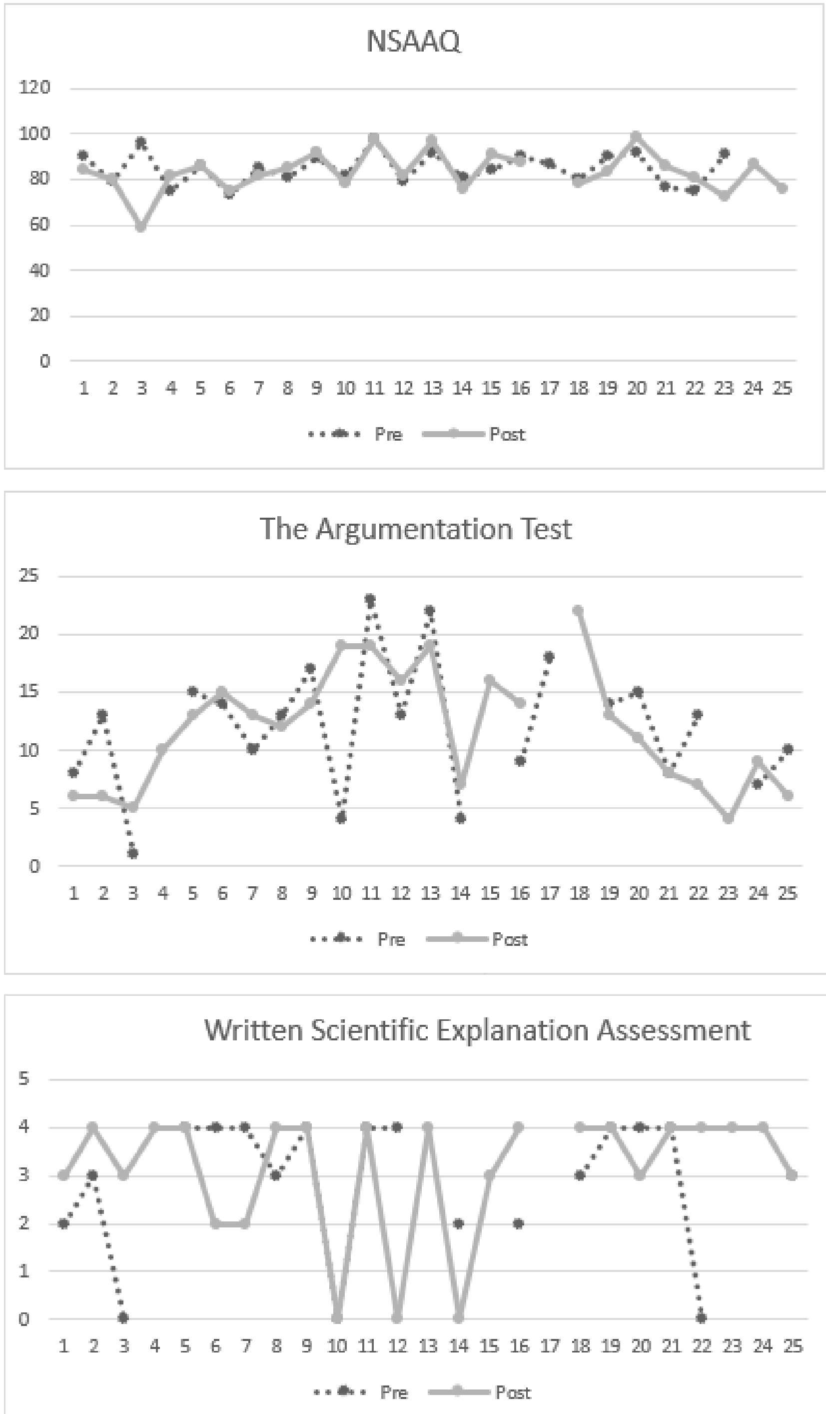


Figure 18. Control Condition Pretest and Posttest Scores

Descriptive Statistics by Condition

Descriptive statistics by condition are displayed in Table 9. The table includes a summary of the number of participants in each condition, participant demographic and background information.

Table 9

Descriptive Statistics by Condition

Descriptors	Treatment Group (N = 20)	Control Group (N=25)
n PSTs	20	25
Gender		
n Male	1	1
n Female	19	24
Ethnicity		
n Caucasian/White	12	13
n Hispanic	2	6
n Black/African American	5	6
n Asian/Pacific-Islander	1	0
Primary Language Spoken		
n English	20	22
n Other	0	3
Class Standing		
Freshman	0	0
Sophomore	0	2
Junior	15	21
Senior	5	2
Pretest *M* (*SD*)	NSAAQ: 88.55 (11.07) ARGTEST: 13.21 (4.06) WSEA: 3.00 (1.70)	NSAAQ: 84.87 (6.96) ARGTEST: 11.95 (5.63) WSEA: 2.84 (1.46)

A between subjects ANOVA revealed that there were no significant differences by condition in the group pretest scores for the NSAAQ [$F(1,41) = 1.751$, $p = .193$], ARGTEST [$F(1,39) = .656$, $p = .423$], or the WSEA [$F(1,36) = .094$, $p = .761$].

Research Questions 1, 2, and 3

Statistical Assumptions

The following statistical assumptions of the RM-MANOVA were examined: (a) independence of observations, (b) linearity between the dependent variables for each group of the independent variable, (c) absence of multicollinearity, (d) normality, (e) absence of univariate and multivariate outliers, (f) equality of covariance matrices, and (g) homogeneity of variances. In this study, there were only two points of measurement (i.e., pretest and posttest) for each dependent variable; thus, the assumption of sphericity did not apply.

Violations of statistical assumptions increase the possibility for a Type I or Type II error (Lomax & Hahs-Vaughn, 2012). A Type I error occurs when the null hypothesis is rejected when it is actually true, and a Type II error occurs when there is a failure to reject the null hypothesis when it is actually false.

The assumption of independence of observations is met when the value of one observation is in no way influenced or related to the value of other observations (Lomax & Hahs-Vaughn, 2012). Independence is achieved when samples are selected randomly from the population. Due to the quasi-experimental design of the study, the independence assumption was violated. Therefore, scatterplots of the residuals were analyzed for evidence of independence. Residuals that fall into some sort of pattern suggest a violation of the assumption, whereas a random distribution of above and below zero suggest evidence of independence of observations. The assumption of independence was tested for each measure (pretest and posttest). Results are reported later in this chapter.

The assumption of linearity assumes that there is a linear relationship between each pair of dependent variables for each group of the independent variable. If the variables are not linearly related, the power of the test to detect differences between groups is reduced (Tabachnick & Fidell, 2014). This assumption was tested by visually inspecting a scatterplot matrix for each dependent measure (pretest and posttest). Results are reported later in this chapter.

Multicollinearity exists when there are very high correlations among the dependent variables. When conducting a RM-MANOVA, the dependent variables should all be moderately correlated with each other, but any correlation over .90 can be problematic (Tabachnick & Fidell, 2014). Absence of multicollinearity was checked using Pearson correlation coefficients between the dependent variables. There was no evidence of multicollinearity, as assessed by Pearson correlation ($|r| < 0.9$).

The assumption of normality is met when sample means are normally distributed. Normality can be examined by using graphs of difference scores, statistical tests, and skewness and kurtosis statistics (Lomax & Hahs-Vaughn, 2012). Graphs that can be used to examine normality include Q-Q plots, box plots, normal probability plots, and histograms. Statistical tests for normality include the Kolmograv-Smirnov Goodness of Fit and Shapiro-Wilk tests. These tests determine the extent to which the sample distribution is statistically different from a normal distribution. A *p*-value greater than alpha suggests that the sample distribution is not significantly different than what would be expected in a normal distribution. When examining skewness and kurtosis statistics, values within a range of +/- 2.0 suggest evidence of normality. In this study, normality was examined for each dependent measure (pretest and posttest) using

the Shapiro-Wilk test, as well as skewness and kurtosis statistics. Results are reported later in this chapter.

A univariate outlier is a data point that lies outside the overall pattern of a distribution. Whereas, multivariate outliers are cases (e.g., participants in the current study) that have an unusual combination of scores on the dependent measures. Both types of outliers have the potential to skew the outcome of statistical analyses (Tabachnick & Fidell, 2014). Univariate outliers were detected by examining boxplots for each dependent measure (pretest and posttest). Results are reported later in this chapter.

Presence of multivariate outliers was examined using Mahalanobis distance. The calculated Mahalanobis distance values were compared against a chi-square ($\chi 2$) distribution with degrees of freedom equal to the number of dependent variables and an alpha level of .001 (Tabachnick & Fidell, 2014). With three dependent variables (each measured at two time points), the Mahalanobis distance values were compared against a critical value of 22.46. There were no multivariate outliers in the data, as assessed by Mahalanobis distance ($p > .001$).

The assumption of homogeneity of variance-covariance matrices assumes that there are similar variances and covariances (Tabachnick & Fidell, 2014). This assumption was tested using Box's *M* test. A statistically significant *p*-value (i.e., $p < .001$) suggests a violation of the assumption of homogeneity of variance-covariance matrices. On the other hand, a non-significant *p*-value (i.e., $p > .001$) indicates that the variance-covariance matrices are equal. Box's *M* ($M = 36.464$) suggested that the assumption of homogeneity of variance-covariance matrices was met, F (21, 4131.664) = 1.401, $p = .105$.

The assumption of homogeneity of variance is met when the population variances are equal for all groups (Lomax & Hahs-Vaughn, 2012). Violations of the assumption of homogeneity of variance results in an increased likelihood of a Type I or Type II error. However, the effect of this violation is minimal as long as group sizes equal (i.e., the ratio of the largest to smallest group is less than 1.5) (Lomax & Hahs-Vaughn, 2012). In this study, homogeneity of variance was determined using Levine's test of equality of error variances. The Levene's test produces an *F*-statistic and a significance value (*p*-value). A *p*-value of less than .05 indicates a violation of the assumption of homogeneity of variance. The assumption of homogeneity was tested for each measure (pretest and posttest). Results are reported later in this chapter.

Research Question 1

A RM-MANOVA was conducted in order to examine whether or not PSTs who received the intervention demonstrated differences in their understanding of the nature of science, as measured by the NSAAQ pre and posttest measures, as compared to PSTs who did not receive the intervention. The within-group factor was time (pretest to posttest) in both conditions. The between-group factor was group (treatment or control). The interaction referred to the interaction between time (pretest and posttest) and group (treatment and control conditions). The test was conducted using an alpha of .05. Partial Eta Squared (η^2) effect sizes were generated via SPSS and were interpreted as follows: small ($\eta^2 = .01$), moderate ($\eta^2 = .09$), and large ($\eta^2 = .25$).

Assumptions Testing Results

The assumption of independence was not met through random assignment to groups. Thus, a scatterplot of residuals was examined for evidence of independence. The analysis of the

simple scatterplot at pretest revealed a random distribution of residuals above and below 0 for both groups (treatment and control). The analysis of the simple scatterplot at posttest also revealed a random distribution of residuals above and below 0 for both groups (treatment and control), thus suggesting evidence of independence of observations.

The assumption of linearity was tested by generating two scatterplot matrices, one for the treatment group and one for the control group. The scatterplot matrices revealed evidence of a linear relationship between NSAAQ pretest and posttest scores in both groups.

The assumption of normality was tested using residuals of the NSAAQ pretest and posttest scores. At pretest, there were nonsignificant results for the Shapiro-Wilk test (SW = .975, df = 43, p = .454), indicating that the residuals were not significantly different from a normal distribution. Additionally, skewness (.266) and kurtosis (.739) statistics were within +/-2, suggesting normality of distribution for the NSAAQ pretest scores. The Q-Q plot revealed evidence of normality with the majority of the points falling on or close to the diagonal line. Examination of the boxplot at pretest revealed one outlier extending above the top whisker. At posttest, there were nonsignificant results for the Shapiro-Wilk test (SW = .987, df = 44, p = .898). Skewness (.208) and kurtosis (.048) statistics were within +/-2, thus suggesting normality of distribution for the NSAAQ posttest scores. The Q-Q plot also suggested normality, with the majority of the points falling close to the diagonal line. Examination of the boxplot at posttest revealed one outlier extending beyond the top whisker.

The Grubbs' Test for Outliers (1969) was applied to the one pretest outlier and one posttest outlier from the box plot visual analysis. The formula for the Grubbs' Test is:

$$\mathrm{G}_{\max} = M_{\max} - M / SD \tag{1}$$

where M_{max} is the extreme value, M is the mean, and SD is the standard deviation. The extreme value at pretest was 113; *M* = 86.58, and *SD* = 9.18. The Grubb's critical value for an alpha of .05 and a sample size of 43 is 2.9. For the extreme value of 113, $G_{2.88} < 2.9$, indicating that the observed value was not different from the pretest mean. Thus, the participant's pretest NSAAQ score was not omitted from the analysis. The extreme value at posttest was 116; *M* = 86.95, and *SD* = 11.00. The Grubb's critical value for an alpha of .05 and a sample size of 44 was 2.91. For the extreme value of 116, $G_{2.64} < 2.91$ indicated that the observed value was not different from the pretest mean. Therefore, the participant's score was not omitted from the analysis.

Levene's Test of Equality of Error Variances was not significant at pretest with $F(1,41) = 2.48$, and $p = .123$ and posttest with $F(1,42) = 2.90$, and $p = .096$; therefore, the assumption of homogeneity of variances was met.

Repeated Measures MANOVA Results

Estimated marginal means for the NSAAQ measure and results from the RM-MANOVA and follow-up univariate tests are presented in Tables 10 and 11.

Table 10

NSAAQ Estimated Marginal Means (N=36)

Group	*M*	*SE*	95% Confidence Interval	
			Lower	Upper
Treatment (n = 19)				
NSAAQ Pretest	88.211	2.203	83.734	92.687
NSAAQ Posttest	91.579	2.483	86.533	96.625
Control (n = 17)				
NSAAQ Pretest	84.882	2.329	80.149	89.615
NSAAQ Posttest	83.176	2.625	77.842	88.511

Table 11

NSAAQ Results from Univariate Tests

Source	*df*	MS	*F*	*p*-value	η^2	Observed Power
Between Subjects						
Group	1	617.325	3.516	.069	.094	.445
Error	34	175.560				
Within Subjects						
Time	1	12.400	.367	.549	.011	.091
Time*Group	1	115.511	3.418	.073	.091	.435
Error	34	33.793				

Results from the RM-MANOVA showed that there was a statistically significant interaction effect between group and time on the combined dependent variables, $F(3, 32)$ = 2.894, p = .050, Wilks' Λ = .787 (η^2 = .213, POWER = .635). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered large.

Follow up univariate ANOVAs were conducted. These tests showed that there was not a statistically significant interaction between group and time on the NSAAQ measure with $F(1,34) = 3.42$ and $p = .073$ ($\eta^2 = .091$, POWER = .435) (See Table 10).

However, given the large effect size for the interaction between group and time on the NSAAQ measure, tests of simple main effects were conducted. Simple main effects for group were tested by conducting two separate one-way ANOVAs to explore differences in NSAAQ scores between groups at both pretest and posttest. There was not a statistically significant difference in NSAAQ scores between the treatment group ($M = 88.55$, $SE = 2.03$) and control group ($M = 84.87$, $SE = 1.90$) at pretest, $F(1,41) = 1.751$, $p = .193$ ($\eta^2 = .041$, POWER = .253). However, there was a statistically significant difference in NSAAQ scores between groups at posttest, $F(1,42) = 6.977$, $p = .012$ ($\eta^2 = .142$, POWER = .733). Mean NSAAQ scores were significantly greater at posttest in the treatment group ($M = 91.45$, $SE = 2.30$) compared to the control group ($M = 83.21$, $SE = 2.10$). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered moderate.

Simple main effects for time were tested by conducting two separate repeated measures ANOVAs to explore differences in NSAAQ scores between time points for both the treatment and control groups. These tests showed that there was a statistically significant effect of time on NSAAQ scores for the treatment group, $F(1, 19) = 4.452$, $p = .048$ ($\eta^2 = .190$, POWER = .517). For the treatment group, the NSAAQ posttest mean ($M = 91.45$, $SE = 2.64$) was significantly greater than the NSAAQ pretest mean (M = 88.55, SE = 2.48). The size of the effect was considered moderate. On the other hand, there was not a statistically significant effect of time on NSAAQ scores for the control group, $F(1, 21) = .425$, $p = .521$ (η^2 =. 020, POWER = .095). For

the control group, there was no difference between the NSAAQ pretest mean (*M* = 84.77, *SE* = 1.52) and the NSAAQ posttest mean (*M* = 83.36, *SE* = 1.94).

In summary, the treatment group made significant gains on the NSAAQ measure from pretest to posttest, whereas there was no change between pretest and posttest scores in the control group. Although there was no statistically significant difference in scores between the two groups at pretest, the treatment group's posttest mean was significantly higher than the control group's posttest mean. The differences based on time and group are represented in the profile plot shown in Figure 19. These results suggest that PSTs who received the intervention demonstrated a significant increase in their understanding of the nature of science, as measured by the NSAAQ pre and posttest measures, as compared to PSTs who did not receive the intervention.

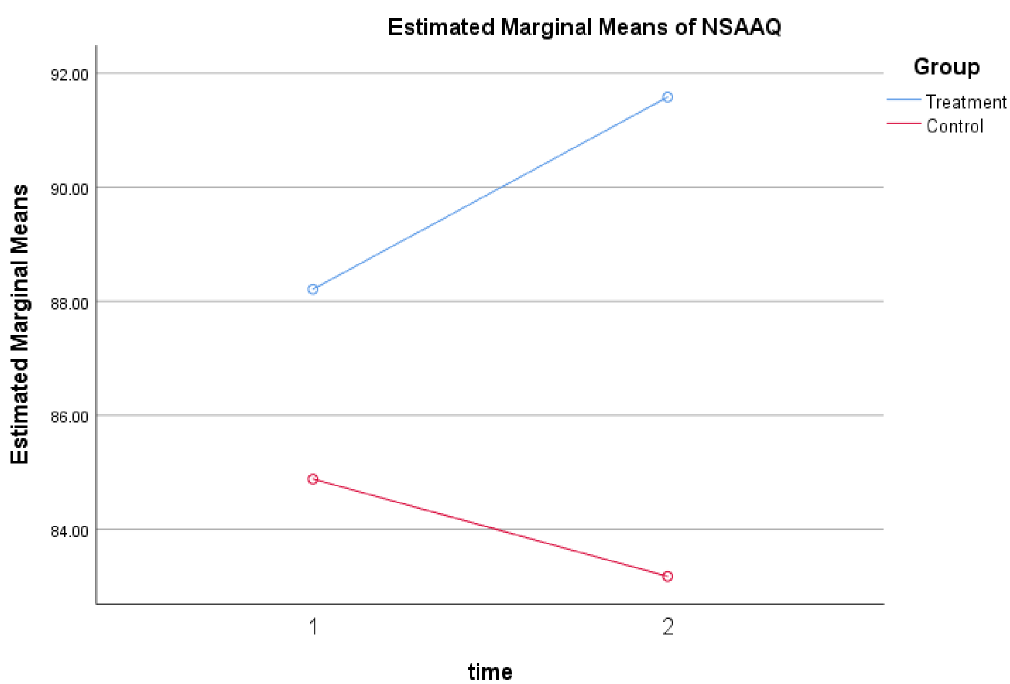


Figure 19. Profile Plot of Interaction between Group and Time on NSAAQ

Research Question 2

A RM-MANOVA was conducted in order to examine whether or not PSTs who received the intervention demonstrated differences in their knowledge of argumentation as measured by the ARGTEST pre and posttest measures, as compared to PSTs who did not receive the intervention. The within-group factor was time (pretest to posttest) in both conditions. The between-group factor was group (treatment or control). The interaction referred to the interaction between time (pretest and posttest) and group (treatment and control conditions). The test was conducted using an alpha of .05. Partial Eta Squared (η^2) effect sizes were generated via SPSS and were interpreted as follows: small (η^2 = .01), moderate (η^2 = .09), and large (η^2 = .25).

<u>Assumptions Testing Results</u>

The assumption of independence was not met through random assignment to groups. Thus, a scatterplot of residuals was examined for evidence of independence. The analysis of the simple scatterplot at pretest revealed a random distribution of residuals above and below 0 for both groups (treatment and control). The analysis of the simple scatterplot at posttest also revealed a random distribution of residuals above and below 0 for both groups (treatment and control), thus suggesting evidence of independence of observations.

The assumption of linearity was tested by generating two scatterplot matrices, one for the treatment group and one for the control group. The scatterplot matrices revealed evidence of a linear relationship between ARGTEST pretest and posttest scores in both groups.

The assumption of normality was tested using residuals of the ARGTEST pretest and posttest scores. At pretest, there were nonsignificant results for the Shapiro-Wilk test (SW = .986, df = 41, p = .880), indicating that the residuals were not significantly different from a

normal distribution. Additionally, skewness (.129) and kurtosis (.040) statistics were within +/-2, suggesting normality of distribution for the ARGTEST pretest scores. The Q-Q plot revealed that majority of the points fell on or close to the diagonal line. Examination of the boxplot at pretest also suggested normality, with no outliers. At posttest, there were nonsignificant results for the Shapiro-Wilk test ($SW = .976$, $df = 43$, $p = .482$). Skewness (.138) and kurtosis (-.561) statistics were within +/-2, thus suggesting normality of distribution for the ARGTEST posttest scores. The Q-Q plot also suggested normality, with the majority of the points falling close to the diagonal line. Examination of the boxplot showed no outliers at posttest.

According to Levene's Test of Equality of Error Variances, the assumption of homogeneity was met at pretest with $F(1,39) = 1.85$, and $p = .182$, but not at posttest with $F(1,41) = 4.95$, and $p = .032$. The effect of this violation is minimal with roughly equal group sizes (i.e., the ratio of the largest to smallest group is less than 1.5). Overall, the violations to the assumptions were not severe, and the researcher decided to proceed with the test. Violations of assumptions, do, however, increase the possibility for a Type I or Type II error; thus, results should be interpreted with caution.

Repeated Measures MANOVA Results

Estimated marginal means for the ARGTEST measure and results from the RM-MANOVA and follow-up univariate tests are presented in Tables 12 and 13.

Table 12

ARGTEST Estimated Marginal Means (N = 36)

Group	*M*	*SE*	95% Confidence Interval Lower	Upper
Treatment (*n* = 19)				
ARGTEST Pretest	13.316	1.093	11.094	15.538
ARGTEST Posttest	13.368	.894	11.552	15.185
Control (*n* = 17)				
ARGTEST Pretest	11.412	1.156	9.063	13.761
ARGTEST Posttest	11.647	.945	9.726	13.568

Table 13

ARGTEST Results from Univariate Tests

Source	*df*	MS	*F*	*p*-value	η^2	Observed Power
Between Subjects						
Group	1	58.963	2.236	.144	.062	.306
Error	34	26.368				
Within Subjects						
Time	1	.372	.032	.859	.001	.053
Time*Group	1	.150	.013	.910	<.001	.051
Error	34	11.530				

Results from the RM-MANOVA showed that there was a statistically significant interaction effect between group and time on the combined dependent variables, $F(3, 32)$ =

2.894, p = .050, Wilks' Λ = .787 (η^2 = .213, POWER = .635). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered large.

Follow up univariate ANOVAs were conducted. As shown in Table 12, there was not a statistically significant interaction between group and time on the ARGTEST measure with F(1,34) = .013 and p = .910 (η^2 = <.001, POWER = .051).

Given the non-significant interaction effect between group and time on the ARGTEST, main effects for the between- and within-subjects factors were examined. Regarding the between-group factor, there was not a statistically significant difference in ARGTEST scores between the treatment and control groups, F(1,34) = 2.236, p = .144 (η^2 = .062, POWER = .306). Estimated marginal means of the treatment group (M = 13.34, SE = .83) did not differ from the control group (M = 11.53, SE = .88). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered small.

Regarding the within-group factor, there was not a statistically significant difference in ARGTEST scores based on time (pretest to posttest), F(1,34) = 0.32, p = .859 (η^2 = .001, POWER = .053). The ARGTEST posttest estimated marginal mean (M = 12.51, SE = .65) did not have statistically significant differences with the pretest estimated marginal mean (M = 12.36, SE = .80). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered very small.

In summary, there was no difference in ARGTEST scores based on group or time (See Figure 20). These results suggest that PSTs who received the intervention did not demonstrate a difference in their knowledge of argumentation, as measured by the ARGTEST pre and posttest measures, when compared to those of PSTs who did not receive the intervention.

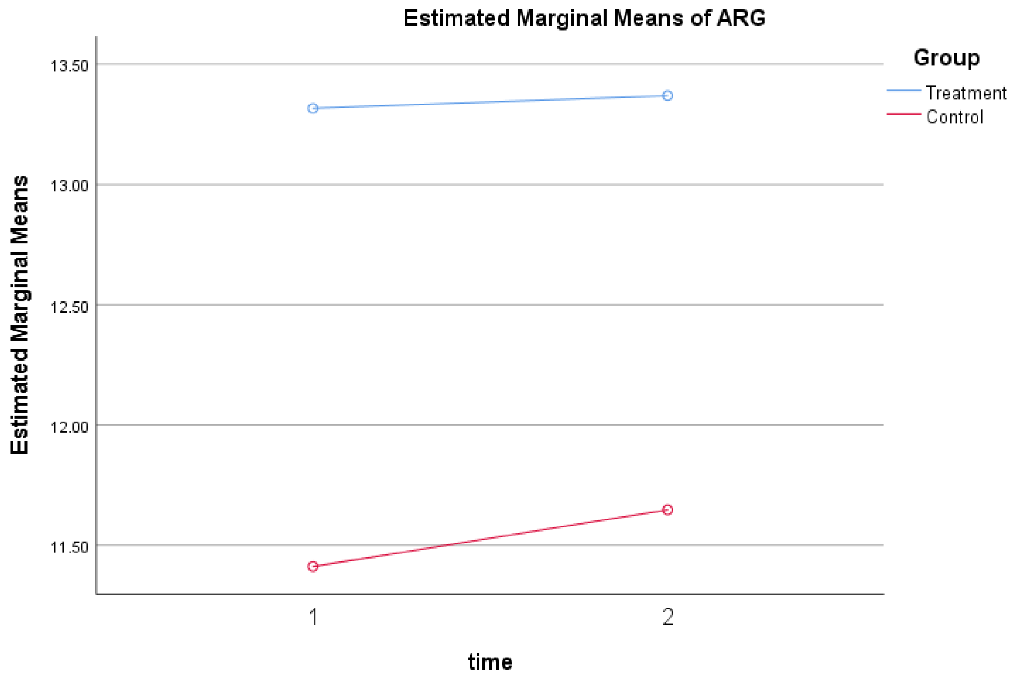


Figure 20. Profile Plot of Interaction between Group and Time on ARGTEST

Research Question 3

A RM-MANOVA was conducted in order to examine whether or not PSTs who received the intervention demonstrated differences in the complexity of their written explanations as measured by the WSEA pre and posttest measures, when compared to PSTs who did not receive the intervention. The within-group factor was time (pretest to posttest) in both conditions. The between-group factor was group (treatment or control). The interaction referred to the interaction between time (pretest and posttest) and group (treatment and control conditions). The test was conducted using an alpha of .05. Partial Eta Squared (η^2) effect sizes were generated via SPSS and were interpreted as follows: small (η^2 = .01), moderate (η^2 = .09), and large (η^2 = .25).

Assumptions Testing Results

The assumption of independence was not met through random assignment to groups. Thus, a scatterplot of residuals was examined for evidence of independence. The analysis of the simple scatterplot at pretest revealed a random distribution of residuals above and below 0 for both groups (treatment and control). The analysis of the simple scatterplot at posttest also revealed a random distribution of residuals above and below 0 for both groups (treatment and control), thus suggesting evidence of independence of observations.

The assumption of linearity was tested by generating two scatterplot matrices, one for the treatment group and one for the control group. The scatterplot matrices revealed some evidence of a linear relationship between WSEA pretest and posttest scores in both groups.

The assumption of normality was tested using residuals of the WSEA pretest and posttest scores. At pretest, there were significant results for the Shapiro-Wilk test (SW = .764, df = 38, p = <.001), indicating that the residuals were significantly different from a normal distribution. However, skewness (-1.093) and kurtosis (.257) statistics were within +/-2, suggesting evidence of normality. Additionally, the Q-Q plot revealed evidence of normality with the majority of the points falling on or near the diagonal line. Examination of the boxplot showed no outliers at pretest. At posttest, there were also significant results for the Shapiro-Wilk test (SW = .761, df = 43, p <.001). Although the skewness statistic (.208) was within +/-2, the kurtosis statistic was not (2.481). The high kurtosis statistic indicated the presence of outliers. Examination of the boxplot confirmed the presence of two outliers extending below the bottom whisker.

The Grubbs' Test for Outliers and critical values of Grubbs' Outlier (G) Test (1969) were applied to the two posttest outliers from the box plot visual analysis. The formula for the Grubbs' Test is:

$$G_{max} = M_{max} – M / SD$$

where M_{max} is the extreme value, M is the mean, and SD is the standard deviation. The extreme values were 2 and 0; $M = 3.53$, and $SD = 1.39$. The Grubb's critical value for an alpha of .05 and a sample size of 43 is 2.9. For the extreme value of 2, $G_{-1.10.} < 2.9$ indicating that the observed value was not different from the postest mean. Thus, the participant's posttest WSEA score was not omitted from the analysis. For the extreme value of 0, $G_{-2.54} < 2.91$ indicated that the observed value was not different from the posttest mean. Therefore, the participant's WSEA posttest score was not omitted from the analysis. Levene's Test of Equality of Error Variances was not significant at pretest with $F(1,36) = .429$, and $p = .488$ and posttest with $F(1,41) = 1.178$, and $p = .284$; therefore, the assumption of homogeneity of variances was met.

Repeated Measures MANOVA Results

Estimated marginal means for the WSEA measure and results from the RM-MANOVA and follow-up univariate tests are presented in Tables 14 and 15.

Table 14

WSEA Estimated Marginal Means (N = 36)

Group	*M*	*SE*	95% Confidence Interval	
			Lower	Upper
Treatment (*n* = 19)				
WSEA Pretest	3.000	.374	2.239	3.761
WSEA Posttest	4.053	.321	3.400	4.706
Control (*n* = 17)				
WSEA Pretest	2.824	.396	2.020	3.628
WSEA Posttest	2.882	.340	2.192	3.573

Table 15

WSEA Results from Univariate Tests

Source	*df*	MS	*F*	*p*-value	η^2	Observed Power
Between Subjects						
Group	1	8.137	2.760	.106	.075	.365
Error	34	2.948				
Within Subjects						
Time	1	5.542	3.309	.078	.089	.424
Time*Group	1	4.431	2.645	.113	.072	.352
Error	34	1.675				

Results from the RM-MANOVA showed that there was a statistically significant interaction effect between group and time on the combined dependent variables, $F(3, 32)$ =

2.894, p = .050, Wilks' Λ = .787 (η^2 = .213, POWER = .635). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered large.

Follow up univariate ANOVAs were conducted. As shown in Table 14, there was not a statistically significant interaction between group and time on the WSEA measure with $F(1,34)$ = 2.65 and p = .113 (η^2 = .072, POWER = .352).

However, given the moderate effect size for the interaction between group and time on the WSEA measure, tests of simple main effects were conducted. Simple main effects for group were tested by conducting two separate one-way ANOVAs to explore differences in WSEA scores between groups at both pretest and posttest. There was not a statistically significant difference in WSEA scores between the treatment group (M = 3.00, SE = .36) and control group (M = 2.84, SE = .36) at pretest, $F(1,36)$ = .094, p = .761 (η^2 = .003, POWER = .060). However, there was a statistically significant difference in WSEA scores between groups at posttest, $F(1,41)$ = 5.227, p = .027 (η^2 = .113, POWER = .607). Mean WSEA scores were significantly greater at posttest in the treatment group (M = 4.05, SE = .30) compared to the control group (M = 3.13, SE = .27). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered moderate.

Sample main effects for time were tested by conducting two separate repeated measures ANOVAs to explore differences in WSEA scores between time points for both the treatment and control group. These tests showed that there was a statistically significant effect of time on WSEA scores for the treatment group, $F(1, 18)$ = 7.157, p = .015 (η^2 = .284, POWER = .716). For the treatment group, the WSEA posttest mean (M = 4.05, SE = .29) was significantly greater than the WSEA pretest mean (M = 3.00, SE = .39). The size of the effect was considered large.

On the other hand, there was not a statistically significant effect of time on WSEA scores for the control group, $F(1,18) = .061$, $p = .807$ (η^2 =. 003, POWER = .056). For the control group, there was no difference between the WSEA pretest mean (M = 2.84, SE = .34) and the WSEA posttest mean (M = 2.95, SE =.34).

In summary, the treatment group made significant gains on the WSEA measure from pretest to posttest, whereas there was no change between pretest and posttest scores in the control group. Although there was no difference in scores between the two groups at pretest, the treatment group's posttest mean was significantly higher than the control group's posttest mean. The differences based on time and group are represented in the profile plot shown in Figure 21. These results suggest that PSTs who received the intervention demonstrated a significant increase in the complexity of their written explanations, as measured by the WSEA pre and posttest measures, when compared to those of PSTs who did not receive the intervention.

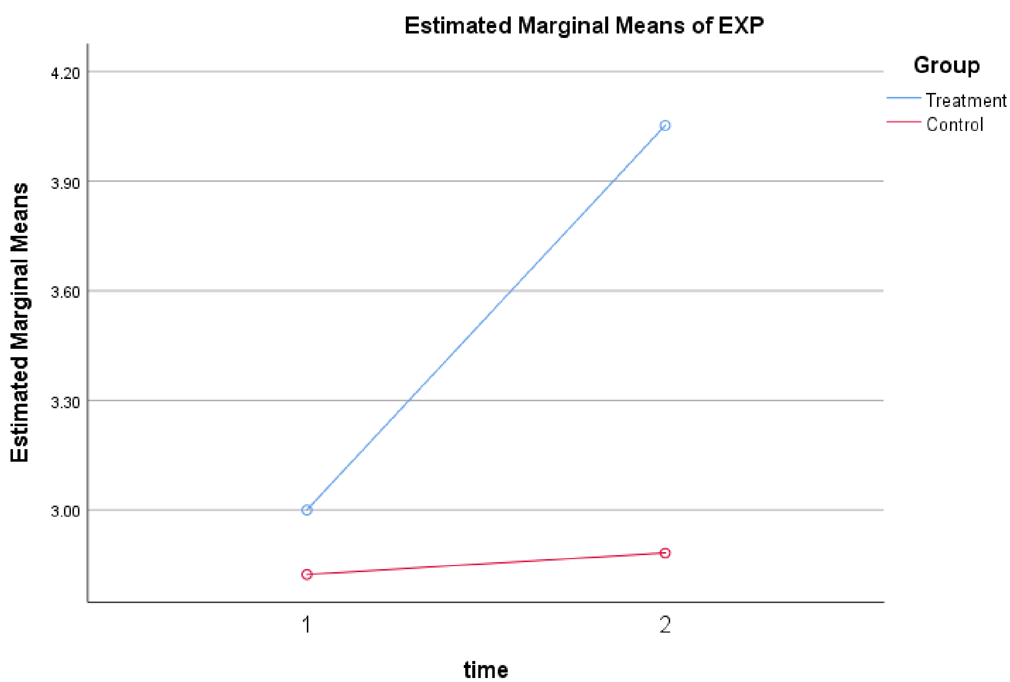


Figure 21. Profile Plot of Interaction between Group and Time on WSEA

The majority of treatment group participants (11) demonstrated noticeable improvement in the complexity of their written explanations, in terms of structure, from pretest to posttest. Table 16 illustrates changes in three PSTs' written explanations before and after receiving the intervention. For example, prior to the intervention, P1 made an accurate claim, but lacked evidence and reasoning. After receiving the intervention, P1 added an element of complexity by effectively using evidence to support the scientific claim. While P10 made appropriate use of evidence prior to the intervention, improvement was made post-intervention with the addition of accurate and complete reasoning. Prior to the intervention, P20 made an inaccurate claim, possibly due to a lack of content knowledge surrounding the topic of erosion. After receiving the intervention, P20 demonstrated noticeable improvement, with the inclusion of an accurate claim and appropriate evidence.

Table 16

Changes in Treatment Group Participants' Written Explanations

Preintervention	Postintervention
Judging by the graph, sweet potato is the most resisitant to the effects of erosion. (P1) Rubric Score: Claim – 2/2 Evidence – 0/2 Reasoning – 0/2	Sweet potatoes are the most resistant to the effects of erosion because based on the chart, it shows crops that have less soil and sweet potatoes have the least amount of soil lost. Therefore, sweet potatoes are the most resistant because they haven’t lost that much soil. (P1) Rubric Score: Claim – 2/2 Evidence – 2/2 Reasoning – 1/2
Sweet potato is the most resistant to the effects of erosion because it has the least amount of soil loss out of all the crops (P10) Rubric Score: Claim – 2/2 Evidence – 2/2 Reasoning – 0/2	The sweet potato is the most resistant to the effects of erosion. The chart shows that sweet potatoes have the less amount of soil loss. Therefore, sweet potato is the crop most resistant because erosion is defined as soil loss and the sweet potato has the less amount of soil loss compared to the others. (P10) Rubric Score: Claim – 2/2 Evidence – 2/2 Reasoning – 2/2
Castor beans are the most resistant to the effects of erosion, due to the highest soil loss of 4 t/ha. (P20) Rubric Score: Claim – 0/2 Evidence – 0/2 Reasoning – 0/2	Sweet potatoes are the most resistant to the effect of erosion, and I know this because there was the least amount of soil loss. (P20) Rubric Score: Claim – 2/2 Evidence – 2/2 Reasoning – 0/2

Research Question 4

Participants’ lesson plans, written in groups of three to five, were collected and analyzed as an additional layer of data to explore how elementary PSTs who participated in the

intervention incorporated components of the TSAF (i.e., argument structure, public reasoning, and the language of science) when planning for inquiry-based science instruction. An overview of each groups' lesson plan, including intended grade level, branch of science, and targeted science concept(s), is provided in Table 17.

Table 17

Overview and Foci of PSTs' Lesson Plans

Participant Group	Grade Level	Branch of Science	Key Concept(s)
Group 1	2nd	Physical Science	1. All objects and substances are made of matter. 2. 2. Objects and substances can be classified by their physical and chemical properties.
Group 2	3rd	Life Science	3. 1. Animals can be classified into major groups (mammals, birds, reptiles, amphibians, fish, arthropods, vertebrates, and invertebrates, those having live births and those which lay eggs) according to their physical characteristics and behaviors.
Group 3	5th	Life Science	4. 1. Plants and animals, including humans, interact with and depend upon each other and their environment to satisfy their basic needs.
Group 4	5th	Earth and Space Science	5. 1. The ocean is an integral part of the water cycle and is connected to all of Earth's water reservoirs via evaporation and precipitation processes.
Group 5	5th	Earth and Space Science	6. A galaxy consists of gas, dust, and many stars, including any objects orbiting the stars. 7. 2. The Solar System includes the Sun, Earth, Moon, and other planets and their moons.

All five lesson plans were analyzed using a constant comparative approach (Glaser & Strauss, 1967). Initial coding involved coding each incident in the data using a priori codes based on the three features of the TSAF (Zembal-Saul, 2009). The initial coding phase was

preceded by two additional rounds, resulting in the addition of six new codes that emerged during analysis. The final codebook consisted of three categories (argument structure, public reasoning, and language of science) to align with the three main features of the TSAF, as well as a fourth category focused on negative instances. The codes within the first three categories encompass different aspects of the three main features of the TSAF and assist to define how those features were incorporated by the participants when planning for science instruction. In an attempt to minimize the effects of researcher bias, negative instances were also examined rather than merely searching for confirmatory data (Kolb, 2012). The codes within this final category identified instances within PSTs' lesson plans that did not align with the TSAF. Table 18 displays the number of instances found in each coding category per participant group.

Table 18

Number of Instances Found in Each Coding Category

Group	Argument Structure	Public Reasoning	Language of Science	Negative Instances
Group 1	4	4	5	0
Group 2	2	1	3	0
Group 3	14	9	5	0
Group 4	2	2	1	2
Group 5	6	1	3	0

The close analysis of participants' written lesson plans led to four emergent themes regarding PSTs' enactment of the TSAF components (i.e., argument structure, public reasoning, and the language of science) when planning for inquiry-based science instruction. These themes

are described in the following section and are supported with examples from participants' lesson plans.

Theme One:
Opportunities for Students to Collect and Analyze Data Associated with a Driving Question

Central to all five participant groups' lesson plans were one or more opportunities for students to collect, record, and interpret data. This critical aspect of scientific inquiry builds the foundation for effective explanation construction. Groups planned meaningful hands-on investigations for students to make observations and collect data and planned opportunities for students to read about the phenomena under study from secondary sources such as science trade books and websites. For example, Group 3 planned three different stations to help students explore different representations of how physical adaptations help animals survive in their habitat. The first station was designed to help students investigate how blubber protects animals from weather; the second station was aimed at helping students explore how camouflage helps keep animals safe; and the third station focused on exploring how webbed feet contribute to birds' survival in their habitat. A fourth station was focused on providing students the opportunity to read about animal adaptations from a wide variety of science texts on the topic. Additionally, computers were made available and a list of relevant websites (e.g., https://www.nationalgeographic.org/encyclopedia/adaptation/; http://kids.nceas.ucsb.edu/biomes/temperateforest.html) was provided for students to explore. Figure 22 shows an image of this station, taken during Group 3's microteaching session. At each of the four stations, students were expected to observe, record data, and collect evidence to support their claims about animal adaptations.

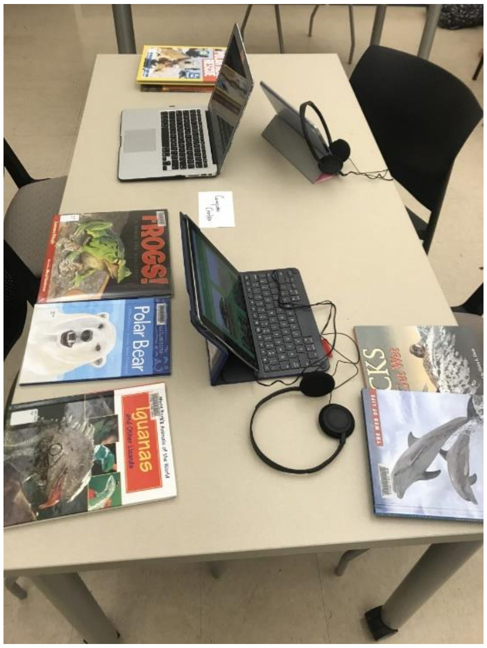
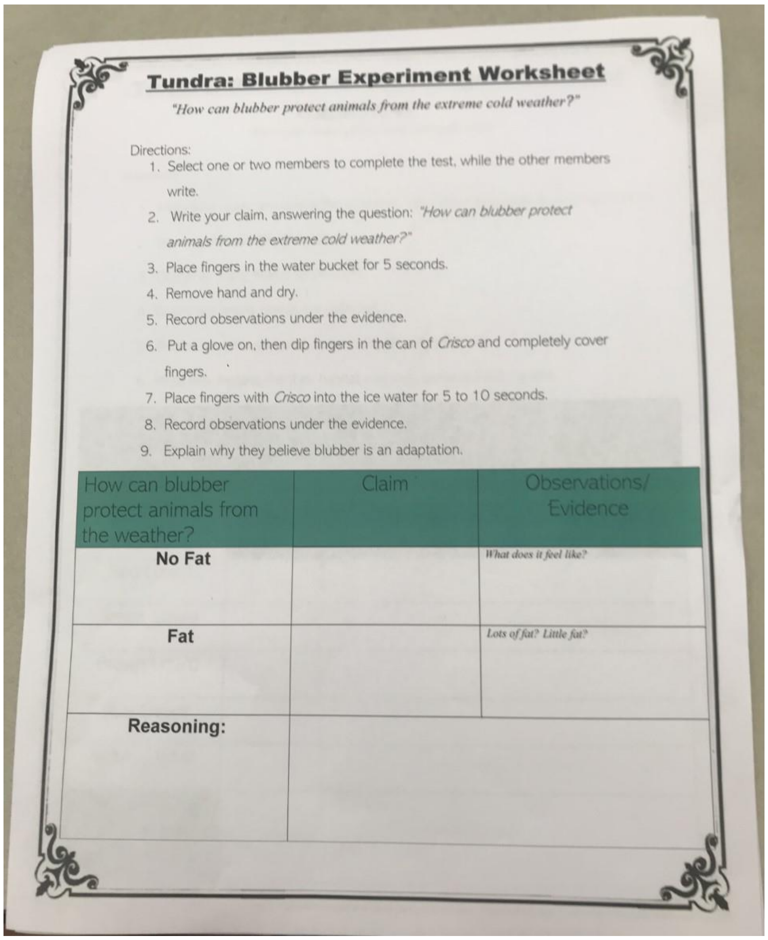


Figure 22. Book/Computer Station

Group 1 also planned stations to help students explore the physical properties of solids and liquids. Each station was intended to provide students with opportunities to interact with and make observations of solids and liquids under various conditions. At one station, students were to observe as honey was poured from one container to another. At a different station, students were asked to observe as a piece of paper was shredded into smaller pieces. Throughout the lesson, students were provided with the opportunity to share and discuss their observations with their peers. Finally, students were to use their observations as evidence to support a claim about whether sand is a solid or a liquid.

All five participant groups also included in their lesson plans a chart or table to help students organize and represent their observations/data. For example, Group 3 provided a separate experiment worksheet for each of the four stations the group had designed. Each

experiment worksheet listed a guiding question, directions for carrying out the investigation or experiment, as well as a table for organizing and representing students' observations. Figure 23 provides an example of an investigation sheet.



Tundra: Blubber Experiment Worksheet

"How can blubber protect animals from the extreme cold weather?"

Directions:
1. Select one or two members to complete the test, while the other members write.
2. Write your claim, answering the question: *"How can blubber protect animals from the extreme cold weather?"*
3. Place fingers in the water bucket for 5 seconds.
4. Remove hand and dry.
5. Record observations under the evidence.
6. Put a glove on, then dip fingers in the can of *Crisco* and completely cover fingers.
7. Place fingers with *Crisco* into the ice water for 5 to 10 seconds.
8. Record observations under the evidence.
9. Explain why they believe blubber is an adaptation.

How can blubber protect animals from the weather?	Claim	Observations/ Evidence
No Fat		*What does it feel like?*
Fat		*Lots of fat? Little fat?*
Reasoning:		

Figure 23. Example of Investigation Sheet

Theme Two: Emphasis on the Use of Text to Support Scientific Inquiry

All five participant groups incorporated the use of text within their science lesson plans. However, the way in which text was utilized varied across groups. Some groups planned to use scientific texts to build students' background knowledge and stimulate interest about a topic. For example, Group 1, whose lesson plan focused on properties of matter, specified that it planned to read-aloud *All About Matter* by Mari Schuh toward the start of the lesson, prior to having students engage in firsthand exploration. Groups 4 and 5 also planned to incorporate a teacher read-aloud at the start of the lesson. However, unlike Group 1 who selected a text with expository structures using the language of science, Groups 4 and 5 chose to read-aloud an informational storybook. This type of text presents science topics using the traditional elements of story structure (i.e., characters, setting, conflict, solution).

Other participant groups positioned text not only as a tool for building students' background knowledge and increasing interest, but also as a source of evidence to support scientific claims. For example, Group 5 incorporated the use articles from a Newsela text set (see https://newsela.com/text-sets/428954) to build students' background knowledge about the planets and other objects in the solar system. Later in the lesson, this group of PSTs planned to encourage students to use evidence from the Newsela articles to make a claim about whether or not Pluto should be considered a planet. This group provided an example of how texts can be used to present information (such as exploration of the solar system) that cannot be obtained through firsthand investigation. Other groups, such as Group 3, incorporated opportunities within their lesson plans for students to read and discuss related science texts in addition to conducting firsthand investigations.

Lastly, some participant groups used scientific texts as a way to extend their lessons and help students acquire additional information about the topics. For example, Group 2 included an extension activity within its lesson plan that involved students in researching an animal and its habitat (using books and websites) and presenting the group's findings to the class.

Only two of the five participant groups made attempts to accommodate students' varying reading abilities. Group 3 noted that it would provide a range of books at different reading levels and in multiple languages for students to use at the book/computer station. Group 5 also noted in its lesson plan the use of Newsela to provide students with texts on the same topic written at different reading levels.

Theme Three: Use of Scaffolds for Helping Students Construct Scientific Explanations

All five participant groups' lesson plans demonstrated PSTs' attempts to engage students in scientific explanation. Although there was much variation in the quality of these attempts, strategies utilized for supporting students' construction of evidence-based explanations were clearly informed by approaches that were modeled in class throughout the semester. A common strategy included using the claim, evidence, and reasoning (CER) framework. For example, all five participant groups included writing scaffolds based on the CER framework to help students appropriately justify their claims in writing. Scaffolds designed by PSTs varied in detail, length, and structure. Although some groups only provided very general sentence starters, other groups provided more detailed and content specific support. Group 5, for example, designed a handout (see Figure 24) including a description and a content specific sentence starter for each component of the CER framework to support students in constructing an evidence-based claim about the classification of Pluto as a planet.

Claim + Evidence = Explanation
+ Reasoning

Directions: Write an explanation on whether or not Pluto should be considered a planet using the CER Framework.

CLAIM: Write a sentence that states if Pluto is or is not a planet.
Pluto ______________.

EVIDENCE: Provide scientific data that is appropriate and sufficient to support the claim. Describe the evidence you collected through the data.

Evidence 1: ____
____

Evidence 2: ____
____

REASONING: Write a statement that shows why the data counts as evidence to support the claim.

Reasoning: For an object to be considered as a plant it has to….
____
____
____
____
____
____.

Figure 24. Writing Scaffolds Developed by PSTs

The majority of participant groups also demonstrated a use of talk moves and teacher questioning techniques focused on evidence and explanation. It was evident that PSTs were using the CER framework to inform the types of questions they planned to pose to students. Teacher questions mainly focused on refocusing students' attention on the guiding question, prompting students to explicate their reasoning (e.g., How do you know? Why?), and encouraging students to consider how a claim aligns with the available evidence (e.g., What evidence do you have to support your claim?). Of the five participant groups, only one group

provided an opportunity within its lesson plan for students to consider alternative claims and opposing viewpoints.

Theme Four: Attention to Developing Students' Vocabulary Knowledge in Science

An emphasis on developing students' vocabulary knowledge in science was evident in participant groups' lesson plans. Most groups included an explicit language-based task or instruction at the start of the 5E lesson sequence, prior to engaging students in an investigation. These instructional tasks/strategies were clearly informed by strategies that were modeled in class throughout the semester. For example, Group 1 included the use of a Frayer "4-square" model to encourage students to think more deeply about the differences between solids and liquids. Group 3 included a word sort activity (See Figure 25) to develop students' understanding of how different types of adaptations help animals survive in their environments. Group 4 included a vocabulary handout (See Figure 26) to be completed by students after discussing a model of the water cycle as a whole-group. The handout consists of four target words (water vapor, evaporation, condensation, precipitation) and their definition, as well as a space for students to draw an illustration and write a sentence. Both Groups 3 and 5 mentioned within their lesson plans the availability of a domain-specific word wall to provide reference support for students during scientific writing activities. Group 2 included a vocabulary matching activity (See Figure 27), but did not make an effort to develop students' understanding of the words beyond the definitional level.

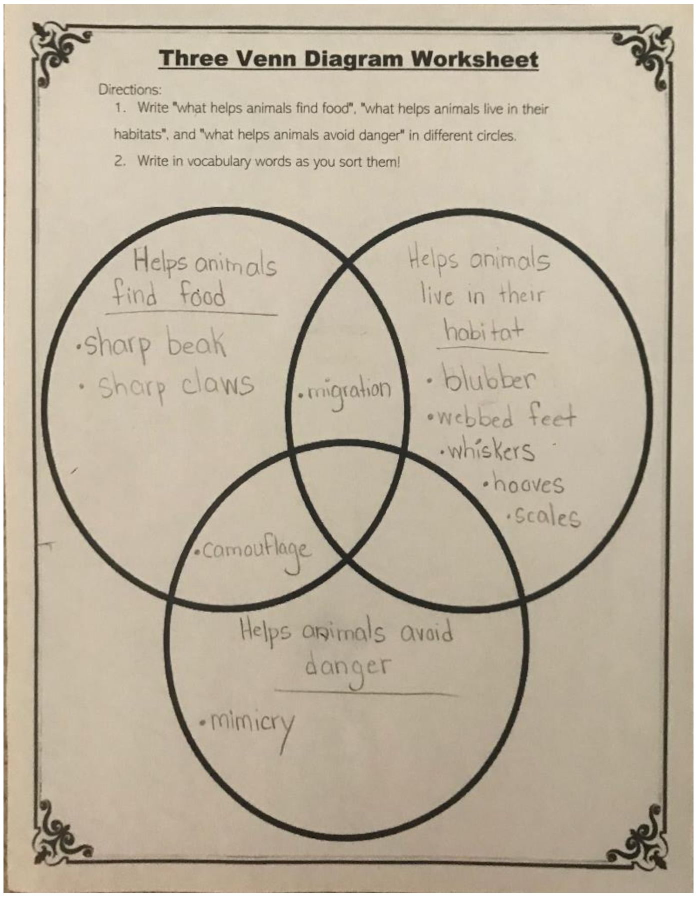


Figure 25. Word Sort Activity

Water Cycle

Vocabulary Word	Illustration	Definition	Sentence (In Context)
Water Vapor		Water in the form of a gas	
Evaporation		The slow changing of a liquid into a gas	
Condensation		The changing of a gas into a liquid	
Precipitation		Any form of water particles that falls from the atmosphere and reaches the ground	

Figure 26. Vocabulary Handout

Mammal	**Bird**	**Amphibian**	**Reptile**	**Fish**

Name that Animal

Directions: Read the following *physical characteristics*. Then using the word bank, write the name of the animal that best corresponds with the description.

1. ________________________________ Aquatic animal that has gills, fins, and scales.

2. ________________________________ Either an aquatic or land animal that has hair or fur, lungs, and produce milk.

3. ________________________________ An animal that has dry skin, scales, and lays eggs.

4. ________________________________ An animal that has a beak, wings, and feathers.
5. ________________________________ An animal that has moist skin, has gills when it is young and then develops lungs when it gets older, and is cold-blooded.

Directions: Read the following *animal behaviors*. Then using the word bank, write the name of the animal that best corresponds with the description.

6. ________________________________ This animal may fly high in the sky to getter a better of view of small animals like a worm.
7. ________________________________ This animal may run away quickly to escape predators.
8. ________________________________ Swims away from bigger animals looking for a place to hide.
9. ________________________________ This animal may croak to attract a mate or show possession of their territory.
10. ________________________________ May lay on a tree branch sleeping and absorbing the sun, while camouflaging to hide from predators.

Figure 27. Vocabulary Matching Activity

Evaluation of Professional Learning

Teacher Satisfaction Survey Results

The course instructor's reaction to the provided PL was evaluated using the TSAF Instructor Satisfaction Survey (TSAF ISS). This survey was completed by the course instructor of the treatment group at the conclusion of the eight-week PL. The TSAF ISS, developed using evidence-based principles for survey development (Dillman et al., 2014), consists of 12 four-point Likert scale questions and a comment section. The survey results showed that the course instructor had an overall positive reaction to the provided PD. As shown in Table 19, the course

instructor rated all questions as a 4 (Strongly Agree) or as a 3 (Agree). None of the questions were rated as a 1 (Strongly Disagree) or a 2 (Disagree). The instructor did not write any additional comments in the section provided.

Table 19

Instructor Satisfaction Survey Results

Items	Strongly Disagree	Disagree	Agree	Strongly Agree
Level 1. Effective professional learning experiences				
L1.1. The objectives of the professional development were clearly stated.				✓
L1.2 The professional development content was aligned to the stated objectives.				✓
L1.3 The professional development was appropriate given my previous level of knowledge.				✓
L1.4 The professional development delivery was engaging.			✓	
L1.5 The professional development content was organized.				✓
L1.6. The professional development content was clearly delivered.				✓
L1.7. The professional development supported me to reflect on my own teaching practices for teaching science as argument.				✓
L1.8 The time allotted for the professional development was sufficient.				✓
Level 2. Essential participant knowledge and skills				
L2.1 I have increased my understanding of the role of language and literacy in science.				✓
L2.2 I have increased my understanding of how to use the TSAF Framework in my science methods course to support PSTs' developing knowledge and practices related to scientific explanation.				✓
L2.3 I have increased my knowledge on how to use writing scaffolds to support PSTs in writing scientific explanations.			✓	
L2.4 I have increased my knowledge on how to use specific talk moves to scaffold PSTs' communication of scientific ideas and evidence in ways that reflect scientific discourse.			✓	

Social Validity Questionnaire Results

The TSAF Social Validity Questionnaire (TSAF SVQ) was also completed by the course instructor of the treatment group at the conclusion of the eight-week PL. The survey was used to obtain instructor feedback regarding acceptability of and satisfaction with intervention goals, procedures, and outcomes (Wolf, 1978). The TSAF SVQ, also developed using evidence-based principles for survey development (Dillman et al., 2014), includes two sections: 12 questions (ten 5-point Likert scale questions and two open-ended questions) and a comment area. Results, shown in Table 20, indicated that the course instructor of the treatment group strongly agreed that the TSAF protocol was an appropriate and effective instructional tool for improving PSTs' knowledge of the NOS and knowledge of argumentation. The instructor did not write any additional comments/feedback in the section provided.

Table 20

TSAF Social Validity Questionnaire Results

Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. The TSAF is appropriate for my students.					✓
2. The TSAF is aligned with the current goals of my science methods course.					✓
3. The TSAF improves mt students' knowledge of the nature of science.					✓
4. The TSAF improves my students' understanding of argumentation.					✓
5. The TSAF protocol procedures are appropriate for my science methods course.					✓
6. The TSAF protocol procedures are easy to implement.				✓	
7. The TSAF protocol is an effective instructional tool.					✓
8. The TSAF protocol is an efficient instructional tool.					✓
9. I would use the TSAF protocol with my students.					✓
10. I would participate in additional TSAF professional learning activities.					✓

Fidelity of Implementation Results

For the purpose of this study, fidelity of implementation (FOI) was defined as the level to which the instructor in the treatment condition adhered to the intervention protocols as intended by the researcher. All 12 intervention sessions of the science methods course were observed by the researcher. Fidelity of implementation was tracked across all three phases of the study using the three researcher-developed fidelity checklists (FCs). The fidelity checklists are contained in Appendices U1-U3. A phase fidelity percentage (PF%) was calculated for each phase of the intervention by dividing the total number of adherence points achieved by the total number of adherence points possible and multiplying by 100. To calculate a PF% for 2, the fidelity scores

from all three investigations (Investigation 1 + Investigation 2 + Investigation 3) were combined. A total fidelity percentage (TF%) for the entire 12-week intervention was calculated by dividing the total number of adherence points achieved across all three phases by the total number of adherence points possible and multiplying by 100.

The science methods instructor of the treatment condition demonstrated moderate to high levels of fidelity over the course of the 12-week intervention period. She achieved 17/17 points (100%) for Phase 1 of the intervention. During Phase 2 of the intervention, the instructor achieved 24/25 points (96%) for Model Lesson 1, 24/25 points (96%) for Model Lesson 2, and 17/25 points (68%) for Model Lesson 3, for a total of 87% fidelity. During Model Lesson 1, the course instructor missed one adherence point during the *Do* section for failing to display a visual representation of the CER Framework. During Model Lesson 2, she missed one adherence point during the *Cue* section for not sharing the specific learning goal(s)/objective(s) of the lesson with PSTs. Fidelity of implementation was lower for the Model Lesson 3 due to a lack of instructional time. PSTs took longer than expected to design and build their model farmsteads during the hands-on investigation portion of the lesson. After engaging in the lesson as learners, time did not allow for PSTs to unpack the lesson from the perspective of the teacher. Thus, the course instructor of the treatment condition missed several adherence points during model lesson 3 in the Review/Reflect section, as well as the Salient Features and Essential Components section.

During Phase 3, the course instructor achieved 13/15 points (87%), and she missed one adherence point during the Cue section for failing to distribute and discuss the planning questions related to the TSAF. Additionally, she missed one adherence point in the Salient

Features and Essential Components section for failing to emphasize the NOS (i.e., what scientists do and why).

Overall, the course instructor of the treatment condition achieved 89% fidelity for the entire 12-week intervention. According to Durlak and DuPre (2008), 60% or higher adherence to the protocol is an appropriate level of fidelity for a new intervention, especially in the early stages of implementation.

Inter-Rater Reliability

In order to establish inter-rater reliability across several important intersections of the study, a graduate student assisted the researcher for the Assessment Scoring, the Fidelity Checklist scores, the Instructor Fidelity Worksheet, and the Lesson Plans Analyses. These protocols are described below.

Assessment Scoring

A CITI certified graduate student research assistant (RA) conducted interrater reliability checks for 100% of the pre and post measures. Using the Assessment Interrater Reliability Worksheet (IRW) displayed in Appendix V1, the RA rescored all pre- and post-assessments (NSAAQ, ARGTEST, and WSEA). The researcher compared the scoring results she recorded with the scoring results recorded by the RA. Every item and the total score were reviewed. Inter-rater reliability on the pretests was 91% for the NSAAQ, 85% for the ARGTEST, and 95% for the WSEA. Inter-rater reliability on the posttests was 93% for two of the measures (NSAAQ and the ARGTEST) and 98% for the WSEA. Most of the differences in recorded scores were a result of scorer error and were corrected. In a few cases, when scoring the WSEA, the RA assigned a

different rubric score than did the researcher. In those cases, the participant's written explanation was discussed, and consensus was reached using the criteria for scoring.

Fidelity Checklist Scores

The RA also conducted interrater reliability checks for the FC scores. The RA reviewed recordings from each weekly session and independently completed the FCs for all three phases of the intervention. Using the point-by-point method of agreement, percentage of agreement between the researcher and RA was 87%.

Instructor Fidelity Worksheet

Lastly, the RA conducted interrater reliability checks for scores recorded on the IFW. The RA recalculated 100% of scores and percentages for the IFW and noted the results on the Interrater Reliability Instructor Fidelity Worksheet (IR-IFW) contained in Appendix V2. Percentage of agreement for all fidelity calculations was 100%.

Lesson Plan Analysis

In order to establish inter-rater reliability, the RA, who is experienced in document analysis, independently coded all five group PST lesson plans using the final codebook (See Table 8). Inter-rater reliability was calculated as the number of agreed upon codes divided by the total number of codes in each document. Inter-rater agreement of 92% was reached through a process of initial coding, discussion, additional rounds of coding, resolution of discrepancies, and final agreement.

Summary

The results of the current study have been presented in this chapter. A RM-MANOVA was conducted to answer the first three research questions. Results from the RM-MANOVA

showed that there was a statistically significant interaction effect between group and time on the combined dependent variables, $F(3, 32) = 2.894$, $p = .050$, Wilks' $\Lambda = .787$ ($\eta^2 = .213$, POWER = .635). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered large. Although follow-up univariate ANOVAs revealed no statistically significant interaction between group and time on the NSAAQ measure with $F(1,34) = 3.42$ and $p = .073$ ($\eta^2 = .091$, POWER = .435), tests of simple main effects showed that the treatment group made significant gains on the NSAAQ measure from pretest to posttest with $F(1, 19) = 4.452$ and $p = .048$ ($\eta^2 = .190$, POWER = .517). In contrast, there was no change between pretest and posttest scores in the control group. Additionally, although there was no statistically significant difference in scores between the two groups at pretest, the treatment group's posttest mean was significantly higher than the control group's posttest mean with $F(1,42) = 6.977$ and $p = .012$ ($\eta^2 = .142$, POWER = .733). This suggests that PSTs who received the intervention demonstrated a significant increase in their understanding of the nature of science, as measured by the NSAAQ pre and posttest measures, as compared to PSTs who did not receive the intervention.

In regard to the ARGTEST, follow-up univariate ANOVAs showed that there was not a statistically significant interaction between group and time on the ARGTEST measure with $F(1,34) = .013$ and $p = .910$ ($\eta^2 = <.001$, POWER = .051). Given the non-significant interaction effect between group and time on the ARGTEST, main effects for the between- and within-subjects factors were examined. There was not a statistically significant difference in ARGTEST scores between the treatment and control groups with $F(1,34) = 2.236$ and $p = .144$ ($\eta^2 = .062$, POWER = .306). Neither was there a statistically significant difference in ARGTEST scores based on time (pretest to posttest) with $F(1,34) = 0.32$ and $p = .859$ ($\eta^2 = .001$, POWER = .053).

This suggests that PSTs who received the intervention did not demonstrate a difference in their knowledge of argumentation, as measured by the ARGTEST pre and posttest measures, when compared to results of the PSTs who did not receive the intervention.

In regard to the WSEA, follow-up univariate ANOVAs revealed that there was not a statistically significant interaction between group and time on the WSEA measure with $F(1,34) = 2.65$ and $p = .113$ ($\eta^2 = .072$, POWER = .352). However, tests of simple main effects showed the treatment group made significant gains on the WSEA measure from pretest to posttest with $F(1, 18) = 7.157$ and $p = .015$ ($\eta^2 = .284$, POWER = .716), whereas there was no change between pretest and posttest scores in the control group. Although there was no difference in scores between the two groups at pretest, the treatment group's posttest mean was significantly higher than the control group's posttest mean, with $F(1,41) = 5.227$ and $p = .027$ ($\eta^2 = .113$, POWER = .607). These results suggest that PSTs who received the intervention demonstrated a significant increase in the complexity of their written explanations, as measured by the WSEA pre and posttest measures, when compared to PSTs who did not receive the intervention.

To answer the fourth research question, PSTs' science lesson plans were analyzed using a constant comparative approach. The close analysis of participants' written lesson plans led to the following four themes regarding PSTs' enactment of the TSAF components (i.e., argument structure, public reasoning, and the language of science) when planning for inquiry-based science instruction: (a) opportunities for students to collect and analyze data, (b) emphasis on the use of text to support scientific inquiry; (c) use of scaffolds for helping students construct scientific explanations, and (d) attention to developing students' vocabulary knowledge in

science. The findings from this study have meaningful implications for practice and future research. These implications are presented in Chapter 5.

CHAPTER FIVE: DISCUSSION AND EDUCATIONAL IMPLICATIONS

Introduction

In the current study, the researcher investigated the impact of a one-semester intervention (12 weeks) focused on teaching science as argument within a science methods course on PSTs' (a) understandings of the NOS, (b) knowledge about argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the Teaching Science as Argument Framework when planning for science instruction. This chapter presents a summary and discussion of the findings of study. Secondly, an overview of implications for teacher educators, classroom teachers, and leaders in education is provided. The chapter concludes with limitations of the current study and recommendations for future research.

Discussion of Findings

Results from the RM-MANOVA showed that there was a statistically significant interaction effect between group and time on the combined dependent variables, $F(3, 32) = 2.894$, $p = .050$, Wilks' $\Lambda = .787$ ($\eta^2 = .213$, POWER = .635). Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered large. This finding suggests that, overall, the intervention had a significant impact on all three dependent variables (i.e., PSTs' understandings of the NOS, knowledge of argumentation, and complexity of written scientific explanations) when considered together. Based on estimated effect sizes for Partial Eta Squared, the size of the effect was considered large. This is a noteworthy finding given the small sample size in the study. A detailed discussion of the findings for each research question is included below.

Research Question 1

Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' understandings of the NOS, as measured by the Nature of Science as Argumentation Questionnaire (NSAAQ)?

The results of the RM-MANOVA and follow-up univariate tests indicated that there was not a statistically significant interaction between group and time on the NSAAQ measure with $F(1,34) = 3.42$ and $p = .073$. The effect size for the interaction between group and time was large ($\eta^2 = .091$) but lacked sufficient power (POWER = .435) to find a significant effect. This may have been due to the small sample size ($n = 36$).

Given the large effect size for the interaction between group and time on the NSAAQ measure, tests of simple main effects were conducted. Results from these tests revealed that: (a) the treatment group made significant gains on the NSAAQ measure from pretest to posttest and (b) the treatment group's NSAAQ posttest mean was significantly higher than the control group's NSAAQ posttest mean. Although there was no change between pretest and posttest NSAAQ scores in the control group, there was a statistically significant effect of time on NSAAQ scores for the treatment group, $F(1, 19) = 4.452$, $p = .048$ ($\eta^2 = .190$, POWER = .517). For the treatment group, the NSAAQ posttest mean ($M = 91.45$, $SE = 2.64$) was significantly greater than the NSAAQ pretest mean (M = 88.55, $SE = 2.48$). The moderate effect size ($\eta^2 = .190$) suggests that approximately 19% of the variance in the treatment group's NSAAQ scores was attributable to time.

Additionally, although there was no statistically significant difference in scores between the two groups at pretest, there was a statistically significant difference in NSAAQ scores

between groups at posttest, $F(1,42) = 6.977$, $p = .012$ ($\eta^2 = .142$, POWER = .733). Mean NSAAQ scores were significantly greater at posttest in the treatment group ($M = 91.45$, $SE = 2.30$) compared to the control group ($M = 83.21$, $SE = 2.10$). The moderate effect size ($\eta^2 = .142$) suggests that approximately 14% of the variance in posttest NSAAQ scores was attributable to condition.

Together, these findings suggest that PSTs who received the intervention demonstrated a significant increase in their understandings of the NOS, as measured by the NSAAQ pre and posttest measures, when compared to PSTs who did not receive the intervention. This finding is consistent with those of previous researchers investigating the effects of explicit argumentation instruction on PSTs' views of the NOS. For example, Ogunniyi (2006) examined the effectiveness of an argumentation-based, reflective NOS course on in-service teachers' NOS views. Findings indicated that participants demonstrated positive changes in their perceptions of the NOS over the duration of the course, and the author concluded that explicit argumentation instruction may be an effective approach for enhancing teachers' views of the NOS.

More recently, McDonald (2010) examined the influence of integrating explicit argumentation instruction within a science content course on PSTs' views of the NOS. Over the duration of the course, PSTs engaged in a variety of course activities designed to support the development of their NOS understandings and/or their argumentation skills. Findings revealed many improvements in participants' NOS understandings over the course of the intervention, with four of the five participants demonstrating partially informed or informed views in the majority of examined NOS aspects at the conclusion of the study.

Thus, the findings revealed in the current study contribute to the emerging body of research. The findings suggest that explicit instruction in argument structure, combined with opportunities to practice constructing, communicating, and critiquing scientific explanations, may aid in the development of PSTs' NOS views. This is an important finding, given the fact that teachers' inadequate understanding of the NOS has been identified as a major barrier to the incorporation of explanation and argument in the classroom (Abd-El-Khalick & Lederman, 2000). Teachers who view science as a body of irrefutable facts are unlikely to engage students in practices such as constructing, communicating, debating, and evaluating scientific explanations and arguments. For this reason, studies that aim to promote explanation and argument in the classrooms should be focused on enhancing prospective teachers' NOS views. It should be noted, however, that although understanding of the NOS is a necessary condition for the successful implementation of reform efforts in science education, it is far from sufficient. Researchers have identified several factors that seem to mediate the translation of PSTs' understandings of the NOS into classroom practice, including science content knowledge, pedagogical knowledge, teacher autonomy, and instructional time (Gess-Newsome & Lederman, 1995). Therefore, in addition to aiming to enhance prospective teachers' NOS views, teacher preparation programs should also focus on developing PST's own knowledge of explanation and argument as well as their pedagogical skills for supporting learners' engagement in these discursive practices.

Research Question 2

Does participation in an intervention focused on teaching science as argument have an impact on elementary PSTs' knowledge of argumentation, as measured by The Argumentation Test (ARGTEST)?

The results of the RM-MANOVA and follow-up univariate tests indicated that there was not a statistically significant interaction between group and time on the ARGTEST measure with $F(1,34) = .013$ and $p = .910$ ($\eta^2 = <.001$, POWER = .051). Given the non-significant interaction effect between group and time on the ARGTEST, main effects for the between- and within-subjects factors were examined. There was not a statistically significant difference in ARGTEST scores based on group (treatment group vs. control group), $F(1,34) = 2.236$, $p = .144$ ($\eta^2 = .062$, POWER = .306). Neither was there a statistically significant difference in ARGTEST scores based on time (pretest to posttest), $F(1,34) = 0.32$, $p = .859$ ($\eta^2 = .001$, POWER = .053).

These results suggest that the intervention did not have a significant impact on PSTs' knowledge of argumentation, as measured by the ARGTEST pre and posttest measure. Participants' overall low scores on the ARGTEST both before and after the intervention were consistent with those found in earlier studies that have assessed teachers' understanding of scientific argumentation. For example, Sampson (2009) conducted a study of 30 middle and high school science teachers. He concluded that the teachers mostly held naïve understandings about scientific argumentation and that their perceptions of what counts as a quality scientific argument were not consistent with the conceptions accepted by the science community. More recently, Aydeniz and Ozdilek (2015) explored 40 elementary PSTs' understandings of scientific argumentation. Similar to Sampson (2009), the researchers found that the majority of

participants demonstrated a deficit understanding of scientific argumentation, failing to acknowledge the role of evidence and the process of justification in reaching solutions.

Scholars have argued that developing prospective teachers' understandings of scientific argumentation is vital because teaching science as argument requires teachers who recognize the role argumentation plays in constructing scientific knowledge and learning science (McNeill & Pimentel, 2010). If students are expected to construct explanations of natural phenomena and engage in argument from evidence (NRC, 2012), they must understand the role of evidence in supporting and validating scientific explanations and arguments. If students are expected to develop such knowledge so they can successfully participate in explanation and argument, developing prospective teachers' conceptual understanding of the role of evidence in argumentation is crucial. For example, PSTs must learn to distinguish between opinion and scientific evidence, evaluate whether or not the evidence presented is relevant and/or trustworthy, and revise an explanation based on available evidence. Because teachers' knowledge and beliefs about scientific argumentation and explanation influence their pedagogical decisions in the science classroom (Beyer & Davis, 2008; McNeill et al., 2006b) future efforts should focus on identifying effective methods for improving PSTs' conceptions of argumentation.

Research Question 3

Does participation in an intervention focused on teaching science as argument have an impact on the complexity of elementary PSTs' written explanations, as measured by a researcher-developed written scientific explanation assessment (WSEA)?

The results of the RM-MANOVA and follow-up univariate tests indicated that there was not a statistically significant interaction between group and time on the WSEA measure with $F(1,34) = 2.65$ and $p = .113$ ($\eta^2 = .072$, POWER = .352). The effect size for the interaction between group and time was moderate ($\eta^2 = .072$) but lacked sufficient power (POWER = .352) to find a significant effect. This may have been due to the small sample size ($n = 36$).

Given the moderate effect size for the interaction between group and time on the WSEA measure, tests of simple main effects were conducted. Results from these tests revealed that: (a) the treatment group made significant gains on the WSEA measure from pretest to posttest and (b) the treatment group's posttest WSEA mean was significantly higher than the control group's WSEA posttest mean. Although there was no change between pretest and posttest WSEA scores in the control group, there was a statistically significant effect of time on WSEA scores for the treatment group, $F(1, 18) = 7.157$, $p = .015$ ($\eta^2 = .284$, POWER = .716). For the treatment group, the WSEA posttest mean ($M = 4.05$, $SE = .29$) was significantly greater than the WSEA pretest mean ($M = 3.00$, S$E = .39$). The large effect size ($\eta^2 = .284$) suggests that approximately 28% of the variance in the treatment group's WSEA scores was attributable to time.

Additionally, although there was no statistically significant difference in scores between the two groups at pretest, there was a statistically significant difference in WSEA scores between groups at posttest, $F(1,41) = 5.227$, $p = .027$ ($\eta^2 = .113$, POWER = .607). Mean WSEA scores were significantly greater at posttest in the treatment group ($M = 4.05$, $SE = .30$) compared to the control group ($M = 3.13$, $SE = .27$). The moderate effect size ($\eta^2 = .113$) suggests that approximately 11% of the variance in posttest NSAAQ scores were attributable to condition.

Together, these findings suggest that PSTs who received the intervention demonstrated a significant increase in the complexity of their written explanations, as measured by the WSEA pre and posttest measure, when compared to PSTs who did not receive the intervention. This finding is consistent with those of previous researchers who investigated the impact of explicit instruction in argument structure on PSTs' written explanation and argument skills. For example, Sadler (2006) documented the structure of PSTs' written arguments as they participated in a science methods course with an explicit focus on scientific discourse and argumentation. Throughout the course, participants received explicit instruction in argument structure and had various opportunities to construct, communicate, debate, and evaluate scientific arguments. Findings revealed that the majority of participants improved the structure of their arguments over the course of the semester.

More recently, Robertshaw and Campbell (2013) examined the effectiveness of a one-semester course featuring explicit instruction in argument structure using the Toulmin Argumentation Protocol (TAP) on PSTs' ability to write sound and logical scientific arguments. Findings revealed a general trend of improvement in PSTs' written argument scores from pre- to post-TAP instruction. This finding was further reinforced by PSTs' reflections on how their arguments evolved over the duration of the course. The majority of participants reported positive changes in their argument abilities, noting that the TAP helped them to write more organized scientific arguments.

Thus, the findings of the researcher in the current study further illuminate the potential of explicit instruction in argument structure for enhancing PSTs' written scientific explanation skills. This is an important finding, because it has been argued that teachers must be able to

construct evidence-based explanations themselves before they can support students' successful engagement in explanation and argument in the classroom (Zohar, 2008).

It is important to note, however, that although participants in the treatment group demonstrated a significant increase in the complexity of their written explanations from pre-intervention to post-intervention, there is still room for improvement. The explicit focus on the CER framework throughout the semester seemed to improve PSTs' ability to generate a scientific claim and support it with appropriate evidence. However, PSTs showed little improvement over time in their ability to apply scientific reasoning to establish a relationship between the evidence and their claim. This finding is consistent with findings of prior researchers who have found the reasoning component to be much more challenging for learners than the claim and evidence components (McNeill, 2011; McNeill & Krajcik, 2007; McNeill et al., 2006b; McNeill & Pimentel, 2010). These researchers found that learners at all grade-levels have a difficult time explaining why the evidence supports their claim. In many cases, students' transcripts of their reasoning are simply a repetition of their claims and evidences. After this one-semester intervention, room for improvement in participants' written explanations remains, especially in regard to the reasoning component. Findings from this study suggest that the CER framework may be a useful tool for scaffolding PSTs' explanation abilities. Efforts to improve PSTs' explanation and argument skills should be initiated and continued, with greater attention given to helping prospective teachers justify the connection between claim and evidence. A limitation of this study is that the researcher looked solely at PSTs' written explanations. Thus, it may be advantageous for future researchers to examine the impact of explicit instruction in

argument structure on PSTs' abilities to construct scientific explanations both orally and in writing.

Research Question 4

How do elementary PSTs incorporate components of the TSAF to support both students' literacy and science learning when planning for inquiry-based science instruction, as evident in their written lesson plans?

The close analysis of participants' written lesson plans led to the identification of the following four themes regarding PSTs' enactment of the TSAF components (i.e., argument structure, public reasoning, and the language of science) when planning for inquiry-based science instruction: (a) opportunities for students to collect and analyze data, (b) emphasis on the use of text to support scientific inquiry; (c) use of scaffolds for helping students construct scientific explanations, and (d) attention to developing students' vocabulary knowledge in science.

Central to all five participant groups' lesson plans were one or more opportunities for students to collect, record, and analyze data associated with a driving question. Groups planned meaningful hands-on investigations for students to make observations and record data and planned opportunities for students to collect evidence from secondary sources such as science trade books and websites. This finding suggests that PSTs in the study began to view the role of scientific investigations as an opportunity for students to collect evidence to support their claims. Because elementary teachers historically place little emphasis on the role of evidence in their science teaching (Newton et al., 1999), this is a noteworthy finding. This finding is also consistent with the results of the quantitative analysis of data that found that the intervention had

a significant impact on participants' understandings of the NOS, including the view of science as a process of exploration and experiment.

Second, all five participant groups incorporated the use of text within their science lesson plans. Although the ways in which text was utilized varied across groups, all groups positioned text as a means for supporting scientific inquiry. For example, some groups planned to use scientific texts to build students' background knowledge and stimulate interest about a topic. Other participant groups positioned text not only as a tool for building students' background knowledge and increasing interest but also as a source of evidence to support scientific claims. Lastly, some participant groups used scientific texts as a way to extend their lessons and help students acquire additional information about the topic. This finding suggests that the PSTs in this study began to acknowledge the important role text and literacy skills play in the learning and doing of science. Reading and interacting with scientific texts enables students to develop rich content knowledge about science and gain familiarity with the nature of scientific language, while also stimulating students' interest in conducting scientific inquiries of their own (Yore, Bisanz, & Hand, 2003).

Although this pattern in participants' lesson plans appears promising, some limitations should be noted. Two of the five participant groups selected an informational storybook to read-aloud during their lesson. This type of text presents science topics using the traditional elements of story structure (i.e., characters, setting, conflict, solution). Although texts of this type can pique students' interest and curiosity, they should not replace purely informational or nonfiction science texts with expository structures using the language of science. A lack of exposure to expository texts in the elementary grades has been identified as a primary reason for older

students' struggles with reading and comprehending science texts (Creech & Hale, 2006). The goals of the CCSS to increase the percentages of nonfiction texts sought to remedy this weakness. For this reason, teacher educators should help prospective elementary teachers understand the importance of selecting texts with appropriate and accessible expository text to prepare students to handle the more demanding science texts required of them in the upper grades, as well as narrative nonfiction texts that introduce students to contemporary socio-scientific issues and portray science with all its moral dilemmas as practiced in the real world.

Furthermore, while all five participant groups attempted to use scientific text in some way during their inquiry-based science lessons, PSTs incorporated few strategies for supporting students' reading comprehension. As argued in a previous chapter, scientific writing is characterized by range of grammatical features (e.g., technical vocabulary, abstraction, impersonal authoritativeness) that present unique comprehension challenges for students (Fang, 2006). Thus, it is not enough to simply expose young children to text with expository structures using the language of science scientific language, but instead, teachers must also equip students with discipline-specific tools for tackling the demands of scientific language. As Wellington and Osborne (2001) argue, "Learning to read science from any source requires structured and scaffolded interaction with text" (p 117). This includes helping students to become familiar with the format of scientific texts and modeling ways to organize textual information.

Although strategies for helping students interact with and comprehend scientific texts (e.g., text annotation, graphic organizers) were modeled in class throughout the semester, PSTs did not incorporate these strategies within their lesson plans. This finding warrants further

attention to assisting PSTs learn about the demands of scientific language and how to use strategies for supporting students' comprehension of scientific texts.

Third, all five participant groups' lesson plans demonstrated PSTs' attempts to engage students in scientific explanation. Though much variation was revealed in the quality of these attempts, instructional strategies utilized for supporting students' construction of evidence-based explanations were clearly informed by the approaches modeled in class throughout the semester. For example, all five participant groups incorporated the use of instructional strategies that reinforced the structure of argument, such as writing scaffolds and visual representations based on the CER Framework. This is an important finding, because explicitly teaching the structure of argument has been identified as a vital pedagogical practice for supporting the explanation building process (McNeill & Krajcik, 2008). This finding also suggests that participants began to connect the instructional strategies modeled throughout the semester with appropriate applications in planning for future classroom practice. Finally, this finding is consistent with the results of the quantitative analysis of data that found that the intervention had a significant impact on PSTs' own abilities to construct evidence-based explanations.

The majority of participant groups also attempted to ask questions consistent with teaching science as argument. It was evident that PSTs were using the CER framework to inform the types of questions they planned to pose to students. For example, teacher questions focused on refocusing students' attention on the guiding question, prompting students to explicate their reasoning (e.g., How do you know? Why?) and encouraging students to consider how a claim aligns with available evidence (e.g., What evidence do you have to support your claim?). The fact that PSTs incorporated strategies for fostering productive science talk is a

promising finding, because talk and discourse play a central role in the collective process of making meaning in science (Lemke, 1990; Sadler, 2006). Furthermore, classroom discussion has been identified as an important way to apprentice young children who are not yet proficient readers and writers into disciplinary literacy practices (National Research Council, 2012; Wright & Domke, 2019). This finding was also consistent with those of previous researchers examining how the TSAF influences PSTs' developing thinking and practices. For example, in a case study of three prospective elementary teachers, Barreto-Espino and colleagues (2014) found that the TSAF helped participants view science talks as a vehicle for engaging students in sense-making.

Although this pattern in participants' lesson plans appears promising, noticeable gaps in the PSTs' attention to promoting argumentation were found. In this study, participants seemed to be focused on oral discourse for the purpose of helping students come to a single, agreed-upon explanation. Of the five participant groups, only one group provided an opportunity within their lesson plan for students to consider alternative claims and/or opposing viewpoints. This finding was not surprising as other researchers have suggested that elementary PSTs avoid disagreement during science talk (Zembal-Saul, 2009). This finding is also consistent with the results of the quantitative analysis of data that found that the intervention did not have a significant impact on participants' knowledge of argumentation.

Moving forward, it will be imperative for teacher educators to help elementary PSTs recognize argumentation as a valuable part of the learning process in science. This includes helping PSTs learn to create a culture of critique in which learners co-construct science understandings through continuous dialogue, conflict, and negotiation.

Lastly, an emphasis on developing students' vocabulary knowledge in science was evident in all five participant groups' lesson plans. This was an important finding, as part of disciplinary literacy instruction in science involves supporting students' understanding of the technical words used to construct and communicate knowledge in science (Fang, 2006). The majority of groups included appropriate strategies for building students' science-specific vocabulary, all of which were modeled in class throughout the semester. These included having students sort words into meaningful categories and asking students to generate examples and non-examples. Again, this finding suggests that participants began to recognize the role vocabulary plays in science teaching and learning as well as began to connect the instructional strategies modeled throughout the semester with appropriate applications in an instructional context.

It should be noted, however, that PSTs tended to front load the vocabulary. In other words, PSTs incorporated vocabulary instruction towards the start of their lesson, prior to engaging students in an investigation. Settlage and Sutherland (2012) found that it is easier for students to learn science vocabulary when they have had prior experience with the phenomenon. This suggests that teachers should use the scientific phenomenon to help students develop the vocabulary instead of using the vocabulary to understand the phenomenon. By first engaging students in concrete experiences and investigation, students have the opportunity to develop conceptual understanding about the phenomena as well as their understanding of related words. This finding warrants further attention to helping PSTs understand how to effectively and authentically anchor the development of science vocabulary in investigations of natural phenomena.

It should also be noted that science texts are known for several linguistic challenges beyond technical vocabulary, such as informational density and complex sentence structure (Fang, 2006). Due to time constraints, the intervention did not explicitly attend to developing PSTs' awareness of the syntactic elements of scientific language. Moving forward, teacher educators should provide PSTs with opportunities to develop strategies for promoting students' understanding and use of scientific language beyond just vocabulary building (e.g., noun deconstruction/expansion, sentence completion, paraphrasing). These strategies will assist PSTs in learning to support young students' ability to make coherent and organized arguments in science.

In summary, all three components of the TSAF were incorporated to some degree as PSTs planned an inquiry-based science lesson for elementary students. First, the structure of argument informed the ways that PSTs planned to support students during the explanation building process. For example, several references to the CER framework were noted within participant groups' lesson plans. Second, regarding making thinking visible though public scientific reasoning, an evidence and explanation lens appeared to have informed the types of questions PSTs planned to pose during their lessons. That is, they planned to ask questions targeted at helping students focus on the guiding question, identify patterns in their data, and explicate their reasoning. Lastly, regarding the language of science, PSTs provided opportunities for students to read and interact with scientific texts, as well as incorporated language-based tasks to support students' vocabulary building in science. Though there is still room for growth, these findings revealed the potential of the TSAF for building PSTs' initial knowledge about ways to support elementary students' science and literacy learning in tandem.

A Revised Framework for Using Argument as a Bridge Between Literacy and Science

The insights gleaned from this study led to the refinement of the TSAF, displayed in Figure 28, to focus more explicitly on the role of language and literacy in scientific inquiry. These revisions were informed by the findings from this study as well as sociolinguistic and sociocultural theories of learning (e.g., Gee, 2004; Halliday, 1994; Lemke, 1990) that view oral and written language as critical for science learning and engagement and perspectives on disciplinary literacy (Fang & Schleppegrell, 2010; Moje, 2015; Shanahan & Shanahan, 2014).

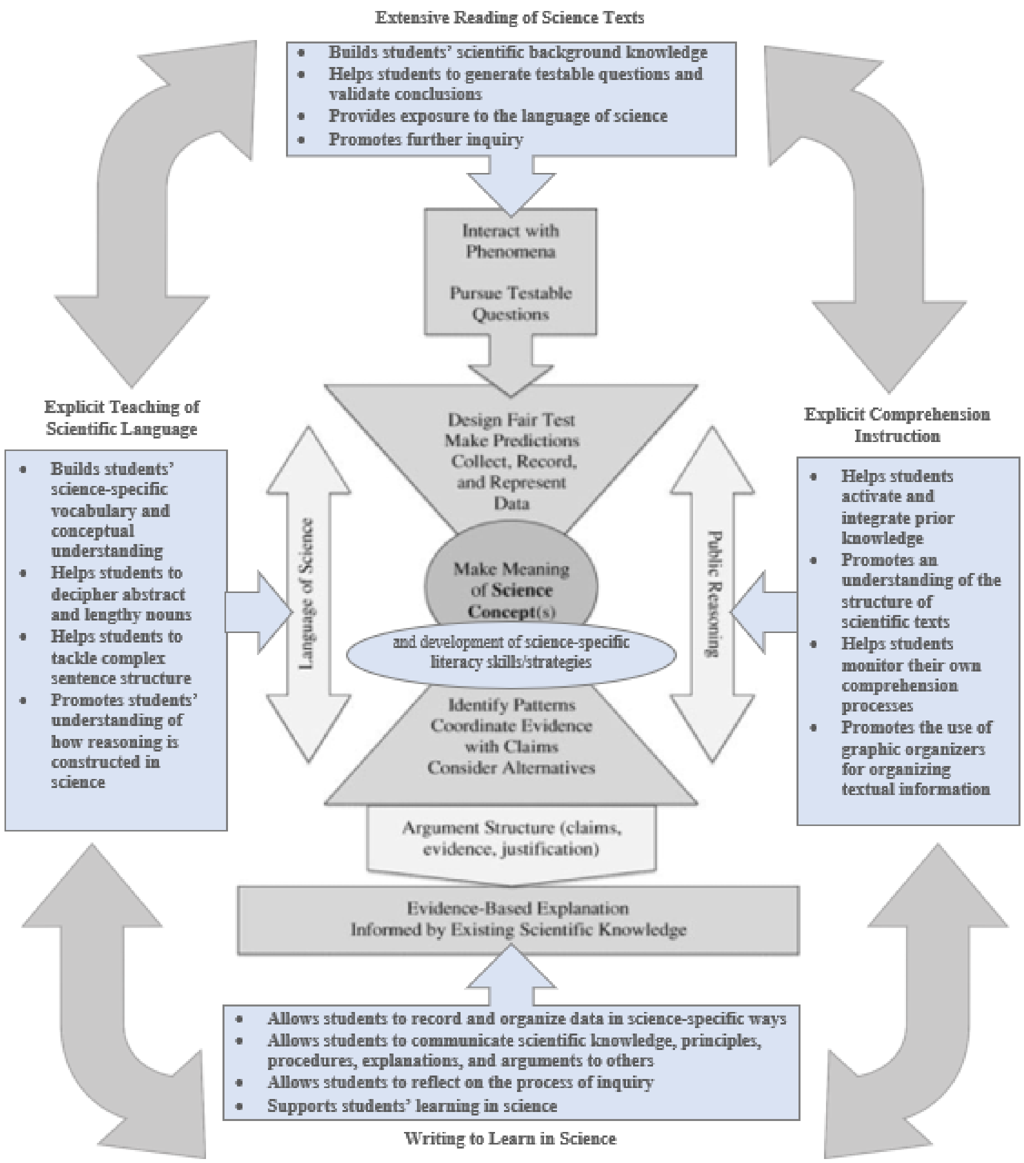


Figure 28. Revised Framework for Using Argument as a Bridge Between Literacy and Science

Source: Adapted with permission from "Learning to Teach Elementary School Science as Argument," by C. Zembal-Saul, 2009, *Science Education, 93*(4), p. 687–719.

The revised framework, titled *A Literacy Guide for Teaching Science as Argument* (LitTSAF), still consists of the three main features (i.e., argument structure, public reasoning, and language of science) as devised by Zembal-Saul (2009). However, emphasized in the revised framework are several key disciplinary literacy teaching practices supportive of engagement in science as argument, including extensive reading of scientific texts, explicit comprehension instruction, explicit teaching of scientific language, and opportunities for scientific writing. As such, the LitTSAF seeks not only to bring attention to the ways in which teachers can support students' science learning, but also to the ways in which teachers can apprentice students into science-specific language and literacy practices. In alignment with policy documents (e.g., NGA & CCSSO, 2010; NGSS Lead States, 2013; NRC, 2012), the LitTSAF positions language and literacy as vital for productive engagement in science learning. For example, the *Framework for K-12 Science Education* stated:

> Any education in science and engineering needs to develop students' ability to read and produce domain-specific text. As such, every science or engineering lesson is in part a language lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering. (NRC, 2012, p. 76)

No single framework can address all the challenges teachers face when it comes to supporting students' engagement and learning in science. However, it is the researcher's hope that the revised framework will help teacher educators increase PSTs' awareness about the role of language and literacy in science and better prepare them for supporting their future students' science and literacy learning in tandem.

Limitations of the Study

There were several limitations which posed a potential threat to the internal and external validity of the study. Limitations and their possible effects follow:

1. Participants were selected using non-probability sampling methods. The sample may or may not have accurately represented the target population, thus limiting the generalizability of the research findings (Creswell, 2003).
2. Participants were not randomly assigned to condition. Non-random assignment violates the statistical assumption of independence, inhibits the ability establish cause and effect relationships, and reduces the generalizability of the results to the wider population (Creswell, 2003).
3. The sample size of PSTs in the treatment condition ($n = 20$) and control condition ($n = 25$) was small. Small sample size decreases statistical power, thus increasing the likelihood of committing a Type II error (Lomax & Hahs-Vaughn, 2012).
4. There were some occurrences of missing pretest and posttest assessment data due to absences and/or course withdrawals. Make-up tests were attempted, but were not always successfully completed due to time and scheduling constraints.
5. A researcher-developed instrument was used to assess the complexity of participants' written scientific explanations. The measure was not tested for reliability or content validity, although it was developed using research-based guidelines for creating appropriate explanation assessment tasks (McNeill & Krajcik, 2012). Similar types of researcher-developed instruments have been used in previous studies (e.g., (McNeill & Krajcik, 2008).

6. The researcher had established a professional relationship with the course instructor of the treatment group prior to the study, which had the potential to introduce researcher bias. Steps were taken to control for researcher bias by monitoring fidelity of implementation throughout the intervention.
7. The treatment group and control group were not taught by the same instructor. The treatment group instructor was an assistant professor in science education with eight years of experience teaching at the post-secondary level. The control group instructor was a first-year doctoral student in science education with less than one-year experience teaching at the post-secondary level. Thus, differences between instructors (e.g., experience, level of competency) were possible confounding factors. In an attempt to achieve comparability between the treatment and control conditions, a graduate teaching assistant (also a first-year doctoral student in science education) facilitated all three inquiry-based model lessons with participants in the treatment condition.
8. The group structure of the lesson plan assignment did not allow for individual analysis of PSTs' application of the TSAF components when planning for inquiry-based science instruction. Furthermore, this study did not capture the rich collaborations that occurred as PSTs worked together to plan instruction.
9. This study took place within a very specific context, thus restricting the generalizability of the findings.

Implications for Practice

Implications for Preservice Teacher Education

A new vision for science education has emphasized the importance of apprenticing students into science-specific language and literacy practices, beginning in the elementary grades (National Research Council, 2012; NGSS Lead States, 2013). These practices include reading and comprehending scientific texts, constructing scientific explanations, engaging in argument from evidence, and using language to communicate scientific findings and understandings. Before they can successfully apprentice students into these practices, PSTs need opportunities to engage in disciplinary literacy practices themselves in the context of inquiry-based science. For example, within their science methods courses, PSTs should be provided with ample opportunities to interact with scientific phenomena, collect and record data, identify patterns, construct claims based on evidence, engage in argumentative discourse, and develop their understandings of the NOS. PSTs also need opportunities to develop the knowledge and practices required to support their future students' engagement in scientific inquiry, including how to select appropriate materials; organize students for instruction; and guide students as they collect, represent, interpret, discuss data, construct evidence-based explanations, argue from evidence, and draw conclusions.

Teacher educators must also make efforts to raise PSTs' awareness about the specialized language and literacy demands of science. As argued in a previous chapter, scientific writing is characterized by a range of grammatical and semantic features (e.g., technical vocabulary, abstraction, impersonal authoritativeness) that present unique linguistic challenges for students (Fang, 2006). In order for PSTs to support their future students in coping with these demands,

they must develop a repertoire of appropriate instructional strategies for scaffolding students' interactions with scientific texts, building students' vocabulary knowledge, and supporting students' communicative competence in science. As demonstrated in this study, modeling the use of such strategies within the context of inquiry-based science is imperative in science methods courses. For example, teacher educators can provide PSTs with opportunities to read and interact with expository texts in science, model explicit language-based strategies for developing students' vocabulary knowledge (e.g., Concept of Definition Map, Semantic Feature Analysis), as well as introduce frameworks for explanation-driven science (e.g., CER Framework) that can be used to help students appropriately justify their evidence-based claims both in writing and orally.

Finally, PSTs need to be provided with ample opportunities to apply their emerging understandings through meaningful class activities, assignments and clinical experiences. This includes engaging in lesson planning, teaching, and ongoing reflection. For example, teacher educators should model might ask PSTs to select an informational science text, bring it to their science methods course, and discuss with their peers the rationale for their text selection as well as how they would utilize the text to build students' background knowledge, teach students to read the texts of science, and support scientific inquiry. Through these experiences, PSTs will hopefully develop an understanding of the role of language and literacy in science and how to effectively apprentice their future students into science-specific ways of reading, writing, and communicating.

Preparing prospective teachers to enact the new vision for science education also necessitates interactions between members of the literacy and science communities. In this

study, members from the literacy and science education communities came together to collaborate and design purposeful teacher education experiences aimed at enhancing elementary PSTs' knowledge, practices, and beliefs for teaching science as argument. Collaborations such as these are absolutely necessary in order to effectively prepare PSTs for supporting students' disciplinary literacy learning in science.

Incorporating these elements places significant demands on existing teacher education programs and requires modifications to courses designed to prepare PSTs as effective teachers of science. When considering course modifications, it is recommended that teacher educators align elements of coursework and field experiences with a coherent, research-based framework, such as the Teaching Science as Argument Framework (TSAF). In this study, the TSAF was used as a learning tool to guide elementary PSTs' thinking about how to support students' science and literacy learning in the context of scientific inquiry. Teacher preparation experiences, like those highlighted in this study, may help to develop PSTs' initial knowledge and practices for effective disciplinary literacy teaching in science. However, ongoing support for novice teachers as they begin their teaching careers will be critical for continued growth and development.

Implications for Classroom Teachers and Professional Development

The call for disciplinary literacy in science places new demands on current elementary teachers. It requires teachers to not only serve as facilitators of knowledge but also to engage students in the kinds of cognitive processes and practices used by professional scientists (Fang, Lamme, Pringle, et al., 2010). Similar to the needs of PSTs, in-service teachers at the elementary level also need support in learning how to develop young students' science and literacy knowledge and skills in tandem. Greater proficiency in science and literacy for all students

requires knowledgeable teachers who understand the vital role that reading and writing play in supporting, rather than replacing, science learning (Pearson et al., 2010).

Because teacher knowledge is the key to student success, ongoing professional development is vital. Teacher professional development should focus on how to incorporate relevant scientific texts that increase students' interest and curiosity; how to develop questions that lead to meaningful inquiry; how to translate these questions into experiments that enhance students' conceptual knowledge; how to guide students to construct explanations from evidence, and how to develop students' ability to communicate their claims and evidence both orally and in writing. Professional development should also focus on assisting teachers in adopting appropriate scaffolds for supporting all students' knowledge, inquiry skills, and habits of mind, including students from diverse linguistic backgrounds and students with special needs. For example, professional development can introduce teachers to the CER framework and demonstrate how different variations of the framework can be used to individualize instruction for students, depending on their level of communicative competence in science.

One area that warrants particular attention is classroom discourse. A key component of the NGSS is engaging in discourse with a focus on constructing, communicating, and evaluating scientific explanations (National Research Council, 2012; NGSS Lead States, 2013). The NGSS requires students in the elementary grades to "ask questions"; "share observations," "describe patterns," and "construct explanations of phenomena." As students take part in scientific discourse, they are apprenticed into scientific ways of using language to communicate findings and understandings (Fang, 2004; Gee, 2004; Lemke, 1990). Especially for young children, who are not yet proficient readers and writers, oral discourse plays a critical role in supporting young

students' engagement in disciplinary literacy and language practices, such as the construction of evidence-based claims. Wright and Gotwasl (2017) suggested that, with adequate teacher scaffolding and support, even children as young as Kindergarten can begin to adopt scientific discourse patterns.

Promoting meaningful science talk among students is not an easy task for teachers. Thus, as the science framework asserts, students "will need support to learn how to facilitate appropriate and effective discourse in their classrooms (National Research Council, 2012), p. 257). Scaffolding students' ability to express their ideas through science talk will require that teachers shift from the traditional Initiate-Repose-Evaluate (IRE) model of questioning to more dialogic discourse aligned with sociolinguistic and sociocultural theories (Gee, 2004; Lemke, 1990). To assist teachers in making this shift, professional development should be aimed at helping teachers adopt questioning techniques and talk moves to make students' thinking visible while also fostering peer-to-peer interactions. This includes restating students' ideas, asking students to explicate their reasoning, and encouraging students to consider alternative explanations.

Implications for Leaders in Education

Supporting young students' disciplinary language and literacy development in alignment with the new vision for science education will require considerable instructional changes in the elementary classrooms. These changes will not only involve classroom teachers but also those who administer educational policies, such as district-level leaders, principals, and curriculum specialists. As stated in the science framework, "What ultimately happens in a classroom is significantly affected by decision making distributed across the levels and multiple channels of

influence” (NRC, 2012, p. 243). At the school level, principals, team leaders, instructional coaches, and other school administrators play an influential role in shaping classroom instruction by outlining expectations for learning, providing professional development opportunities, and making decisions about time and resources. Leaders at the school district level are responsible for allocating funds, setting instructional priorities, and providing resources and support structures that enhance teachers’ ability to implement effective instruction. The state level also plays an instrumental role in regulating funds and administering policies on standards adoption, student assessment, and educational accountability. Together, leaders at the school, district, and state levels have a considerable influence on what is taught, when it is taught, and how it is taught.

One critical issue has been the declining time spent on teaching science in the elementary grades. In the current climate of educational accountability, science instruction often takes a backseat to helping children prepare for state-wide standardized assessments in mathematics and reading. On average, students in Grades K-2 receive only 18 minutes per day of science instruction, and students in Grades 3-5 receive only 22 minutes per day of science instruction (Trygstad, 2013). School, district, and state leaders in education need to understand that rather than reducing time on science to focus on reading instruction, students should be engaged in disciplinary literacy and language practices during inquiry-based science instruction. The new vision for science teaching and learning positions language and literacy as tools for productive engagement in disciplinary learning, and views disciplinary learning as an opportunity for students to develop discipline-specific literacy skills and practices. In other words, just as literacy practices can enhance knowledge building and inquiry in science, science instruction

provides an ideal setting for developing and refining literacy skills that can improve subsequent reading and writing efforts (Pearson et al., 2010). Thus, it is vital that sufficient time is allocated to science instruction in the elementary grades.

In addition to making time for science a priority, school and district leaders should also facilitate collaboration between elementary school teachers, science content area teachers, and literacy coaches. As argued earlier, these types of interactions are important for co-constructing knowledge about the role of literacy and language in science and identifying best practices for supporting students' disciplinary literacy learning in science.

Recommendations for Future Research / Next Steps

Based on the findings and limitations of the current study, there are several recommendations for future research. The sample size of PSTs in the treatment condition (n = 20) and control condition (n = 25) was small. Small sample size decreases statistical power, thus increasing the likelihood of committing a Type II error (Lomax & Hahs-Vaughn, 2012). For this reason, it may be beneficial to analyze the quantitative data from this study using non-parametric statistical techniques.

Additionally, differences between instructors (e.g., pedagogical content knowledge, teaching experiences related to preservice teacher education) were possible confounding factors in the current study. Given these limitations, it would be advantageous to repeat this study using a larger sample of PSTs and to assign the same instructor to both the treatment and control condition.

In order to capture the co-construction of knowledge among PSTs, it may be beneficial to record and analyze group discussions as PSTs work together to plan a lesson.

Throughout the intervention period, several additional sources of data were collected including PSTs' pre- and post-course written reflections. These data sources were not analyzed since they were outside the scope of the current study. However, analyzing them in the future may help to establish a more comprehensive understanding of the impact of the intervention on participants' understandings about how to support students' science and literacy learning in tandem. Future research should also strive to include measures that better capture participants' understandings about the role of language and literacy in science in addition to the measures employed during the current study. Lastly, in addition to analyzing each group's final lesson plan submission, it may also be beneficial to record and analyze group discussions as PSTs work together to plan instruction. This type of data collection and analysis will help capture the co-construction of knowledge among PSTs as they select scientific texts, design investigations to enhance students' conceptual knowledge, and plan scaffolds for supporting student' construction of scientific explanations and arguments.

Based on the findings, it is suggested that several revisions be made to the professional development modules and intervention prior to study replication. These changes include:

(1) addition of resources for helping PSTs select high-quality informational science texts;

(2) increased attention to helping PSTs learn to support students' comprehension of scientific texts through explicit reading strategy instruction;

(3) more attention to helping PSTs learn strategies for promoting students' understanding and use of scientific language beyond just vocabulary building (e.g., noun deconstruction/expansion, sentence completion, paraphrasing)

(4) increased attention to helping PSTs facilitate argumentative discourse

The findings from this study provided initial evidence that participation in teacher preparation experiences grounded by a coherent framework for teaching science as argument may contribute to PSTs' understanding of how to support elementary students' language and literacy development within the context of scientific inquiry. What remains unknown is how PSTs who have participated in such experiences continue to develop their knowledge after they complete their science methods courses and teacher preparation program. For this reason, longitudinal studies are needed to investigate the impact of coherent teaching frameworks, such as the TSAF, beyond the science methods course context. For example, how does an intervention focus on teaching science as argument impact PSTs' instructional practices and decisions during their clinical and field experiences? Do PSTs who participate in teacher education experiences grounded by a research-based conceptual framework apply their understandings once they enter into the profession as in-service teachers? Also, what types of long-term supports are needed to continue to foster teacher development? As argued by Zembal-Saul (2009), "When teacher learning is systematically examined over time, what emerges is a learning progression associated with fundamental aspects of the framework being employed" (p. 714). Thus, future researchers should aim to track PSTs' longitudinal development, starting by exploring their initial knowledge and practices for teaching science as argument and continuing to investigate their ongoing development during student teaching and into their first years of teaching.

Newer standards (NGA & CCSSO, 2010; NGSS Lead States, 2013) require students in Grades K-5 to read, comprehend, and evaluate scientific texts, engage in explanation and

argumentation and use language to communicate scientific ideas. A great deal of teacher scaffolding and support will be needed in order for young students to effectively engage in such practices. Thus, further research is needed to identify best practices for apprenticing young children into disciplinary ways of reading, writing, and communicating in science, especially for those who are still developing foundational literacy skills.

Lastly, with the increased emphasis on the role of language and literacy use in the disciplines, greater attention will need to be devoted to examining language as a social practice in science (Gee, 2004) as well as how scientific knowledge is constructed and assessed through language (Lemke, 2001). Though the role of language and literacy in the science classroom has been previously examined (e.g., Fang, 2006; Freeman & Taylor, 2006; Krajcik & Sutherland, 2010; Norris & Phillips, 2003), investigation of the impact of specific practices as outlined in the TSAF on student learning, including ELLs and students with special needs, requires further inquiry.

Challenges and Solutions

Some challenges occurred throughout this study. These challenges were mostly related to (a) a lack of instructional time, (b) the need to attend to programmatic goals and/or requirements, and (c) participants' varying levels of prior knowledge and experiences.

Insufficient time for participant engagement in reflection was a reoccurring challenge throughout the intervention. For example, in Phase 2 of the intervention, the hands-on inquiry portion of the model lessons consistently took longer than expected due to student questions and whole-class discussions in which the instructor provided additional clarifications and prompted students to reflect on their observations and data. As a result, the review/reflection portion of the

lesson was often condensed or did not take place at all (i.e., as in the case of the third lesson). Given the central role which reflection plays in developing teachers' knowledge, beliefs, and practices (Brookfield, 1995; Dewey, 1933), the next iteration of this study will strive to provide participants more opportunities to partake in reflective activities. This will include providing participants with time to unpack each model lesson from a teaching perspective, to make meaningful connections to the three core components of the TSAF, and to reflect upon their emerging understandings about the role of language and literacy in science.

Additionally, a large portion of classroom activities/assignments were dictated by programmatic goals outside the researcher and course instructor's control. For example, the lesson plan rubric utilized by PSTs when developing their own inquiry-based science lesson was not only informed by the TSAF, but also reflected programmatic expectations such as the focus on the inclusion of appropriate accommodations/instructional supports for ELLs. In the future, it will be beneficial to integrate language and literacy expectations throughout each 5E phase of the lesson plan for the purpose of supporting all students' science and literacy learning, including ELLs.

Lastly, the PSTs in this study came from different backgrounds and had varying levels of prior experience working with school-aged children. For example, while none of the participants had yet to engage in student teaching, a few mentioned prior experiences working with young children in daycare and camp settings. Others discussed previous observations they had conducted in classroom settings as a requirement for their other method courses. Participants' prior knowledge and experiences could have impacted the way they constructed knowledge during the intervention and their ability to plan effective science instruction. In any future

iterations of this study, it may beneficial to collect more specific information about participants' pre-existing knowledge, skills, and experiences related to teaching science. Collecting such information will help design and differentiate classroom experiences which build upon the knowledge, skills, and experiences that PSTs bring to their science method courses.

Summary

The purpose of this study was to investigate the impact of a one-semester intervention (12 weeks) focused on teaching science as argument within a science methods course on PSTs' (a) understandings of the NOS, (b) knowledge about argumentation, (c) complexity of their written explanations, and (d) ability to incorporate components of the Teaching Science as Argument Framework when planning for science instruction. Findings revealed that, although the intervention did not have a significant impact on PSTs' knowledge of argumentation, PSTs who received the intervention did demonstrate a significant increase in their understanding of the NOS and in the complexity of their written explanations, as compared to PSTs who did not receive the intervention. Furthermore, the close analysis of PSTs' written lesson plans revealed several patterns (i.e., opportunities for students to collect and analyze data, use of scaffolds for helping students construct scientific explanations, emphasis on the use of text to support scientific inquiry, and attention to developing students' science vocabulary) consistent with the framework for teaching science as argument.

These findings contribute to a growing body of evidence illustrating the effectiveness of intentionally designed teacher preparation experiences for improving PSTs' views of the NOS (McDonald, 2010), ability to construct scientific explanations (Robertshaw & Campbell, 2013; Sadler, 2006), as well as their initial knowledge and practices for teaching science as argument

(Barreto-Espino et al., 2014; Boyer, 2016; Zembal-Saul, 2009). Given the emphasis on disciplinary literacy in the new standards documents NGA & CCSSO, 2010; NGSS Lead States, 2013), it is absolutely crucial that teacher educators continue to work toward developing prospective teachers' understandings about the role of language and literacy in science and how to effectively apprentice their future students into science-specific ways of reading, writing, arguing, evaluating, and communicating.

APPENDIX A
PILOT STUDY

Learning to Teach ALL Students Including English Language Learners through an Integrated Disciplinary Literacy Science Methods Course: Examinations of Preservice Teachers' Lesson Plans and Reflection

Introduction

A major instructional and learning challenge in science education in the U.S.A. is the achievement gap in the science achievement between English language learners (ELs) and native English speaking students.

New educational standards and 21st century workforce demands have presented a renewed urgency for the equitable preparation, including English learners (ELs), and the need for all to have access to opportunities to participate in science, technology, engineering, and mathematics (STEM) learning. Supporting ELs to develop disciplinary content and language in tandem is not a recent educational focus. Several educational policies (i.e., the Civil Rights Act of 1964, the Bilingual Education Act enacted in 1968, the Equal Educational Opportunity Act of 1974, the No Child Left Behind Act of 2001, the Every Student Succeeds Act of 2015) have highlighted the reciprocal role of language and content learning in all students' academic proficiency (Lee & Fradd, 1996; Lee, 2018; National Academies for Sciences, Engineering, and Medicine, 2018).

The 2009 National Assessment of Educational Progress (NAEP) shows only 12% of 12th grade ELs scored at or above basic level in science, compared to 62% of native English speakers (NCES, 2010). Moreover, this gap is persistent (NCES, 2012), and has been attributed to the readability of the academic language student assessments (Visone 2009, 2010). According to the Common Core State Standards (CCSS) for English Language Arts and Literacy in History/Social Studies, Science, and Technical Subjects (2010) and the Next Generation Science Standards

(NGSS Lead States, 2013), students need to develop specialized literacy skills that will help them comprehend content texts and develop content knowledge. These expectations require teachers to engage students in science practices, such as making sense of data and discussing findings, despite potential language obstacles (Lee, Quinn, & Valdés, 2013; National Research Council, 2012).

Most U.S. fourth-graders spend less than three hours a week in science and one in five don't even get two hours based on the 2015 NAEP survey data for fourth-grade science (Education Commission of the States, 2018). In most elementary schools, because elementary teachers typically teach both language arts and science, they need to have knowledge of the connections between science practices and literacy.

Language proficiency and content learning are not developed in a vacuum. Students bring language and content knowledge with them and they also develop both types of knowledge in science classrooms. The co-dependency of language and content development are the "foundational stones" upon which science instruction is built. Attention to language in STEM instruction is vital to developing all students' STEM proficiency and preparation (Author, 2015). Engaging elementary preservice teachers in questioning their preconceived assumptions and developing new understandings about the role of language in science teaching and learning and also about what science is and how it is conceptualized in the *Next Generation Science Standards* (NGSS Lead States, 2013) is vital to their pedagogical content knowledge (National Academies of Sciences, Engineering, and Medicine, 2018; Shulman, 1986).

In order to help teachers better meet these demands, science teacher educators should prepare elementary preservice teachers (PSTs) to develop science and literacy knowledge in

tandem. An instructional framework of disciplinary literacy may help PSTs learn the importance of facilitating the teaching of science and literacy in tandem and apprenticing students into how science experts construct knowledge and learn (Shanahan & Shanahan, 2008; Author, 2015).

In virtually every teacher preparation program, PSTs engage in learning about science teaching in writing lesson plans (Cerbin & Kopp, 2006; Richards & Rogers, 2014). A lesson plan is teachers' main tool for instructional planning. Lesson plans help PSTs to bridge the gap between theory and practice and been documented as a significant area (Clark & Peterson, 1986) for examining PSTs' understanding of content and pedagogical strategies (Clark & Dunn, 1991), and for linking learning to practice (Johnson, 2000). However, few studies have been documented how PSTs serve ELs through lesson planning (Cervetti, Kulikowich, & Bravo, 2015). To address these gaps and contribute to the knowledge base in science teacher preparation, this qualitative exploratory case study examined PSTs' understanding of the role of literacy in science teaching, through writing lesson plans and examining PSTs' reflections, to support all students learning in a disciplinary literacy integrated elementary science methods course.

Theoretical Perspectives

Learning is a sociocultural process

Most science education research is informed by the sociocultural theory of learning. Vygotsky (1978) highlighted the importance of interactions with an experienced other (i.e., adult, parent) in scaffolding a novice's conceptual development. According to this theory, human learning is mediated by culture and the development of individuals is embedded in the culture in which they live. This process allows students in a science classroom setting to develop

knowledge and to also become participant of that community (Lave & Wegner, 1991). From this stance, a student in an elementary science classroom needs to have social interactions that will allow him or her to learn the language, norms, habits of mind and ways in which knowledge is developed, evaluated, and communicated in the broader science community and also in the local science class or peer group, sociocultural classroom community. Language is a core sociocultural tool for constructing meaning and knowledge for all students (Lemke, 1990, 2001). Without language, students cannot access knowledge. It is imperative for PSTs to learn how to develop and scaffold all students' language development in the elementary science classroom. Scientific concept development cannot be isolated from language development (Driver, 1989). Language development is especially important for ELs and other students whose linguistic needs may present roadblocks to science learning. This framework informed our study's focus on preparing PSTs to learn how to develop all learners' academic language and literacy in ways that support all students' science learning in the elementary classroom.

Disciplinary literacy and science learning

According to the sociocultural lens, literacy is developed through the language, the practices, and the cultural values of a situated community (Gee, 1996). Each community has its specific language, norms, routines, symbols, and ways of doing and learning (Lave & Wenger, 1991; Wenger, 1998). Through this lens, a discipline is a community that has its unique set of literacy practices and ways of knowing. Disciplinary literacy refers to the ways of reading, writing, thinking, and reasoning within academic fields (Moje, 2007; Shanahan & Shanahan, 2008). Science is not just a body of knowledge; it is also a way of knowing. Through this lens, as members of an elementary science classroom community, all students should learn about the

nature of science, the structure of scientific knowledge, and how knowledge is developed and communicated (National Reading Council [NRC], 2007). Viewing language, literacy, and science learning through a science-specific disciplinary literacy lens students will learn how to read the texts of science, use the norms and conventions of science, form scientific explanations and engage in scientific investigations using scientific habits of mind (Moje, 2007; NGSS Lead States, 2013; Shanahan & Shanahan, 2008, 2012, 2014; Schleppegrell, 2004, 2007; Author, 2015). In this study, we integrated a disciplinary literacy framework in a science methods course and engaged PSTs in learning about the benefits of developing students' literacy and science knowledge and skills in tandem.

Literature Review

The Role of Literacy in Science Learning

Reading, writing, reasoning and communicating are authentic components of learning and doing science. According to the NRC (2014), the Common Core State Standards for English Language Arts (CCSS) for English language arts and the Next Generation Science Standards (NGSS) intersect in the importance they place on students' ability to make sense of the world and developing critical thinking skills. In the study of science, students need to develop literacy skills in science relevant ways to be able to develop their understanding of disciplinary core ideas, engage in science and engineering practices (e.g., constructing explanations, engaging in argument from evidence), apply crosscutting concepts, and communicate their knowledge (NGSS Lead States, 2013). The focus of science learning is not only on learning core concepts, but also on the processes of how knowledge is developed. Some scholars argue that science teaching approaches have to promote students' deeper engagement into scientific inquiry

(Sinatra et al., 2015). These science-domain specific aspects of engagement include the eight science and engineering practices in the NGSS (NGSS Lead States, 2013).

The foundational principle of content-area literacy instruction is to help students engage with texts and develop conceptual understanding. Literacy strategy instruction has been used in the content areas as a way to engage students in the process of attending to text ideas before, during, and after reading in the forms of organizing and monitoring their understanding of ideas, making connections between new content and prior knowledge, summarizing, etc. (e.g., McKeown, Beck, & Blake, 2009; Palinscar & Brown, 1984; Pressley et al., 1992). Strategy instruction that supports the development of students' prior knowledge is key to students' construction of understanding of content (Krajick & Sutherland, 2010; Sutherland et al., 2008).

Research findings from three research-based instructional models provide evidence about the importance of literacy and science integration. First, Seeds of Science/Roots of Reading was developed by the Lawrence Hall of Science at the University of California, Berkeley, and is designed to integrate science and literacy for students in grades 2-5. The program aims to strengthen students' understanding of science concepts, by instructing teachers how to teach students to read, write, and communicate their learning in science-specific ways. External evaluations have shown positive effects on elementary students' science vocabulary, writing fluency and science content knowledge (Goldschmidt & Jung, 2011; Wang & Herman, 2005).

Second, The Concept-Oriented Reading Instruction (CORI) (Guthrie & Wigfield, 2000) combines reading strategy instruction, conceptual knowledge in science, and support for student

motivation. The program provides explicit instruction in reading comprehension strategies such as, strengthening and activating students' background knowledge, questioning, searching for information, summarizing, graphic organization of learning, and structuring stories. Research on CORI shows a positive impact on students' motivation, engagement, and comprehension (Guthrie et al., 2004; Guthrie et al., 2007; Guthrie, Klauda, & Ho, 2013).

Third, The In-depth Expanded Applications of Science (Science IDEAS) is a K-5 interdisciplinary instructional model that integrates literacy and science through comprehension and writing instruction (Romance & Vitale, 1992). The IDEAS model provides in-depth science instruction through six elements: hands-on investigations, reading, journaling/writing, propositional concept maps, application activities, and prior knowledge/cumulative review. Studies have shown a positive impact on students' science efficacy, academic achievement, and reading comprehension (Romance & Vitale, 1992, 2001, 2011a, 2011b).

Disciplinary Literacy in Science

Integrating literacy in science teaching and learning is not a new phenomenon. However, what is new is the call for students to receive explicit instruction in disciplinary practices (NRC, 2012; NGSS Lead States, 2013) in a way that does not compete with content learning. According to Fang and Wei (2010), literacy is "a powerful vehicle for engaging students' minds, fostering the construction of conceptual understanding, supporting inquiry, and cultivating scientific habits of mind" (p. 263). Many content area teachers integrate literacy instruction and supports to assist students, especially struggling readers, ELs, and others who are experiencing difficulties with reading and comprehending texts, have underdeveloped vocabulary, and need assistance with organizing information. In many cases, literacy is viewed as an instructional

add-on or as something teachers will try to carve time to do as the need arises in the classroom. Many students still struggle with having the needed literacy and science skills that unlock their access to science learning. Although there are many benefits of literacy integration in science, new educational standards call for a need to re-conceptualize the role of literacy in the content areas for the purpose of improving all students' preparation for both the academic and the literacy demands of each subject area (Moje, 2010; Shanahan & Shanahan, 2012; Author, 2012).

Disciplinary literacy offers a different instructional and learning framework in the content areas. It focuses on learning from how the experts in a discipline read, write, think, reason, develop, evaluate, and communicate knowledge (Moje, 2008; Shanahan & Shanahan, 2014; Author, 2015). In science, a disciplinary literacy approach will help teachers develop students' science and literacy knowledge and skills in tandem (Shanahan & Shanahan, 2008). For example, while students are learning how to form scientific explanations and arguments orally and in writing, they will also be learning about scientific discourse, as well as developing scientific knowledge and advanced and science-specific literacy skills (Osborne, 2010). When teachers teach students how to read the texts of science (print or multimodal) using a scientific inquiry lens, students will be doing close reading of texts, they will be learning how language is used in science texts (Fang, 2004), they will be identifying claims and biases authors make in texts, and they will also be learning how to use evidence from the texts to support (or not support) a claim and then share their reasoning.

Other scholars (Lee, Quinn, & Valdés, 2013) propose that providing opportunities to engage students, especially ELs, in these practices is beneficial for scientific sense-making and academic language development. Since reading, writing, and communicating are all essential, it

is critical that science-specific literacy practices be components (Howes, Lim, & Campos, 2009). Integrating disciplinary literacy in science teaching and learning can help students acquire a deeper understanding of how knowledge is created, evaluated, and communicated in science. It also presents unique challenges as it requires teachers to provide all students, especially ELs, with appropriate instructional supports that will help them to develop and use science-specific ways of thinking and communicating (Hammond & Gibbons, 2005; Turkan, de Oliveira, Lee, & Phelps (2014). Improving literacy in science is vital to narrowing the achievement and participation gaps of ELs.

English Language Learners' Needs in Science

The US classrooms have become increasingly diverse. The NRC strongly advocates for science education for all students, and especially for ELs who experience unique challenges with learning in science. Students cannot develop their scientific literacy without learning and practicing the academic language and discourse of science (NRC, 2012). Academic language represents the language of a discipline. Students use academic language to develop and express their content understanding and participate in content learning. Without academic language students cannot participate or engage in meaningful ways in the content area. For example, without academic language students cannot communicate scientific ideas, form scientific explanations, and engage in scientific argumentation (Gee, 2004; Yore, Pimm, & Tuan, 2007). Academic language also demands knowledge of vocabulary, language functions, syntax, and discourse. Teachers need to consider how to support students' academic language learning as they plan their instruction (Anstrom et al., 2010). Vocabulary refers to the general and subject-specific words of the discipline. In each discipline, words and phrases have specialized

meanings that differ from the meanings used in everyday life (e.g., medium). General academic vocabulary can be used across disciplines (e.g., identify, compare, contrast, analyze, evaluate). Discipline-specific words can be defined for use in a discipline (e.g., whelk, isotope, magma) (Beck, McKeown, & Kucan, 2013). Discourse refers to the structures of oral and written language and also how the members of a discipline talk, write, and engage in knowledge construction.

The specialized language of science can be challenging to most learners, especially to struggling readers, ELs, and students with linguistic and learning exceptionalities. Science texts (a) have text structures that differ from those of fictional text; (b) present information in rich and specialized ways, and (c) present explanations using language that differs from the everyday language students are accustomed to (Fang, 2004; Schleppegrell & Paliscar, 2013). Because many science words have are polysemous, teachers need to plan for vocabulary instruction, supports, and opportunities for students to learn and use science vocabulary in the classroom (Cervetti et al., 2015). ELs can have a wide range of difficulties with science academic language. For example, some many have underdeveloped everyday vocabulary, science vocabulary, and also lack in structures that are necessary for them to participate in scientific inquiry.

To provide instructional language supports for ELs, teachers must be aware of their students' English language proficiency, the language demands of the science lesson or hands-on inquiry, and the supports they will need to provide to scaffold student learning (National Academies of Science, Engineering, and Medicine, 2018). Planning for science instruction that integrates literacy and science content is useful to ELs' learning (Bruna, Vann, & Escudero,

2007). Research has also shown that ELs benefit from language and communication instructional supports that make vocabulary accessible to them (Faggella-Luby et al., 2016), illustrated charts that help them to visualize the works (Calderón et al., 2005), use cognates (Buxton et al., 2014), vocabulary and comprehension instruction (Symons, 2017), engage in experiencing natural phenomena (Lee, Valdés, & Llosa, 2015–2019), create a model of what they are learning (Brasser & Fargason, 2013), design an investigation (Cuevas et al., 2005), use graphic organizers to learn about concepts and investigations (Beck, McKeown, & Kucan, 2013), use notebooks and multimodal forms of expression and communication (Quinn, Lee, &Valdés, 2012), and participate in collaborative learning (Lee, Quinn, & Valdés, 2013).

Research shows that U.S. preservice teachers are not adequately prepared to support ELs to meet the academic standards (Ballantyne, Sanderman, & Levy, 2008). Dong (2004) found that preservice teachers had difficulties with aligning language and curricular objectives, identifying ELs' potential learning difficulties, and providing cultural background information to help ELs make connections with their learning.

Lesson Planning and Preservice Teachers' Pedagogical Capacity

Lesson plan writing is an integral part of teaching and student learning. It is a process teachers use to organize how they will teach. A lesson plan is the main tool a teacher uses to plan and organize what students will learn and how they will learn within a time period. Every teacher who intends to teach something has to prepare a practical outline of his or her subject or topic in written form that is known as a lesson plan. For

Lee (2007) defines a lesson plan "…as an organized statement of general and specific educational goals together with the specific means by which these goals are to be attained by the

learners under the guidance of the teacher on a given day" (p. 72). In writing a lesson plan, a teacher has to apply his or her theoretical, pedagogical and content knowledge (Shulman, 1986). A teacher has to apply his or her theoretical knowledge in planning and administering a lesson plan. A lesson plan is a written document for multiple audiences that shows what the teacher and the students will do in a specific timeframe (Whitton et al., 2004). For teachers, a lesson plan is an indicator of one's content and pedagogical knowledge (Shulman, 1986). In the case of PSTs, most of their lesson plans are written for college professors and for inservice teachers who supervise and evaluate PSTs in their clinical experiences. PSTs learn how to write lesson plans prior to their clinical internship experiences as part of their teacher preparation programs and continue to write them throughout their professional careers.

Writing a lesson plan is no easy task, especially for PSTs who are developing so many types of knowledge about content, pedagogy, and student learning (Johnson, 2000; Sahin-Taskin, 2017). An effective lesson plan includes specific steps that should engage students in thinking, asking questions, investigating new ideas, and building new knowledge and skills. Understanding PSTs perspectives about lesson planning will help teacher educators understand how to best prepare them, how they think about subject matter and bridge theory and practice, how PSTs view the role of the teacher and the student in the learning process, and how they make instructional decisions (Choy et al., (2013; Nilsson, 2009).

Research on teacher preparation initiatives for linguistic diversity is in its infancy. Very few studies have focused on how PSTs in teacher preparation science course are prepared to teach science to ELs (Lee, 2005). A number of studies have examined impact of the Effective Science Teaching for English Learners (ESTELL) intervention model on PSTs' preparation to

teach science to ELs (Bravo et al., 2011; Bunch, 2013; Solis et al., 2011; Stoddart, 2002; Stoddart et al., 2011). The model includes the following practices: integrating science, language, and literacy development; engaging students in scientific discourse; developing scientific understanding; collaborative inquiry science learning; and contextualized science instruction, to help students improve their science learning and language and literacy development. Only one quasi-experimental study (Stoddart et al., 2013) examined the impact of ESTELL on 85 PSTs' instructional practices and compared them with the practice of 50 PSTs who participated in the control group. The results showed a statistical difference between the two groups; the experimental group implemented significantly more ELL-responsive practices in their practicum experiences than the control group.

Second, two recent studies directly addressed science PST's lesson planning through their preparation course work and only one of them focused on secondary PSTs. The first study (Kahn, Pgman, & Ottley, 2017) investigated how 26 PSTs planned their 5E (Bybee, et al., 2006) science lessons to help all students through an early childhood science methods course and an adaptation course for learners with "exceptionalities and diverse needs" and ELs. The lesson plan template included a section entitled "Adaptations for Students with Special Needs." The study found that PSTs chose more "relying on others strategies," such as paring up ELs with another student who could help them, than developing instructional supports and changed to the classroom environment to encourage students to learn. Because this study did not focus only on ELs, there were only a few examples of PSTs' instructional adaptations for ELs.

The second study (Siegal et al., 2014) investigated the development of 23 secondary PSTS' understanding and ability to design Equitable Assessment (EA) for ELs in a science

methods course. Three kinds of data included PST's teaching philosophies, reflective journals, and a science unit that consisted of five inquiry-based lesson plans. The analysis of self-reported learning in PSTs' journals and teaching philosophy paper showed that PSTs demonstrated learning during the course and developed their own knowledge and beliefs in four categories, including views of assessment, views of learners, assessment as a learning tool, and 'benefits and drawbacks of EA (Siegal et al., 2014). However, PSTs had difficulty transferring what they had learned to their unit's lesson plans. For example, only one participant stated that an assessment was specifically designed for ELs and only two of them met all the EA principals individually. Since lesson plan analysis was not the focus of the study, only a few data on those outcomes has been described and it is not clear how those data were analyzed.

Reflecting on lesson plans. Preservice teachers' conceptions of lesson plans range from the belief that experienced teachers neither write detailed lesson plans nor need to implement given curriculum materials with fidelity. Research shows that nowadays there is a shift in teacher's belief about the use of educative curricula—i.e., a good teacher is someone who implements materials well (Drake, Land, & Tyminski, 2014). Current models of teacher evaluation also support this current shift (e.g., The Marzano Teacher Evaluation Model; The Danielson Framework for Teaching). Most teacher preparation programs also focus on PSTs learning how to use curriculum materials in instructive and flexible ways for the purpose of meeting all students' needs (Drake, Land, & Tyminski, 2014). Reflecting on and critiquing lesson plans is one useful way to engage PSTs in examining their own content and pedagogical knowledge, beliefs, and professional identifies.

Studies report that a lesson plan critique assignment can provide PSTs with opportunities to examine their knowledge, beliefs, orientations, and professional identities (Brown, 2009; Forbes & Davis, 2010). In a methods course, a lesson plan critique assignment involves a close examination and reflection, evaluation, and reflection on the following areas: (a) alignment between lesson plan objectives and related standards; (b) strengths, (c) weaknesses, and (d) challenges with lesson plan writing, and (e) ideas for improvement. Research shows that PSTs' lesson plan critiques and reflections tend to focus on listing surface-type elements such as listing the presence or absence of specific procedures and the affective aspects of lesson plan writing (Nelson & Davis, 2009) rather than engaging in a deeper critique of how scientific content is presented or how students, including ELs, will be developing scientific knowledge (Davis, 2006; Dong, 2004).

Both the acquisition of science knowledge and literacy-related skills are important to promote all students' participation in science. However, elementary PSTs tend to see science and literacy learning as separate. As a result, they tend to think about the role of literacy in supporting students' knowledge and skills in isolated ways and focus on it mainly as it relates to improving the language skills of ELs (Krajick & Sutherland, 2010). Our study aims to address PSTs' understanding of the role of literacy in science teaching through writing lesson plans to support all students learning in a disciplinary literacy integrated elementary science methods course. Specifically, our research questions are as follows: 1. What science-specific literacy strategies did elementary PTS include in their lesson plan about using science-specific literacy strategies to teach science for all, including ELs? 2. What challenges did elementary PSTs report in their reflections about including science-specific literacy strategies to teach science for all,

including ELs? 3. What instructional accommodations did elementary PTS include in their science lesson plan to support ELs' learning needs? 4. What challenges did elementary PTS report in their reflections about developing instructional accommodations for ELs in their science lesson plan?

Methodology

Context

This study is part of a larger study that explored the effectiveness of integrating science-specific literacy instruction within a science methods course on PSTs beliefs, attitudes towards teaching science, and lesson planning practices. This study took place at a large metropolitan university in the South Eastern United States. During the spring semester of 2018, 31 elementary education PSTs (8 juniors and 23 seniors) attended a science methods course before they starting any internship in elementary classrooms. The course instructors who are also researchers of this study, include two faculty members from science education and literacy education with their two doctoral students as teaching assistants. This science methods course was the only course focusing on teaching science and was designed to prepare PSTs to incorporate the state science teaching standards, and implement them to teach all students in elementary science classroom settings. State standards of English for Speakers of Other Languages (ESOL) had been infused within the objectives of this course in order to prepare PSTs for state ESOL Endorsement and all PSTs had already taken a prerequisite Teaching English to Speakers of Other Languages (TESOL) course. In the previous TESOL course, Academic Subjects Protocol (Nutta et al., 2014), a protocol for developing instructional accommodations for ELs have been taught. The protocol is divided into two phases (see Figure

1 and 2) and has been used to guide this study. It starts with an analysis of the task within teaching activities, such as how is nonverbal or verbal communication used within the lesson. SLIDE and TREAD (see Table 1) include verbs for analyzing student and teacher actions in the lesson. The SLIDE category requires less language-intensive actions in the class while the TREAD category indicates more language intensive actions. In the second phase, SHOW and TELL (see examples from Table 2) accommodation strategies were introduced to provide non-verbal and verbal support for different level ELs so that they could implement these tasks to meet learning objectives. The key assignment for this science methods course was to use 5E instructional model (phases include engage, explore, explain, elaborate, and evaluate) (Bybee, et al., 2006) to plan an inquiry-based science lesson and provide instructional accommodations within each E to support all students learn science.

A majority of the course time was also devoted to integrate Disciplinary literacy (DL) in science in this course (see Table 3). Starting from the fourth week of the course, a disciplinary literacy professor and a doctoral student co-taught with a science education instructor to integrate science-specific literacy in the elementary science education course. The co-teaching took place for 12 weeks and included presentations on DL in science, engaging PSTs in the process of interacting with scientific text (McKeown, Beck, & Blake, 2009) and introduction of reading tools (Author, 2015), demonstration of three science lessons including life science, physical science, and earth science lessons with specific DL practices (e.g., engaging student in scientific explanation and science arguments through a Claim-Evidence-Resoning (CER) framework), resources for selecting informational text and how to teach it, and literacy strategies to support all students', especially ELs, science learning.

Table 1. SLIDE and TREAD

Less Language-Intensive	More Language-Intensive
• **S**how (watch, pantomime, model, display) • **L**ook (smell, taste, feel, & other non-verbal senses) • **I**nvestigate (measure, weigh, categorize, classify, connect) • **D**emonstrate (draw, design, act out) • **E**xperience (act, move, do, make, create)	• **T**ell (also present information, lecture, narrate, recount, go over, report out, share) • **R**ead (also skim, scan, review) • **E**xplain (also listen) • **A**sk/Answer (also solicit, write, respond, predict) • **D**iscuss(also describe, define, barnstorm)

Table 2. Examples of SHOW and TELL strategies

SHOW strategies	TELL strategies
• Hands-on activities • Demonstrate a process • Model tasks • Dramatizations • Experiential learning • Pictures • Props	• Word lists • Vocabulary/grammar support • Graphic organizers to complete • Fill-in-the-blank phrases and sentences to scaffold language • Highlight keywords • Scaffold reading comprehension—strategies • Scaffold writing development—targeted error correction

Table 3. Relative Activities and Curriculum Materials in the Science Methods Course

Activity	Curriculum Material
Discuss teaching standards	Ch. 2 The Purpose of Science Teaching Guided questions CCSS, NGSS, NGSSS, School district planning
Lesson planning Write content and Language objective	Ch. 3 Planning to Teach Science Lesson plan template and criteria
Discuss science practices and 5E instructional model ("Engage", "Explore", "Explain", "Elaborate", and "Evaluation") Teach Science through a Disciplinary literacy lens	Ch. 8 Inquiry and Science Teaching NGSS (Science practices) Science text ("Issue Overview: Fracking" from Newsela
Experience a physical science lesson focusing on scientific argument	Science lesson 1_scientific argument using Claim-Evidence-Reasoning (CER) framework
Experience a life science lesson focusing on explanatory model	Science lesson 2_cell modeling
Experience an earth science lesson focusing on vocabulary instruction and communicating like scientists	Science lesson 3_Erosion
Reflect on three science lessons and make explicit connections to supporting all students, especially ELs, learning science and literacy in tandem.	Revised 5E lesson reflection instrument (Goldston et al, 2013) Review Academic Subject Protocol (Nutta et al., 2015) Lesson plan rubric.
Design an inquiry-based science lesson to teach all students including ELs	NGSS standards Lesson plan template and rubric
Peer evaluation on lesson plan with specific attention to ELs' accommodations	Lesson plan template and rubric
Revise the lesson plan based on the feedback provided by methods course instructor	lesson plan draft
Reflect on lesson planning process	Reflection framework

A qualitative exploratory case study (Creswell, 1998) was used to examine our four research questions. A qualitative exploratory case study was useful in building an in-depth and

contextualized understanding about complex issues in the social context (Yin, 2003) through collecting, describing, interpreting, and triangulating various kinds of data (Tellis, 1997).

Data collection

For the purpose of this proposal, we only focused on the analysis of two data sources. First, the final submission of an inquiry-based science lesson plans was collected from eight groups, composed by 31 participants. This lesson plan includes eight components, including state science standards and objectives, misconception, detailed procedures structured by a 5E instructional model, ESOL accommodations within each E phase to help beginning, intermediate, and advanced ELs access the content of the lesson, science practices, materials list and safety precaution. Second, a reflection paper guided by five questions (see Appendix) focusing on participants' learning process of planning this science lesson from each PSTs was collected after they submit the final lesson plan. Although as part of the course PTs worked in small groups of four to develop a lesson plan, they had to submit an individual reflection on the process.

Data analysis

Research Question 1: What science-specific literacy strategies did elementary PTS include in their lesson plans to teach science for all, including ELs?

To answer research question 1, PSTs' inquiry-based science lesson plans were analyzed through a series of steps. The first step in analysis consisted of reading through all eight groups' lesson plans to become familiar with the data and note overall impressions. The second step involved rereading each lesson plan and coding all literacy activities/strategies included by PSTs. Codes related to research question 1 included (1) activating prior knowledge, (2) using graphic

organizers, (3) writing predictions, (4) incorporating scientific text, (5) validating or revising predictions based on scientific data and observations, (6) using science notebooks to record and organize information, (7) defining science-specific vocabulary, (8) engaging in evidence-based explanation using the CER Framework, (9) using sentence frames for scaffolding students' science writing, and (10) using teacher questioning to scaffold students' scientific explanation skills. These activities/strategies were then categorized as either science-specific or general. Finally, this led to the identification of several themes related to research question 1.

Research Question 2: What challenges did elementary PSTs report in their reflections about including science-specific literacy strategies to teach science for all, including ELs?

To answer research question 2, PSTs' individual written reflections were analyzed. Since research question 2 asks "What challenges did elementary PSTs report in their reflections about including science-specific literacy strategies to teach science for all, including ELs?", the analysis was focused solely on the second part of question two of the reflection assignment (see Appendix). The first step in analysis involved reading through each participant's written reflection to become familiar with the challenges self-reported by PSTs regarding including science-specific literacy strategies within their lesson plans. The second step in analysis involved coding and categorizing all challenges reported by PSTs. Categories related to research question 2 included (1) difficulties in selecting relevant and age-appropriate scientific texts, (2) challenges related to developing students' science-specific vocabulary, (3) challenges with assessing students' science and literacy learning, (4) difficulties in facilitating meaningful science talk, and (5) challenges with providing opportunities for students to write in science-specific ways. Finally, from the challenges self-reported by PSTs, several themes related to

research question 2 were identified. Categories, codes, and example quotes from PSTs' written reflections are displayed in the Table 4.

Table 4. Coding System for PST' Challenges in Including Science-specific Literacy Strategies

Categories	Codes	Quote examples	# of participants
Selecting relevant and age-appropriate scientific texts	· finding appropriate websites · incorporating scientific-text	"The most challenging aspect of this was finding websites at a fifth-grade reading level that were still based in science and related to the content we were teaching." "Some of the challenges we faced was trying to incorporate children's literature into the lesson."	4
Using strategies to develop students' science-specific vocabulary knowledge	· identifying grade-level appropriate vocabulary terms · explicit vs. implicit vocabulary instruction	"The challenging part was maintaining the focus on our 6 vocabulary terms without talking about other organs and systems that help our body function." "Something that I found challenging about it was trying to keep the vocabulary on the correct grade level. When writing out lesson plans, it is easy to forget who it is for so we had to make sure to remember the grade level it was intended for." "We did face challenges in trying to integrate this vocabulary throughout our lesson. We wanted students to have the chance to explore concepts, and reach conclusions about rock classification on our own. Because of this, we were reluctant to explain vocabulary such as sedimentary, igneous, metamorphic, texture, luster, and hardness too early in the lesson, worried the lesson would turn into a direct teach rather than an inquiry-based lesson."	2

Categories	Codes	Quote examples	# of participants
Incorporating appropriate methods to assess students' science and literacy learning	·assessment	"We had challenges in assessing students. Luckily, a classmate suggested the CER framework." "Challenges we faced were figuring out of the students should complete the assessments aloud or write the answers down to submit."	2
Facilitating meaningful science talk	· time for discussion · using strategies to promote talk	"However, a most significant challenge was time to exploit all discussions and communication phases to consolidate conceptual learning by the students." "I think our most challenging part of that was encouraging meaningful conversation."	4
Providing opportunities for students to write in science-specific ways	· science journal · using strategies to promote talk	"The most challenging for me was the science journal, I think we could have explained better how to use it and what specifically we wanted the students to write or do on it."	3

Research Question 3: What instructional accommodations did elementary PTS include in their science lesson plan to support ELs' learning needs?

To answer research question 3, PSTs' inquiry-based science lesson plans were again analyzed, focusing on the types of accommodations PSTs included to support ELs at varying levels of English proficiency (i.e., beginning, intermediate, and advanced) within each E phase of their lesson plan. The first step in analysis consisted of summarizing the tasks students would engage in during each 5E phase as described by the PSTs' within their inquiry-based science lesson plans. These tasks were then coded using the SLIDE and TREAD analysis in order to determine the language load required for each activity. SLIDE verbs correspond to tasks with a low language load and TREAD verbs correspond to high language load. Next, EL

accommodations PSTs included within each 5E phase were coded using the SHOW and TELL framework that students utilized in their TESOL course. SHOW accommodations include visual strategies (e.g., demonstrations, pictures, props) while TELL accommodations include verbal strategies (i.e., vocabulary/grammar support, reading comprehension strategies, scaffolded writing development). Table 5 shows one group's instructional accommodations for ELs for each phase of the 5E model and for each level of EL's English proficiency.

Table 5. An Example of Coding for Each of the Phase of the 5E Instructional Model

	Tasks	Beginner	Intermediate	Advanced
Phase	SLIDE (S) and TREAD (T)	Show (S) and Tell (T) * = science specific accommodation, # = general accommodation		
Engage	Asking students to **look (S)** at photos and **verbally (T) answer** questions about erosion.	Ask simpler questions (T) (#) individually while looking at the pictures, like pointing (S) (#) or one word answer (T) (#)	Same procedure as for a beginner, but expecting an answer of more than one word (T) (#)	Pair with a native English speaker to answer the questions during the discussion (T) (#)
Explore	**Observe (S)** a demonstration of erosion and **draw (S)** pictures of their observations using a handout that the instructor made. Students **manipulate (S)** the demonstration and then record a final observation by **drawing (S)**.	Beginner ELL students will be partnered with a non-ELL (T)(S) student for additional guidance with the recording sheet (T)(S) (*) The ELL student will first observe another non-ELL student (S) (T) doing the activity, so that they may have a demonstration of what is expected. The teacher will explain each step as the student performs the action. (T) (#) All ELL students will only be required to draw pictures on the recording sheet. (S) (#)	The ELL student will first observe another non-ELL student (S) (T) (#) doing the activity, so that they may have a demonstration of what is expected. The teacher will explain each step as the student performs the action. (T) (#) All ELL students will only be required to draw pictures on the recording sheet. (S) (#)	The ELL student will first observe another non-ELL student (S) (T) (#) doing the activity, so that they may have a demonstration of what is expected. The teacher will explain each step as the student performs the action. (T) (#) All ELL students will only be required to draw pictures on the recording sheet. (S)(#)

	Tasks	Beginner	Intermediate	Advanced
Explain	**Define (T)** wind and water erosion after **listening (T)** and **watching (T)** a teacher led PowerPoint. Then **talk (T)** and **listen (T)** in a class discussion on differences between weathering and erosion.	Ask students' simple questions (T) (#) that require yes or no answers, and provide pictures for the student to point to (S) (#)	Pair student with someone who speaks fluent English (T) (#), and have them both share between them during discussion.	Pair with a student who speaks fluently (T) (#) and have them share their thoughts between themselves, then the class
Elaborate	**Watch (S)** a video and then they will be **verbally ask (T)** questions about the video.	Stop at certain parts of the video to clarify or further explain (T)(#) to ensure understanding. Explain what happened during the video using simpler language (T)(#)	Ask about what they saw during the video (T)(#) and provide further explanation (T)(#) if needed to.	Ask questions about what they saw (T)(#), and ensure understanding.
Evaluate	**Discuss (T)** with partner what they learned about erosion. Then, **write (S)** about erosion following guidelines from a rubric.	Pair the student with a speaker of their native language (T) (#), or work individually with the student. The student can draw a picture instead (S)(#) to show the changes occurring for both wind and water erosion.	The student will be allowed to draw their observations (S)(#), and insert keywords (T)(#) that address the steps. The keywords will be provided in an illustrated word bank (S)(#), and sentence frames for "fill-in-the-blank" (T)(#) can be provided as well.	Provide with a word bank (T)(#) to reference when writing.

From this analysis, the following codes emerged: (1) SLIDE and TREAD task-oriented accommodations; (2) science-specific and general accommodations framed by SHOW and TELL; and (3) same accommodation used for more than one ELL proficiency level. In order to identify patterns across the analyses, the data for research questions 1 and 3 were organized in a combined coding table (See Table 6 for example from Group 4). The combined coding table included all literacy strategies coded as either general or science-specific as well as accommodations/instructional supports per each 5e phase.

Table 6 Combined Coding System for Literacy Strategies and ELL Accommodations/Instructional Supports

E	Task SLIDE/ TREAD	Literacy strategies		Accommodations/Instructional Support (SHOW and TELL)			
		General	Science-specific	low	mid	high	All ELL Students
Explain	Write in science notebooks misconceptions about the human body. Construct explanations that make sense of the world/human body. Discuss organs and their functions with peers with prompted questions given by the teacher.		Using science notebooks to record and organize information Engagement in written and oral evidence-based explanation using C-E-R Framework Provided teacher questioning to scaffold students' scientific explanation skills	Pre-teaching, word walls, gestures, slow speech, allowing drawings for responses, seat the student close to the front of the room, keep directions short and simple, give verbal information and explanations along with a visual presentation, use as many of the senses (seeing, hearing, touching, smelling and tasting) as possible to present information to students.	video presentations for subject-matter content; highlighted vocabulary in subject matter content, such as science and social studies materials; main ideas offered through graphic organizers and concept mapping; speech-to-text options; pre-teaching opportunities for new vocabulary and concepts; color shading used for emphasis	simple self-monitoring checklists; curriculum handouts for students to self-assess completion and accuracy; frequent feedback; use of computer software to teach early reading skills (e.g., Starfall); paired peers to share small-group activities; use of CAST UDL Book Builder to create engaging topical books for science; keep directions short and simple; slower speech; use of gestures; video presentations for subject-matter content	Student can draw their misconceptions or work with teacher one on one in expressing the facts learned verbally or by drawing.

Research Question 4: What challenges did elementary PTS report in their reflections about developing instructional accommodations for ELs in their science lesson plan?

To answer research question 4, PSTs' individual written reflections were analyzed, focusing solely on the second part of question four of the reflection assignment. The first step in the analysis involved reading through each participant's written reflection to become familiar with the PSTs' self-reported challenges regarding instructional accommodations for ELs. The second step in the analysis involved coding and categorizing all challenges reported by the PSTs. Categories related to research question 4 included (1) difficulties in providing accommodations to different level (beginner, intermediate, and advanced) ELs, (2) challenges related to vocabulary teaching, (3) challenges related to diverse culture, (4) challenges for accommodations for using specific presentation media, and (5) challenges of thinking about accommodations through each E phase of teaching. Lastly, from the PST's self-reported challenges, we identified several themes related to research question 4. Table 7 includes codes, categories and sample quotes from PSTs' written reflections.

Table 7. Coding System for PSTs' Challenges in Creating Instructional Accommodations for ELs

Categories	Codes	Quote examples	# of participants
Difficulties in providing differentiated accommodations for beginners, intermediate and advanced ELs.	· different level ELs · differentiating between the intermediate and advanced · struggle to come up with different accommodations for each level.	· "were having a difficult time differentiating between what intermediate and advanced levels" · "we were not sure what a beginner ELL student was capable of"	9
Challenges of vocabulary teaching for ELs.	· vocabulary teaching · word bank · graphic organizer · advance content knowledge	· "constantly remind ourselves to use the vocabulary words" · "Since our lesson was vocabulary heavy, I wanted an activity that would be able to incorporate visuals and colorful graphic organizers to assist ELS."	4
Challenges of providing ELL's accommodation when using video in their teaching.	· video	"A challenge we faced was trying to find a better way to accommodate ELL students through the video."	2
Thinking about accommodations for ELs through the whole lesson	· hinder · diversified culture · every part of lesson	"There is a challenge when teaching a class with students from diversified culture, as it requires more effort to integrate all learners into a common understanding." "The challenges we faced was making sure we covered accommodation for every part of our lesson."	3

Findings

Overall, findings indicated that elementary PSTs began to develop their understanding of the role of literacy in science teaching and in supporting all students to learn science, especially the needs of ELs, through planning an inquiry-based science lesson. First, PSTs were able to

plan tasks/activities within each phase of an 5E learning model to engage students in an inquiry-based science learning process. Second, PSTs were able to provide at least one literacy strategy within each phase to help all students learn science. Third, PSTs were able to provide ELs instructional accommodations to help them engage in each activity. At the same time, and as reflected in their written reflections about the lesson writing process, they also reported challenges they experience with planning to supporting students' literacy and science learning.

Research Question 1: What literacy strategies did elementary PTS include in their lesson plans to teach science for all, including ELs?

Analysis of the lesson plans also revealed that all eight groups incorporated at least one science-specific literacy strategy into their lesson plans. General literacy strategies incorporated by PSTs included activating prior knowledge, writing predictions, building background knowledge, summarizing learning, using graphic organizers, reading aloud scientific text, labeling diagrams, and matching vocabulary words to their definitions. For example, group 3, whose lesson focused on teaching students to classify rocks according to their physical properties, included specific questions to be posed to students during the Engage section of the lesson in order to activate students' prior knowledge on the topic. These questions included: (1) *What do you already know about rocks?*, (2) *What steps do you think a scientist needs to take before classifying things/objects into different categories* and (3) *How do you think you might be able to classify rocks into different groups?*

Science-specific literacy strategies incorporated by PSTs included recording scientific data, defining science-specific vocabulary terms, engaging students in science-specific writing supported by evidence, validating or revising predictions and making conclusions based on

scientific data and observations, engaging students in written evidence-based explanation using the CER Framework, providing sentence frames for scaffolding students' science writing, and using science notebooks to help students record and organize information. For example, in the Evaluation phase of their lesson plan, group 7 included an opportunity for students to construct a scientific explanation explaining why a certain object sinks or floats using the CER Framework. This group also included sentence frames based on the CER Framework (e.g., *The _____ will sink/float. I think this because _____________.)* to further assist students in writing a complete and accurate scientific explanation.

PSTs Reported the Use of Teacher-Led Read-Alouds of Science Text(s) but they Did Not Specify How they Would Guide Students' Engagement with the Text(s)

Following a 5E learning model, PSTs were able to plan tasks/activities within each phase to engage students in the inquiry-based science learning process. Four of the eight groups included a teacher read-aloud of a science text to build students' background knowledge within the Engage section of their inquiry-based science lesson. For example, Group 3, whose lesson focused on categorizing rocks based on their physical properties, included a teacher read-aloud of *If You Find a Rock* by Peggy Christian to introduce students to the ways in which rocks are classified. Group 7, whose lesson plan focused on teaching students to distinguish human body parts and their basic functions, included a teacher read-aloud of *Me and My Amazing Body* by Joan Sweeney. Although several groups incorporated a science text within their inquiry-based science lesson, very few PSTs specified how the read-aloud would be used to support students' science and literacy development. For example, what specific questions would be posed before,

during, and after the read-aloud to promote student discussion and support students' active involvement in the conceptual knowledge building process?

Using the CER Framework to Construct Scientific Explanations but Limited Support for Promoting Science Talk

Five of the eight groups incorporated the CER Framework for supporting students' engagement in scientific explanations. The CER Framework was incorporated most during the Explain, Elaborate, and Evaluate phases. For example, Group 2 included the use of the CER Framework in their lesson plan to support students in explaining what time of year would be best to vacation to their assigned geographical location, using evidence from a WebQuest to support their claim. Group 7 described how they would use the CER Framework to assist students in developing an evidence-based scientific explanation, using evidence such as color, hardness, luster, texture, layering, and particle size, to classify a particular rock as either igneous, sedimentary, or metamorphic. Several groups also developed a rubric based on CER Framework to assess student' scientific understanding. While these groups incorporated strategies for helping students write in science-specific ways (e.g., CER Framework, sentence frames), only one group provided a description of how the teacher would encourage students to talk about their scientific ideas. Group 4 listed questions the teacher would pose to guide the students in the interpretation of their evidence. These questions included: What is the function of the heart?; Is skin an organ?; Do you think the human body would still function if some of these body parts weren't there?; Other than thinking, what is the brain responsible for?. None of the groups included opportunities for students to critique the scientific explanations of others.

Building Students' Science Specific-Vocabulary without Specific Strategies to Support Students' Science Learning

All groups included a list science-specific vocabulary terms related to the topic of their inquiry-based science lesson plans. For example, within their lesson plan, Group 5 specified that students would able to define the words *brain, heart, lungs, stomach, muscles, and skeleton* as well as describe the function of each body part. Group 8 explained that students would be able to use scientific terms such as *volume, shape, size, measurement, and liquids* when recording their observations and findings. However, while several groups included an assessment of vocabulary knowledge during the Evaluate phase, very few groups included appropriate strategies for building students' science-specific vocabulary beyond the definitional level. For example, Group 1 explained that they would define content specific vocabulary and describe the differences between weather and erosion. However, they included very few further opportunities for students to interact with or develop their knowledge of these vocabulary words. Similarly, Group 8 stated that they would discuss vocabulary such as volume, shape, size, measurements, and liquids during the Engage phase, but did not include any specific strategy for developing students' knowledge of these technical terms.

Research Question 2: What challenges did elementary PSTs report in their reflections about including science-specific literacy strategies to teach science for all, including ELs?

Analysis of PSTs' individual written reflections showed evidence of a developing understanding of the role of literacy in science teaching and learning. For example, one PST reported that one of the most important things she learned through the lesson planning process was "how imperative it is to incorporate literacy practices with science practices; they are

incongruent with one another for true understanding of science concepts." However, PSTs also noted several challenges within their reflections regarding the inclusion of science-specific literacy strategies in inquiry-based science instruction. These challenges included: (1) selecting relevant and age-appropriate text, (2) facilitating meaningful science talk, and (3) providing opportunities for students to write in science -specific ways.

Selecting Relevant and Age-Appropriate Text

Four PSTs mentioned difficulties with selecting relevant and age-appropriate texts within their written reflections. For example, one PST mentioned that the most challenging aspect of this assignment was "trying to incorporate children's literature into the lesson". Another PST stated that they had difficulty "finding websites at a fifth-grade reading level".

Facilitating Meaningful Science Talk

Four PSTs expressed challenges with promoting meaningful science talk. For example, one PST noted that it was difficult to find "time to exploit all discussions and communication phases to consolidate conceptual learning by the students." Another student expressed concerns because she had not had any prior experience with leading a classroom discussion.

Providing Students with Opportunities to Write in Science-Specific Ways

Three PSTs described challenges related to providing students with opportunities to write in science-specific ways. For example, one student reflected that the most challenging part of the science inquiry lesson was the science journal. In her reflection, she mentioned that

she could have explained better how students were expected to utilize the science journal and she should have outlined more specifically what students need to write in it.

Research question 3: What instructional accommodations did elementary PTS include in their science lesson plan to support ELs' learning needs?

PSTs showed evidence of a developing understanding of what accommodations might look like for ELs to learn science. They were able to follow a 5E learning model and transfer their knowledge from a general TESOL course to a specific science lesson planning process and provide instructional support for ELs through the whole lesson.

SHOW and TELL Accommodations for SLIDE and TREAD Tasks Focusing on Different Science Practices

All groups used SHOW and TELL accommodations to help support ELs complete SLIDE and TREAD tasks within each E phase in science lessons. A common SHOW accommodation is that six groups planned to allow ELL students to draw their understanding of science concepts as an option to writing about them. For example, one group planned to have 2nd grade ELs to draw pictures of their observations about the changes wind makes on a sand hill simulated in the "Explore" phase of their lesson, using an "Erosion Observation" handout which provided three spots for three observations. A common TELL accommodations is that six groups planned to use sentence frames to support ELs' in composing scientific explanations. For example, one group used sentence frame, "The weather in ______ will warmer in July and cooler in January", to guide 2nd graders to learn how to use evidence to support their claims about when will be the best time to visit a place to enjoy winter weather or summer weather. Also, six groups used accommodation, graphic organizers that were categorized as both SHOW and TELL

strategy for ELs. For example, a Human Body Parts chart including the body parts (brain, heart, skeleton, muscles, lungs, and stomach), functions, and location was used in "Exploration" phase to help students organize their data and information obtained from their investigating each body part through the resources provided by teacher. All groups planned to allow ELs work with a Native English speaking student.

Limitations Related to PSTs' Planned Instructional Accommodations for ELs

Even though within each E all groups produced accommodations for ELs to be engaged in science practices, some of them were not specific enough to support the tasks proposed in the activities for two main reasons. First, some accommodations did not include necessary details that would helpful in classroom implementation. For example, one group of PSTs who planned to facilitate a lesson on weathering and erosion used a series of questions to engage students to discuss land formations created by wind erosion. For this task they stated the following for beginning EL students, "Ask simpler questions individually while looking at the pictures, like pointing, or one word answer." However, the group did not list or suggest questions that are easier to answer. Second, none of the differentiate their EL accommodations nor did they provide specific accommodations for the three levels (beginning, intermediate, advanced) of EL English proficiencies as expected. All groups used pairing native-English speaking students with EL students without explain how Native-English speaking students would assist EL students. Furthermore, all groups used the same accommodation for different EL proficiency levels for at least one of their 5E phases. Groups did not explain how these accommodations would help ELs across phases and language proficiency levels.

Research question 4: What challenges did elementary PTS report in their reflections about developing instructional accommodations for ELs in their science lesson plan?

In their individual reflection papers, PSTs mentioned that during lesson planning process, they had to rely on some of the accommodations they learned in a previous TESOL course and also on what they learned from a modeling lesson (i.e., Oobleck lesson) in their current science methods course. PSTs reported four types of challenges related to developing ELs' instructional accommodations in their science lesson plan.

First, nine PSTs reported they found it difficult to provide differentiated accommodations for beginners, intermediate and advanced ELs. Some of them "were having a difficult time differentiating between what intermediate and advanced levels" while others reported that they were not sure "what a beginner ELL student was capable of".

Second, four PSTs reported challenges of vocabulary teaching for ELs. For examples, some of them were not sure about how to provide pictures for developing a word bank and others reported they had a hard time in providing non-verbal visuals and colorful graphic organizers as accommodations to support ELs' needs.

Third, two PSTs reported their challenges with providing ELL's some specific accommodations when integrating video in their instruction. They had a hard time in finding appropriate questions or other supports to help ELs understand the content of the video.

The last type of challenge the PSTs reported in their reflection was related to how hard and how much effort it required of them to think about accommodations for ELs through the whole lesson, including each E phase within the teaching procedure. One of PSTs was even

wondering if these proposed accommodations throughout the whole lesson might hinder the rest of the class in learning science.

Discussion

This study provided an in-depth examination of elementary PSTs' understanding of the role of literacy in science teaching and learning of all students, especially ELs, through planning an inquiry-based science lesson. Our findings indicate that elementary PSTs benefited overall from the lesson planning process within this situated disciplinary-literacy integrated science methods course. Major findings are summarized below with discussion based on the previous literature.

One important finding was that in planning their science lessons, PSTs were able to provide at least one literacy strategy within each phase through a 5E instructional model to help all students learn science. Of the different science-specific literacy strategies PSTs included in their science lesson plans, using a CER framework to support students' constructing their scientific explanations were the most common. This is an important finding because constructing scientific explanations is considered a central component of science inquiry (Osborne, 2000) and one of eight practices of science in NGSS (NGSS Lead States, 2013). In addition, recent reform efforts in both science and literacy (NGA & CCSSO, 2010; NGSS, 2013) advocate for helping students develop scientific explanations. This finding is also consistent with the findings in other research (Stoddart et al., 2013), which indicated that it is helpful to integrate literacy in science methods course to support PSTs' teaching practice.

Another important finding is that PSTs also used specific literacy strategies to provide instructional accommodations to engage ELs in different science practices. Instead of only

providing some general “relying on others” strategies (Kahn, Pgman, & Ottley, 2017) PSTs identified some science-specific strategies in their lesson plans which that are especially helpful for ELs who can experience difficulties in communicating their scientific ideas (Fang, 2004; Schleppegrell & Paliscar, 2013). For examples, the CER framework, graphic organizers, and sentence frames were used to support ELs in constructing scientific explanations, carrying out investigations, analyzing and interpreting data, and obtaining and evaluating information. This finding enriches research in preparing PSTs working with ELs in science teacher education programs and provides some evidence compared to previous studies (e.g., Kahn, Pgman, & Ottley, 2017). More follow-up research is needed to identify what and how the interventions in the science methods course contributed to PSTs’ learning to planning. Due to the study’s research design and related research questions, the researchers cannot explain if the literacy strategies PSTs incorporated in their lesson plans to scaffold students’ ability to construct and communicate scientific explanations was due to the fact that those strategies were taught and modeled in the disciplinary-literacy integration in this situated science methods course. The study’s findings show potential for future research on the models for integrating literacy in science instruction at the preservice education level (DiCerbo, Anstrom, Baker, & Rivera, 2014).

A third important finding of the study identified challenges PSTs faced when learning to use literacy as a tool to support students’ science learning. The literacy strategies they provided in their lesson plans and reflected upon in their written reflections indicted that PSTs need more knowledge in how to (a) engage students during a real aloud time; (b) teach specific strategies for learning science vocabulary; (c) support student science talk; and, (d) guide science writing. This is important to note because research has highlighted the critical role of classroom

discussion in supporting students' conceptual knowledge building in science (Chen, Hand, & Norton-Meier, 2017; Chin, 2007). In order to effectively encourage scientific discussion in the classroom, PSTs will have to learn how to use questioning techniques and discourse moves to scaffold students' scientific sense-making and reasoning abilities. This finding provided empirical evidence to identify the areas teacher educators, especially science teacher educators, need to continue to work on through university courses. More research is needed to explore what adjustments need to be made in science methods courses to provide more appropriate interventions to help PSTs learn and apply literacy strategies in a science teaching and learning context.

A fourth important finding of the study identifies some of the specific challenges PSTs' face when learning to support ELs in science classrooms and successfully adapting the knowledge base acquired from previous courses to science teaching (Jazen, 2008). Even though some specific literacy strategies were being used to support ELs students learning, most still fell short of providing specific and differentiated strategies for ELs with varied language proficiencies and were simply derived from the PSTs' previous TESOL training. For examples, in PSTs' lesson plans, it was not clear how they would plan to use of less complex questions, starting from the "Engagement" phase and how native speakers can help different level of ELs learn across the whole lesson. More information is needed to address what specific literacy strategies can be used to conduct vocabulary instruction besides providing a word wall. This finding is consistent with a reflection from a middle school science methods course instructor which also indicated difficulties in incorporating TESOL content into science methods course (Bautista, 2014). This finding also echoes the obstacles that Dong (2004) identified for PSTs to

help ELs make connections with their learning. One reason could be the lack of cohesion and collaboration within teacher preparation programs as other studies (Bunch, 2013; Kahn, Pgman, & Ottley, 2017) have concluded. Since a major barrier to science learning is the academic language of science, especially for ELs (Fang, 2004; Lemke, 1990; Wellington & Osborne, 2001), more research is needed to examine how general TESOL instructional strategies can be applied in science teaching context and how science teacher educator can collaborate with literacy and TESOL experts to prepare PSTs to better serve ELs.

Applications

Case study designs allow for limited generalizations because of the limited sample size and bounded context to which the study is connected (Creswell, 2013). This study was conducted using a purposive and convenience sample at a large, Metropolitan University located in the Southeastern United States. Therefore, different preservice student populations may be different and unaccounted for in this study. Additionally, the limited sample size, the length of the study, the use of self-reported data, and researcher biases pose related methodological limitations that carry implications for the potential design of science methods courses through interdisciplinary collaborations (Cervetti, Kulikowich, & Bravo, 2015).

In order to better prepare elementary PSTs to teach science and meet the need of all students, including ELs, it is necessary to reform science methods courses through collaboration between science teacher educators, and experts in literacy and TESOL. First, to address challenges identified in PSTs science lesson planning and reflection, more research-based resources and information, such as specific strategies of teaching science vocabulary, facilitating science talk and writing, and differentiating strategies for supporting different level ELs need to be integrated into the curriculum of science methods courses. Second, a disciplinary literacy framework needs to be further integrated into the specific curriculum of science methods courses to truly help PSTs understand the development of science and literacy knowledge and skills in tandem, instead of viewing literacy only as a tool or even an instructional add-on to support students' science learning. Third, reflections of lesson planning could be more meaningful if PSTs are provided opportunities to critique their lesson plans rather than just simply reporting what challenges they perceived related to using literacies and instructional accommodations for

ELs. Fourth, instructors of science methods courses need professional development through collaborating with experts outside of science education in order to provide explicit connections between science methods courses and other general methods courses.

Follow up research is also needed to explore and examine how to explicitly connect university courses to actual teaching practices in classrooms (Jazen, 2008). Beside science methods courses, it is necessary to track PSTs experiences of internships in the classroom, and even their first year of teaching in order to investigate whether and how they apply the knowledge they gained through university courses to real teaching contexts, what supports they need, and determine if future students benefit from the PSTs in terms of science learning.

References

Anstrom, K., DiCerbo, P., Butler, F., Katz, A., Millet, J., & Rivera, C. (2010). A review of the literature on academic English: Implications for K-12 English language learners. Arlington, VA: The George Washington University Center for Equity and Excellence in Education.

Ballantyne, K.G., Sanderman, A.R., & Levy, J. (2008). Educating English language learners: Building teacher capacity. Washington, DC: National Clearinghouse for English Language Acquisition. Retrieved from http://www.ncela.gwu.edu/practice/mainstream_teachers.htm.

Beck, I. L, McKeown, M. G, & Kucan, L. (2013). Bringing words to life: Robust vocabulary instruction (2nd Edition). New York, NY: Guilford Press.

Bravo, M. A., Solís, J. L., Mosqueda, E., Collett, J. M., & Mckinney De Royston, J. M. (2011, April). Integrating science and diversity education: Examining novice teacher practices and impact on student writing achievement. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Bresser, R. and Fargason, S. (2013). Scientists: inquiry-based teaching in diverse classrooms, grades 3-5. Portland, ME: Stenhouse Publishers.

Brown, M. W. (2009). The teacher-tool relationship: Theorizing the design and use of curriculum materials. In J. T. Remillard, B. A. Herbel-Eisenmann, & G. M. Lloyd (Eds.), Mathematics teachers at work: Connecting curriculum materials and classroom instruction (pp. 17–36). New York: Routledge.

Bruna, K. R., Vann, R., & Escudero, M. P. (2007). What's language got to do with it?: A case study of academic language instruction in a high school "English Learner Science" class. *Journal of English for Academic Purposes*, 6(1), 36-54.

Bunch, G. C. (2013). Pedagogical language knowledge: Preparing mainstream teachers for English learners in the new standards era. *Review of Research in Education, 37*(1), 298-341.

Buxton, C., Allexsaht-Snider, M., Aghasaleh, R., Kayumova, S., Kim, S., Choi, Y., & Bybee, R. W., & Fuchs, B. (2006). Preparing the 21st century workforce: A new reform in science and technology education. *Journal of Research in Science Teaching, 43*(4), 349-352.

Calderón, M., August, D., Slavin, R., Cheung, A., Durán, D., & Madden, N. (2005). Bringing words to life in classrooms with English language learners. In Hiebert, A & M. Kamil (eds.) Research and development on vocabulary. Nahwah, NJ: Lawrence Erlbaum.

Cerbin, W., & Kopp, B. (2006). Lesson study as a model for building pedagogical knowledge and improving teaching. *International Journal of Teaching and Learning in Higher Education, 18*(3), 250-257.

Cervetti, G. N., Kulikowich, J. M., & Bravo, M. a. (2015). The effects of educative curriculum materials on teachers' Use of instructional strategies for English language learners in science and on student learning. *Contemporary Educational Psychology, 40*(1), 86–98.

Choy, D., Wong, A. F., Lim, K. M. & Chong, S. (2013). Beginning teachers' perceptions of their pedagogical knowledge and skills in teaching: A three-year study. *Australian Journal of Teacher Education, 38*(5), 68–79.

Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. In M. C. Wittrock (Ed.), Handbook of research on teaching (pp. 255e295). New York: Macmillan.

Clark, C.M. & Dunn, S. (1991). Second-generation research on teachers' planning, intentions, and routines. In H. Waxman & H. Walberg (Eds.), Effective teaching: Current research (pp. 183-201), Berkeley, CA: McCutchan Publishing Corporation.

Cohen A. (2014). Potential benefits of bilingual constructed responses science assessments for understanding bilingual learners' emergent use of language of scientific investigation practices. *Double Helix, 2*(1), 1–21.

Creswell, J. W. (1998). Qualitative inquiry and research design: Choosing among five tradition. Thousand Oaks, CA: Sage.

Creswell, J. W. (2013). Qualitative inquiry and research design choosing among five traditions (3rd ed.). Thousand Oaks, CA: Sage.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching, 42*(3), 337–357. doi:10.1002/tea.20053

Davis, E. A. (2006). Preservice elementary teachers' critique of instructional materials for science. *Science Education, 90*(2), 348–375.

DiCerbo, P. a., Anstrom, K. a., Baker, L. L., & Rivera, C. (2014). A review of the literature on teaching academic English to English language learners. *Review of Educational Research, 84*(3), 446–482.

Driver, R., (1989). The construction of scientific knowledge in school Classroom. In R.Millar (Ed.), Doing science: Images of science in science education (pp. 8-105). New York,NY: Falmer Press.

Dong, Y. R. (2004). Preparing secondary subject area teachers to teach linguistically and culturally diverse students. *The Clearing House, 77*(5), 202-206.

Drake, C., Land, T. J., & Tyminski, A. M. (2014). Using educative curriculum materials to support the development of prospective teachers' knowledge. *Educational Researcher, 43*, 154-162.

Faggella-Luby, M., Griffith, R. R., Silva, C., & Weinburgh, M. (2016). Assessing ELs' reading comprehension and science understandings using retellings. *Electronic Journal of Science Education, 20*(3). Retrieved from ejse.southomeworkestern.edu

Fang, Z. (2004). Scientific literacy: A systemic functional linguistics perspective. *Science Education, 89*(2), 335–347. doi:10.1002/sce.20050

Fang, Z., & Wei, Y. (2010). Improving middle school students' science literacy through reading infusion. *The Journal of Educational Research, 103*, 262–273.

Forbes, C. T., & Davis, E. A. (2010). Curriculum design for inquiry: Preservice elementary teachers' mobilization and adaptation of science curriculum materials. *Journal of Research in Science Teaching, 47*(7), 820-839.

Gee, J. P. (1996). Social linguistics and literacies: Ideology in Discourses (2nd ed.) London, UK: Taylor & Francis.

Gee, J. P. (2004). Language in the science classroom: Academic social languages as the heart of school-based literacy. In E. W. Saul (Ed.), Crossing borders in literacy and science instruction (pp. 13–32). Arlington, VA: NSTA Press.

Goldschmidt, P., & Jung, H. (2011). Evaluation of Seeds of Science/Roots of Reading: Effective tools for developing literacy through science in the early grades—Unit on planets and moons (CRESST Report 803). Los Angeles, CA: University of California, National Center for Research on Evaluation, Standards, and Student Testing (CRESST).

Guthrie, J. T., & Wigfield, A. (2000). Engagement and motivation in reading. In M. L. Kamil, P. B. Mosenthal, P. D. Pearson, & R. Barr (Eds.), Reading research handbook (Vol. 3, pp. 403–424). Mahwah, NJ: Erlbaum.

Guthrie, J. T., Wigfield, A., Barbosa, P., Perencevich, K. C., Taboada, A., Davis, M. H., Scafiddi, N. T., & Tonks, S. (2004). Increasing reading comprehension and engagement through Concept-Oriented Reading Instruction. *Journal of Educational Psychology, 96*, 403–423.

Guthrie, J. T., Hoa, L. W., Wigfield, A., Tonks, S. M., Humenick, N. M., & Littles, E. (2007). Reading motivation and reading comprehension growth in the later elementary years. *Contemporary Educational Psychology*, *32*, 282 - 313.

Guthrie, J. T., Klauda, S. L., & Ho., A. N. (2013). Modeling the relationships among reading instruction, motivation, engagement, and achievement for adolescents. *Reading Research Quarterly, 48*, 9-26.

Hammond, J., & Gibbons, P. (2005). Putting scaffolding to work: The contribution of scaffolding in articulating ESL education. *Prospect, 20*(1), 6-30.

Howes, E. V., Lim, M., & Campos, J. (2009). Journeys into inquiry-based elementary science: Literacy practices, questioning, and empirical study. *Science Education*, *93*(2), 189–217.

Janzen, J. (2008). Teaching English language learners in the content areas. *Review of Educational Research, 78*(4), 1010–1038.

Johnson, A. P. (2000). It's time for Madeline Hunter to go: A new look at lesson plan design. *Action in Teacher Education, 22(*1), 72–78.

Kahn, S., Pigman, R., & Ottley, J. (2017). A Tale of two courses: Exploring teacher candidates' translation of science and special education methods instruction into inclusive science practices. *Journal of Science Education for Students with Disabilities, 20*(1), 50-68.
Krajcik, J. S., & Sutherland, L. (2010). Supporting students in developing literacy in science. *Science, 328*(5977), 456–459.
Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge: Cambridge University Press.
Lee, O. (2005). Science education with English Language learners: Synthesis and research agenda. *Review of Educational Research, 75(*4), 491–530.
Lee, J. M. (2007). Lesson planning in the classroom. *Techniques, 82*(8). Retrieved from https://www.questia.com/magazine/1G1-171294893/lesson-planning-in-the-classroom
Lee, O. (2018). English language proficiency standards aligned with content standards. Educational Researcher. Available: http://journals.sagepub.com/doi/abs/10.3102/0013189X18763775 [June 2018].
Lee, O., & Fradd, S. H. (1998). Science for all, including students from non-English-language backgrounds. *Educational Researcher, 27*(4), 12–21.
Lee, O., Quinn, H., & Valdés, G. (2013). Science and language for English language learners in relation to Next Generation Science Standards and with implications for common core state standards for English language arts and mathematics. *Educational Researcher, 42*(4), 223–233.
Lee, O., Valdés, G., and Llosa, L. (2015–2019). Development of language-focused three-dimensional science instructional materials to support English language learners in fifth grade. Alexandria, VA: National Science Foundation, Discovery Research K–12.
Lemke, J. L. (1990). Talking science: Language, learning and values. Norwood, NJ: Ablex.
Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching, 38*(3), 296-316.
McKeown, M.G., Beck, I.L., & Blake, R.G.K. (2009). Rethinking reading comprehension instruction: A comparison of instruction for strategies and content approaches. *Reading Research Quarterly, 44*(3), 218-252.
Moje, E. B. (2007). Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. Review of Research in Education, 31(1), 1–44.
Moje, E. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent & Adult Literacy, 52*(2), 96–107.
Moje, E. (2010, March). Disciplinary literacy: Why it matters and what we should do about it. Paper presented at the National Writing Project Conference, New Orleans, LA. Retrieved from http://www.nwp.org/cs/public/print/resource/3121
National Academies of Sciences, Engineering, and Medicine. (2018). English learners in STEM subjects: Transforming classrooms, schools, and lives. Washington, DC: The National Academies Press.
National Center for Education Statistics. (2010). Science 2009: National assessment of education progress at grade 12. Retrieved from http://www.nationsreportcard.gov/science_2009/g12_nat.aspx?tab_id=tab2&subtab_id=Tab_6#tabsContainer

National Center for Education Statistics. (2012). Science 2011: National assessment of education progress at grade 8. Retrieved from http://nces.ed.gov/nationsreportcard/pdf/main2011/2012465.pdf

National Research Council. (2007). Taking science to school: Learning and teaching science in grades K-8. Washington, DC: The National Academies Press. https://doi.org/10.17226/11625.

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

National Research Council. (2014). Literacy for science: Exploring the intersection of the Next Generation Science Standards and Common Core for ELA standards, A Workshop summary, H. Rhodes and M.A. Feder, Rapporteurs. Steering Committee on Exploring the Overlap between "Literacy in Science" and the Practice of Obtaining, Evaluating, and Communicating Information. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). Next generation science standards: For states, by states. Washington, DC: The National Academies Press.

Nilsson, P. (2009). From lesson plan to new comprehension: Exploring student teachers' pedagogical reasoning in learning about teaching. *European Journal of Teacher Education 32*(3), 239–258.

Nutta, J. W., Strebel, C., Mokhtari, K., Mihai, F. M., & Crevecoeur-Bryant, E. (2014). Educating English learners: What every classroom teacher needs to know. Cambridge, MA: Harvard Education Press.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328*(5977), 463–466.

Quinn, H., Lee, O., and Valdés, G. (2012). Language demands and opportunities in relation to Next Generation Science Standards for English language learners: What teachers need to know. Stanford, CA: Stanford University, Understanding Language. Retrieved from http://ell.stanford.edu/sites/default/files/pdf/academic-papers/03-Quinn%20Lee%20Valdes%20Language%20and%20Opportunities%20in%20Science%20FINAL.pdf

Palincsar, A. S. & Brown, A. (1984). Reciprocal teaching of comprehension-fostering and comprehension monitoring activities. *Cognition and Instruction, 1*(2), 117-175.

Pressley, M., Wood, E., Woloshyn, V. E., Martin, V., King, A., & Menke, D. (1992). Encouraging mindful use of prior knowledge: Attempting to construct explanatory answers facilitates learning. *Educational Psychologist, 27*(1), 91–109.

Richards, J. C., & Rodgers, T. S. (2014). Approaches and methods in language teaching. Cambridge, UK: Cambridge University Press.

Romance, N. R., & Vitale, M. R. (1992). A curriculum strategy that expands time for in- depth elementary science instruction by using science-based reading strategies: Effects of a year-long study in grade four. *Journal of Research in Science Teaching, 29*(6), 545-554.

Romance, N. R., & Vitale, M. R. (2001). Evolution of a model for teaching in-depth science in elementary schools: Longitudinal findings and research implications. *International Journal of Science Education, 23*, 373-404.

Romance, N. R., & Vitale, M. R. (2011a). A research-based instructional model for integrating meaningful learning in elementary science and reading comprehension: Implications for policy and practice. In N. Stein & S. Raudenbush (Eds.), Developmental cognitive science goes to school (pp. 127-148). New York, NY: Routledge.

Romance, N. R., & Vitale, M. R. (2011b). Interdisciplinary perspectives for linking science and literacy: Implications from multi-year studies across grades K-5. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA.

Sahin-Taskin, C. (2017). Exploring preservcie teachers' perceptions of lesson planning in primary education. *Journal of Education and Practice, 8*(12), 57-63. Retrieved from https://files.eric.ed.gov/fulltext/EJ1140566.pdf

Schleppegrell, M. J. (2004). The Language of schooling: A functional linguistics perspective. New York, NY: Routledge.

Schleppegrell, M. J. (2007). The linguistic challenges of mathematics teaching and learning: A research review. *Reading & Writing Quarterly, 23*(2), 139–159.

Schleppegrell, M. J., & Palincsar, A. S. (2013). What do teachers need to know about the language of science text? Presentation at the Exploring the Overlap between "Literacy in Science" and the Practice of Obtaining, Evaluating, and Communicating Information: A Workshop, December 9-10, National Research Council, Washington, DC. Retrieved from http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_086553.pdf

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review, 78*, 40-59.

Shanahan, T., & Shanahan, C. (2012). What is disciplinary literacy and why does it matter?. *Topics In Language Disorders, 32*(1), 7-18.

Shanahan, C., & Shanahan, T. (2014). Does disciplinary literacy have a place in elementary school? *The Reading Teacher, 67*(8), 636–639.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 4-14.

Siegel, M. A. (2014). Developing preservice teachers' expertise in equitable assessment for English learners. *Journal of Science Teacher Education, 25*(3), 289-308.

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational Psychologist, 50*(1), 1–13.

Solís, J. L., Bravo, M. A., Mosqueda, E., Collett, J. M., & Mckinney De Royston, J. M. (2011, April). Situating responsive science pedagogy with preservice teachers. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Stoddart, T., Bravo, M., Mosqueda, E., & Solis, J. (2013). Restructuring preservice teacher education to respond to increasing student diversity. *Research in Higher Education Journal*, 1-19.

Stoddart, T., Bravo, M., Solis, J., Mosqueda, E., & Rodriguez, A. (2011, April). Effective science teaching for English language learners (ESTELL): Measuring pre-service teacher practices. Paper presented at the annual meeting of the American Educational Research

Association, New Orleans, LA. Retrieved from http://education.ucsc.edu/estell/Stoddart_et_al_2011_AERA.pdf
Stoddart, T., Pinal, A., Latzke, M., & Canaday, D. (2002). Integrating inquiry science and language development for English language learners. *Journal of Research in ScienceTeaching, 39*, 664–687.
Sutherland, L. M. (2008). Reading in science: Developing high-quality student text and supporting effective teacher enactment. *Elementary School Journal, 109*, 162.
Symons, C. (2017). Supporting emergent bilinguals' argumentation: Evaluating evidence in informational science texts. *Linguistics and Education, 38*, 79–91.
Tellis, W. M. (1997). Application of a case study methodology. *The qualitative report, 3*(3), 1-19.
Turkan, S., de Oliveira, L. C., Le, O., & Phelps, G. (2014). Proposing a knowledge base for teaching academic content to English language learners: Disciplinary linguistic knowledge. *Teachers College Record, 116*(3), 1-30.
Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.
Wang, J., & Herman, J. (2005). Evaluation of Seeds of Science/Roots of Reading project: Shoreline science and terrarium investigations. Los Angeles: National Center for Research on Evaluation, Standards, & Student Testing.
Wenger, E. (1998). Communities of practice: Learning, meaning, and identity. New York, NY, US: Cambridge University Press.
Whitton, D., Sinclair, C., Barker, K., Nanlohy, P. & Nosworthy, M. (2004). Learning for teaching: Teaching for learning. Southbank, Victoria: Thomson Social Science Press.
Visone, J. D. (2010). Science or reading: What is being measured by standardized tests? *American Secondary Education, 39*(1), 95–112.
Yin, R. K. (2003). Case study research: Designs and methods. Thousand Oaks, CA: Sage Publications.
Yore, L. D., Pimm, D., & Tuan, H. (2007). The literacy component of mathematical and scientific literacy. *International Journal of Science and Mathematics Education, 5*, 559–589.
Zygouris-Coe, V. (2012). Disciplinary literacy and the common core state standards. *Topics in Language Disorders*, *32*(1), 35–50.
Zygouris-Coe, V. (2015). *Teaching discipline-specific literacies in grades 6-12*. New York, NY: Routledge.

APPENDIX B
UCF INSTITUTIONAL REVIEW BOARD APPROVAL

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Determination of Exempt Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Vassiliki I. Zygouris-Coe** and Co-PIs: **Jonathan L. Hall, Rebeca A. Grysko, Su Gao**

Date: **May 23, 2018**

Dear Researcher:

On 05/23/2018, the IRB reviewed the following activity as human participant research that is exempt from regulation:

Type of Review:	Exempt Determination
Project Title:	Learning to teach science to all students: Integrating literacy in science teaching through an elementary science methods course
Investigator:	Vassiliki I. Zygouris-Coe
IRB Number:	SBE-18-13880
Funding Agency:	The Brinson Foundation
Grant Title:	**" Ethics in Education"**
Research ID:	N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

This letter is signed by:

Signature applied by Gillian Morien on 05/23/2018 04:09:18 PM EDT

Designated Reviewer

APPENDIX C
EXPLANATION OF RESEARCH

EXPLANATION OF RESEARCH

Title of Project: Learning to teach science to all students: Integrating literacy in science teaching through an elementary science methods course

Principal Investigator: Rebeca Grysko, M.Ed.

Faculty Supervisor: Dr. Zygouris-Coe

You are being invited to take part in a research study because the course you are enrolled in is serving as either a treatment or control group. Your participation is entirely voluntary.

The purpose of this study is to examine elementary preservice teachers' knowledge and practices for teaching science as argument. Findings will hopefully contribute to the understanding of how teacher educators can help preservice teachers become effective teachers of science.

The duration of this study is one semester. Participants will be asked to complete two in-class questionnaires during the first few weeks of the course (pre-test) and once again at the end of the semester (post-test). Participants will also be asked to complete an in-class written scientific explanation task once during the first few weeks of the course (pre-test) and once again at the end of the semester (post-test). The remainder of activities are taking place regardless of research, and the researcher is simply asking for access to these assignments on Webcourses. If you agree to participate, a code will be used to identify you as a research participant and ensure your anonymity in this study. **Your decision to participate in this study is voluntary and will have no impact on your course grade.** You must be 18 years of age or older to take part in this research study.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, contact Rebeca Grysko, Graduate Student, Reading Education Program, College of Community Innovation and Education, rebeca.grysko@ucf.edu or Dr. Vicky Zygouris-Coe, Faculty Supervisor, College of Community Innovation and Educaiton, vzygouri@ucf.edu .

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901.

APPENDIX D
TSAF PROTOCOLS

Appendix D1: Phase 1 Protocol

Materials	Cue	Do	Review
PPT displayed on projector screen CER Framework handout (1 for each PST) Base rubric (1 for each PST) Packet of sample scientific explanations (1 for each pair of PSTs) Highlighters (three for each pair of PSTs)	Remind PSTs that they previously discussed the importance of providing inquiry-based science instruction. Tell them that today's class session will focus on one essential practice of scientific inquiry: constructing scientific explanations. Explain that first you will provide a PPT overview of the importance of engaging elementary students in scientific explanation. Explain that after this presentation, you will introduce a framework that can help them plan effective science instruction that includes opportunities for students to engage in scientific explanation. Tell them that they will also learn to critique the quality and complexity of scientific	**1. Provide PPT overview:** • Discuss importance/benefits of engaging elementary students in scientific explanation • Discuss connections between literacy and science -introduce the TSAF and provide examples of how each of the three components can be employed during classroom instruction **2. Introduce CER Framework:** • Explain that the CER Framework is designed to help elementary students construct scientific explanations. • Distribute handout with definitions and examples of each component. • Tell PSTs that they can refer to this handout when constructing their own scientific explanations throughout the semester. **3. Distribute and provide an overview of scientific explanation base rubric:** • Explain that rubric is based on the CER Framework and can be used to assess the quality of a scientific explanation.	***"Today, we discussed the importance of engaging elementary students in scientific explanation. We also learned about a Framework that can be used to plan effective science instruction that supports students in constructing scientific explanations. What are the three core components of the TSAF?" (Call on PSTs to review each component)."*** ***"You were also introduced to a framework designed to help elementary students construct scientific explanations. What is the name of that framework? What are the three components of the CER framework?" (Call***

Materials	Cue	Do	Review
	explanations using a rubric.	• Model how to use the rubric to assess a sample explanation. **4. Engage PSTs in the process of critiquing three sample explanations using the base rubric.** • -Distribute a packet of sample explanations to each pair of PSTs. • Provide each pair of students with three different color highlighters (i.e., yellow, blue, and green.) • Ask PSTs to use their highlighters to identify the claim, evidence, and reasoning in each explanation. • After pairs have highlighted the claim, evidence, and reasoning in each explanation, ask that they use the base rubric to assign a total score to each explanation. • Afterwards, lead a whole-class discussion to emphasize how the samples ranged in complexity, from simple (claim + 1 piece of evidence) to complex (claim + multiple pieces of evidence + reasoning) • ***<u>Ask:</u> Which scientific explanation was the least complex? Why? Which scientific explanation was the most complex? Why?***	***on PSTs to review each component (i.e., claim, evidence, and reasoning).*** Conclude the session by **reminding PSTs that supporting students in constructing scientific explanations is an essential aspect of effective science teaching.** For this reason, they will have opportunities to not practice constructing scientific explanations themselves throughout the semester but will practice planning a science lesson using the TSAF near the end of the semester.

Appendix D2: Phase 2 Protocol

Materials	Cue	Do	Review
See specific inquiry-based science lesson plan for complete materials list.	**Introduce the topic/bridge from previous class session.** **Access prior knowledge.** **Share specific learning goal(s)/objectives as listed in the lesson plan.**	**Introduce the testable question.** **Engage PSTs in reading about the phenomena under study.** See lesson plan for name of scientific text as well as before, during, and after reading activities. **Introduce, model, and engage PSTs in an academic vocabulary building strategy as described in the lesson plan.** **Engage PSTs firsthand with the phenomena under study.** • Have PSTs record their observations and data in their science notebooks. • As you are circulating, be sure to pose questions that encourage PSTs to notice patterns in their data (i.e., *What claim can you make based on the evidence?)* **Review how scientists make explanations. Remind PSTs that a scientific explanation has three important components: claim, evidence, and reasoning**. • **Review *claim*.** Ask, “What is a claim?” [A scientist’s best idea for an answer to a question.] Say, “A claim is based on evidence.” • **Review *evidence***. Remind PSTs that the clues a scientist finds during an investigation is evidence. Evidence can help a scientist make a claim or decide if a claim needs to be changed. • **Review *reasoning*.** Explain that the reasoning explains how the evidence supports the claim. **Engage PSTs in writing a scientific explanation.**	**Guide PSTs in unpacking the lesson from the perspective of the teacher (using the three features of the TSAF as a heuristic).** Say, “Now that you had an opportunity to engage in the lesson as learners, you will use the TSAF to unpack the lesson plan from the perspective of the teacher.” Provide each pair of PSTs with a hard copy of the Oobleck lesson plan and the lesson plan rubric. Ask PSTs to evaluate the lesson using the provided rubric. **Ask PSTs to provide examples of how the lesson supports *all* students in constructing, communicating, and debating evidence-based claims (e.g., lesson-specific supports for ELLs).**

Materials	Cue	Do	Review
		• Encourage PSTs to use information from the text as well as their observations from the investigation as evidence to support their claim • Provide writing scaffolds (see complete lesson plan) and post visual representation of CER Framework **Facilitate whole-class science talk.** • Use specific teacher talk moves and questioning techniques to promote peer interactions and scaffold PSTs' communication of scientific ideas and evidence in ways that reflect scientific discourse. • Examples of teacher talk moves: o *What claim can you make based on the evidence?* o *Do you agree or disagree and why?* o *Would someone like to add on to that?* o *Why do you think that?* o *What evidence helped you to arrive at that answer* **Make connections to the big idea/science concept as described in the lesson plan.**	Conclude the session by **reminding PSTs that supporting students in constructing scientific explanations is an essential aspect of effective science teaching.** For this reason, they will have further opportunities to practice constructing scientific explanations throughout the semester and will also practice planning a science lesson using the TSAF near the end of the semester.

Appendix D3: Phase 3 Protocol

Materials	Cue	Do	Review
Lesson Plan Rubric Planning Questions Related to the TSAF Group Teaching Observation Sheet (to be completed by PSTs during each group's lesson plan presentation)	**Share the rationale for the lesson plan assignment.** Explain that the purpose is to provide PSTs an opportunity to apply their developing understandings of the TSAF to plan effective science instruction for elementary students. **Distribute and discuss planning questions related to the TSAF.** **Distribute and discuss lesson plan rubric.**	**1. Provide in-class time for PSTs to work on their lesson plans with their group members (Week 12 of the course).** • Provide support during the planning process. • Refer to the planning questions to help PSTs negotiate the content and sequencing of their lessons. **2. Have PSTs submit an initial draft of their group lesson plan (Week 13 of the course).** • During class time, engage PSTs in the process of reviewing other groups' lesson plans (using the TSAF as a heuristic) and to offer suggestions for improvement. • Encourage PSTs to use their peers' suggestions to revise their lessons. 3. **Schedule time for each group to present/microteach their final inquiry-based science lesson (Weeks 14-15 of the course).** • As groups are presenting, ask that PSTs complete a *Group Teaching Observation Sheet* for each of the lessons presented.	**Have PSTs complete and submit a self-reflection of their own lesson plans.** PSTs will reflect on how their lesson supports *all* students in constructing, communicating, and debating evidence-based explanations in science. PSTs will also reflect on the role of language and literacy in science. **Remind PSTs that supporting students in constructing scientific explanations is an essential aspect of effective science teaching.**

APPENDIX E
SAMPLE EXPLANATIONS

Examine the following data table:

	Density	Color	Mass	Melting Point
Liquid 1	0.93 g/cm^3	no color	38 g	-98 °C
Liquid 2	0.79 g/cm^3	no color	38 g	26 °C
Liquid 3	13.6 g/cm^3	silver	21 g	-39 °C
Liquid 4	0.93 g/cm^3	no color	16 g	-98 °C

Write a **scientific explanation** that states whether any of the liquids are the same substance.

Write a **scientific explanation** that states whether any of the liquids are the same substance. Liquid 1 and 4 are the same substance. They both have a density of .93g/cm^3, have no color, and start to melt at -98°C. For substances to be the same, they must have the same properties. Since Liquids 1 and 4 have the same properties, they are the same substance. The other 2 Liquids are differents substances because they have different properties.

Write a **scientific explanation** that states whether any of the liquids are the same substance.

I believe that liquid 1 and liquid 4 are the same substance. There densities and melting point are the same. The mass is different but that only means that the portion or part is smaller than the other. Like butter, the mass doesn't have to be the same but the melting point and density are the same. Therefore, I believe that liquid 1 and 4 are the same substance.

Write a **scientific explanation** that states whether any of the liquids are the same substance.

Two of these substance's are the same becouse Liquid 1 and liquid 4 have the same density and melting point. But not the ~~mass~~, but their could be more water in Liquid 1 than Liquid 4 or a biger container.

Write a **scientific explanation** that states whether any of the liquids are the same substance.

None of the liquids are the same. Some of the data is similar but the main properties that help determine if their the same don't match. The melting points are all different. Liquid #1 and #4 seem similar but have different mass measurments.

Write a **scientific explanation** that states whether any of the liquids are the same substance.

Liquids 1 and 4 are the same substance. A substance is something that is made of the same atoms and molecules throughout. Mass is not a property because the mass can change. Liquids' 1 and 4 have the same properties. So they are the same substance. Therefore, Liquids 1 and 4 are the same because their propertits are the same.

APPENDIX F
LESSON PLAN RUBRIC

	Target (2 points)	Developing (1 point)	Unacceptable (0 point)	Evidence
Format	Follow the template of inquiry-based lesson plan including all components.	One components is missing.	Two or more components are missing.	
Teaching Standards	Three different kinds of science standards (content standards, Nature of Science standards, and TESOL standards) in the Next Generation Sunshine State Standards (NGSSS) are identified.	One kind of standards is missing.	Two kinds of standards are missing.	
Content Objectives	Three components (performance, condition, and criteria) are identified in each content objective.	One component is missing.	Two or more components are missing.	
Engage	A clear, complete description of the engage component is included. Engage elicits students' prior knowledge (based upon the objectives) and incorporates engaging scientific text to accomplish all of the following: 1. Raises student interest/motivation to learn 2. Build student background knowledge 3. Provides opportunities for student discussion/questions 4. Leads into the exploration	The lesson includes an incomplete description of the engage component. The engage component accomplishes only one or two of the following: 1. Raises student interest/motivation to learn 2. Build student background knowledge 3. Provides opportunities for student discussion/questions 4. Leads into the exploration	Engage component is missing.	
Explore	A clear, complete description of the learning activities in the exploration phase is included. The exploration phase involves hands on/minds on activities that are student centered and provide opportunities for students to conduct science and engineering practices. Students do many of the following: make observations, collect data, hypothesize, predict, and discuss.	Lesson includes an incomplete description of the learning activities in the exploration phase. Some activities are not hands on/minds on and student centered. Students do one or two of the following: make observations, collect data, hypothesize, predict, and discuss.	Explore component is missing.	

	Target (2 points)	Developing (1 point)	Unacceptable (0 point)	Evidence
Explain	Clearly and completely describes how the teacher will provide opportunities and facilitate students to construct and communicate an evidence-based scientific explanation in reasoning publicly using the C-E-R Framework to illustrate the concept or skill.	Lesson fails to specify how the teacher will provide opportunities and facilitate students to construct and communicate an evidence-based scientific explanation using the C-E-R Framework to illustrate the concept or skill	Explain component is missing.	
Elaborate/Extend	Clearly and completely describes activities that will provide students with the opportunity to apply the newly acquired concepts and skills into new areas. The elaborate activities encourage students to find real life (every day) connections with the newly acquired concepts or skills.	Lesson includes an incomplete description of activities that will provide students with the opportunity to apply the newly acquired concepts and skills into new areas. Activities do not encourage students to apply scientific concepts to every day situations.	Elaborate/Extend component is missing.	
Evaluation	The lesson includes clear and complete descriptions of the assessments (formative and /or summative assessment) being used to measure student learning. The evaluation matches the Objectives of the lesson. The lesson includes a variety of forms/ approaches of assessment. The evaluation criteria are measurable.	Assessments are not varied OR fail to measure student achievement of each objective.	Evaluation component missing.	
Academic Vocabulary	Lesson incorporates at least one appropriate strategy to help students develop academic vocabulary in science (can be included into any of the above 5E phases).	Lesson incorporates at least one strategy to help students develop academic vocabulary in science, but strategy is not explicitly specified.	Lesson does not incorporate a strategy to help students develop academic vocabulary in science.	
ELL Accommodations/	Lesson includes appropriate accommodations/instructional supports to	Lesson only includes general accommodations/	Accommodations/	

	Target (2 points)	Developing (1 point)	Unacceptable (0 point)	Evidence
Instructional Supports	assist ELLs in developing scientific language and content knowledge within each E phase.	Instructional supports to assist ELLs in developing scientific language and content knowledge within each E phase.	Instructional supports for ELLs are missing within each E phase.	

APPENDIX G
OOBLECK LESSON PLAN

1. Rationale/Purpose:

Science Standards:

SC.4.P.8.1: Measure and compare objects and materials based on their physical properties including: mass, shape, volume, color, hardness, texture, odor, taste, attraction to magnets.

SC.5.P.8.1: Compare and contrast the basic properties of solids, liquids, and gases, such as mass, volume, color, texture, and temperature.

SC.4.N.1.4 : Attempt reasonable answers to scientific questions and cite evidence in support.

SC.4.N.1.7: Recognize and explain that scientists base their explanations on evidence.

SC.5.N.2.1: Recognize and explain that science is grounded in empirical observations that are testable; explanation must always be linked with evidence.

ELA Standards:

LAFS.4.RL.1.1: Refer to details and examples in a text when explaining what the text says explicitly and when drawing inferences from the text.

LAFS.4.SL.1.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade *4 topics and texts*, building on others' ideas and expressing their own clearly.

LAFS.K12.W.1.1: Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.

LAFS.4.W.1.2: Write informative/explanatory texts to examine a topic and convey ideas and information clearly.

English Language Development Standards:

ELD.K12.ELL.SC.1: English language learners communicate information, ideas and concepts necessary for academic success in the content area of Science.

Content Objectives:

1. Students will be able to classify Oobleck as a solid or liquid based on the physical properties of Oobleck (such as mass, shape, volume, hardness, texture) by collecting both textual evidence and evidence collected through a firsthand investigation.

2. Students will be able to construct a scientific explanation (orally and in writing) about the state of Oobleck using valid reasoning and relevant and sufficient evidence to support their claim.

2. Misconceptions:

"It is liquid because it takes the shape of the container."

"It is a liquid because you can pour it." (Troncale, 2016)

3. Detailed Procedures:

Engagement: Physical Properties of Matter

Ask students to suggest some ways they might classify different objects (i.e., shape, texture, color, size, and hardness). Present some sample items (such as a marker/pen/pencil, water, soda, oil, vinegar, coffee, or piece of fruit, sands in a bottle) and ask students how they would classify each one using this method. Students will record the name of the object they are observing and provide evidence that supports the property of matter for each of these objects.

Table 1: Property of Matter and Evidence Task

Solids	Evidence	**Liquids**	Evidence

Guided Discussion: Have students to share which items they classified as solids or liquids, and what evidence they recorded to support their classification. Explain that as they have discussed evidence they collected through their own observation, they can also collect different kinds of evidence from what other scientists have done.

Accommodations: Arrange beginning ELL students in small groups and pair them with non-ELL students. Provide specific objects, such as marker/pen/pencil, water, soda, tables, chairs, oil, vinegar, coffee, fruit, or rulers for the students in the classroom. Write down terms, such as color, smell, shape, size, sounds, state, texture, to help intermediate, and advanced ELLs students describe the physical properties of the objects. Provide graph organizers (Table 1).

Text-Based Inquiry

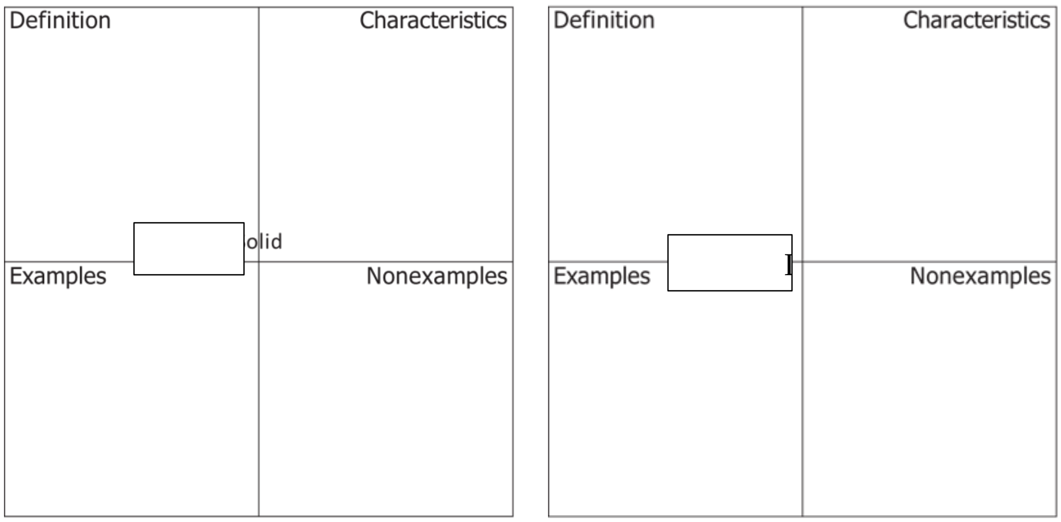
Students will read an informational article about the properties of matter. Students will compare and contrast a solid and a liquid. Students will use the information from the text to help them determine whether Oobleck is a solid or a liquid.

Place students into collaborative pairs and give each student a copy of the Newsela article, titled "Matter and Energy: What is matter?". While reading in pairs, students should underline any properties and examples of solids in RED and underline any properties and examples of liquids in GREEN.

Pose these questions to help students reflect upon the text: *What is matter? How are solids and liquids the same? How are solids and liquids different? What properties can we use to distinguish between a solid and a liquid?*

Contrasting between “Solid” and “Liquid”

Students will use their color-coded article to create and complete a Frayer Model for the vocabulary terms “solid” and “liquid”. Facilitate students to compare these two states of the matter. On their Frayer Model, students will circle the different characteristics between solids and liquids. (These are scientific principles that they can use later on to decide about the difference between them.)



Accommodations: ELL students and non-ELL students will work in pairs to read the article. Articles with images allow ELL students to visualize the concepts. The color-coding will focus students on key characteristics and examples of solids and liquids. Students will use the article to help them complete the Frayer Model graphic organizer. The complexity of the text can be reduced. The teacher can provide the properties and examples on paper for the students to cut and glue in the correct column of the graphic organizer.

Explore: Hands-on Oobleck

Hands-on Inquiry

Students will make their own Oobleck using a mixture of about 1 cup of cornstarch to 1/2 cup of water is a good starting point. They will have to tweak these amounts to get the ideal Oobleck texture.

Accommodations: Beginning ELL student will be grouped with non-ELL students and teacher should be available to demonstrate how to make Oobleck. A picture of the recipe will be shown through Power Point when students make their Oobleck for intermediate, and advanced ELLs.

Students will conduct 7 stretch tests and record their observations about how Oobleck responds (Buchanan, 2005) on Table 2.

1. Pour the Oobleck out of the cup onto a plate or pie pan.
2. Hit the puddle of Oobleck with your fist.
3. Pour a small amount of Oobleck onto the lab table.
4. Pull the Oobleck apart, quickly then slowly.
5. Roll the Oobleck into a ball.
6. Place a penny on a puddle of Oobleck.
7. Try to cut a piece of the Oobleck away.

Accommodations: Beginning ELL students will be grouped with non-ELL students during the tests, and they will be allowed to record the observations by drawing. Teacher should also make an effort to demonstrate each test for them. A handout as following with a chart including 7 tests and questions will be provided for intermediate, and advanced ELLs. They will be allowed to record the observations by drawing pictures.

Test	**Question** to consider…	**Verbal/Visual Description of Observation**
1. Pour the Oobleck out of the cup onto a plate or pie pan.	What does it do when it hits the plate?	
2. Hit the puddle of Oobleck with your fist.	What happens to the substance?	

3. Pour a small amount of Oobleck onto the lab table.	Does it stick?
4. Pull the Oobleck apart, quickly then slowly.	How does it behave?
5. Roll the Oobleck into a ball.	Does it bounce?
6. Place a penny on a puddle of Oobleck.	What happens to the penny?
7. Try to cut a piece of the Oobleck away.	What do you see?

Explain: Developing the Oobleck Explanation

Write the prompt, "Is "Oobleck" as solid or a liquid?" on the board and then read it aloud. Remind students that a scientific explanation has three important components: *claim, evidence,* and *reasoning*.

Review *claim*. Ask, "What is a claim?" [A scientist's best idea for an answer to a question.] Say, "A claim is based on evidence."

Review *evidence*. Remind students that the clues a scientist finds during an investigation is evidence. Evidence can help a scientist make a claim or decide if a claim needs to be changed.

Review *reasoning*. Explain that the reasoning incorporates a scientific principle and explains how the evidence supports the claim.

Have students construct a written explanation in their science notebooks. Encourage students to use their observations from the investigation as well as textual information as evidence to support their claim.

Accommodations: Writing scaffolds utilizing the claim, evidence, and reasoning framework will be provided to support students in constructing their scientific explanations. In addition to providing writing scaffolds, a visual representation will be displayed for students to refer to as a reminder of how to construct a scientific explanation. These supports are especially helpful for supporting ELLs.

Visual Representation:

Writing Scaffolds:

Claim: Write a sentence stating whether Oobleck is a solid or a liquid.
Oobleck is a _____ (solid or liquid).

Evidence: Provide scientific data to support your claim. The evidence should include the observations you made when conducting the tests.
Evidence 1: My evidence to support my claim is that the Oobleck ________________________.
Evidence 2: Also, the Oobleck ________________.
Reasoning: Write a statement of sentences that explains why your evidence supports your claim.
For the substance to be a liquid, it should________________.
For the substance to be a solid, it should______________.
Oobleck has the properties of a ______ (solid or liquid), so I conclude that it is a ______ (solid or liquid).

Discuss the students' explanations as a whole class.

Students will present their scientific explanation within a team which is composed of the peers who have the similar claims. Student will debate with the "opposing" team and critique the reasoning of others. Scaffold students' communication of scientific ideas and evidence in ways that reflect scientific discourse. Examples of teacher talk moves:

What claim can you make based on the evidence?
Do you agree or disagree and why?
Would someone like to add on to that?
Why do you think that? What evidence helped you to arrive at that answer?

Note: Some students may be especially sensitive to having their explanation evaluated. In order to avoid hurt feelings, talk about which explanation is "supported by more evidence" rather than which one is "better".

Accommodations: ELL students will be paired with non-ELL students to complete the CER sentence starters. Students may use their color-coded article, the Frayer Model graphic organizers, and the observations from the Oobleck tests to help them complete the CER sentence starters. Students may use evidence, examples, and pictures from these resources to help them present their explanation to their team.

Elaborate/Extend: Scientific Argumentation-Oobleck is a…

Ask students to specify what else they would like to know about this substance. Assist students in conducting further research about Oobleck's properties through the Internet and make connections to non-Newtonian fluids. The following video can be used to extend students' understanding of Oobleck (https://www.youtube.com/watch?v=-wiYtoG9kZE) and make connections to non-Newtonian fluids.

Accommodations: Teacher will provide extra time for beginning ELLs to ask questions individually. Several appropriate resources on internet will be provided for intermediate and advanced ELLs. The YouTube Video can be provided to preview independently prior to the lesson to create context for the activities of Oobleck for all level ELLs. Closed-captioning will be used for viewing the video.

Evaluation: Assessing Understanding of Oobleck's Properties

Students are formatively evaluated and assessed at the engage, explore, explain, and extension stages through classifying Oobleck as a solid or liquid based on its' physical properties and through constructing their scientific explanations and argumentation. The Oobleck CER-Assessment Rubric can be a specific tool to guide this aspect of evaluation process.

Oobleck CER-Assessment Rubric

CER Element &	Proficient	Developing	Needs Improvement
Claim	Claim statement clearly states the state of matter of Oobleck.	Claim statement lacks a specific state of matter.	Claim statement is not present, unclear, incomplete in structure.
Evidence	The *two* evidence statements provide 1) appropriate and sufficient scientific data to support the claim, <u>and</u> 2) describe evidence of Oobleck's property from the Stretch Test.	The *two* evidence statements lack the appropriate and sufficient data to support the claim. OR The *two* evidence statements lack evidence from the Stretch Test to support the claim.	The *two* evidence statements are not present OR there is one evidence statement that is incomplete.
Reasoning	The reasoning statement: 1) appropriately describes why the data from the Stretch Test supports the claim, <u>and</u> 2) includes established scientific rules, principles, or knowledge that justifies the claim.	The reasoning statement lacks a description of data from the Stretch Test. OR The reasoning statement lacks a reference to or accurate understanding of established scientific rules, principles, or knowledge to justify the claim.	The reasoning statement is either 1) not present, 2) rewords either the claim or evidence statements, **or** 3) lacks a description of data <u>and</u> established scientific rule, principle, or knowledge.

<u>Accommodations:</u> ELL beginning students can use handouts provided during the exploration and explanation phases and verbally communicate their scientific argument to the teacher. The teacher will provide individual feedback to them. Consider reading and reviewing the written report rubric with intermediate ELLs and accept short answers or incomplete sentence formation in their essays. For advanced ELLs, allow grammatical errors and provide opportunities to correct them.

4. Adaptations for ELLs
See highlighted adaptations throughout procedures**.**

5. Science Practices: Asking questions, carrying out investigations, constructing explanations, obtaining, evaluating, and communicating information

6. Materials:

For the whole class:

- Sample items (such as a marker/pen/pencil, water, soda, oil, vinegar, coffee, or piece of fruit)

For each student:

- Science notebook
- Informational text passage on matter
- Highlighters/pens/colored pencils (1 green and 1 red)

For each group:

- Room temperature water
- Cornstarch
- Green food coloring
- Plastic cups (one for water, one for cornstarch, measured beforehand)
- Table cloth

7. Safety:
There is no significant safety issue related to this lesson.

8. References:

Brunsell, E. (2012). Designing science inquiry: Claim + evidence + reasoning = explanation. Edutopia, September 25, 2012. From <https://www.edutopia.org/blog/science-inquiry-claim-evidence-reasoning-eric-brunsell>

Buchanan, K. (2005). Oobleck and beyond. *The Science Teacher*, *72(*9), 52-54.

Florida Department of Education. (2008). Next Generation Sunshine State Standards (K-12 Science). Retrieved from http://www.cpalms.org/homepage/index.aspx

Troncale, J.M. (2016). Sensing matter: Is it a liquid or solid? *Science and Children, 54*(3), 58-63.

APPENDIX H
MUSCLES, BONES, AND THE BODY LESSON PLAN

1. Rationale/Purpose:

Science Standards:

SC.2.L.14.1 Distinguish human body parts (brain, heart, lungs, stomach, muscles, and skeleton) and their basic functions.

SC.5.L.14.1 Identify the organs in the human body and describe their functions, including the skin, brain, heart, lungs, stomach, liver, intestines, pancreas, muscles and skeleton, reproductive organs, kidneys, bladder, and sensory organs.

SC.6.L.14.5 Identify and investigate the general functions of the major systems of the human body (digestive, respiratory, circulatory, reproductive, excretory, immune, nervous, and musculoskeletal) and describe ways these systems interact with each other to maintain homeostasis.

SC.5.N.2.1 Recognize and explain that science is grounded in empirical observations that are testable; explanation must always be linked with evidence

ELA Standards:

LAFS.5.L.3.6 Acquire and use accurately general academic and domain-specific words and phrases as found in grade level appropriate texts, including those that signal contrast, addition, and other logical relationships (e.g., *however, although, nevertheless, similarly*, *moreover*, *in addition*).

LAFS.5.SL.1.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on *grade 5 topics and texts*, building on others' ideas and expressing their own clearly.

English Language Development Standards:

ELD.K12.ELL.SC.1: English language learners communicate information, ideas and concepts necessary for academic success in the content area of Science.

Content objectives:

1. Students will be able to identify structures (***joint, tendons, ligaments, voluntary muscles,*** and ***skeletal muscles***) of the muscular system and skeletal system through analyzing a text and a modeling activity.
2. Students will be able to describe how the muscular and skeletal systems function in the human body for movement, structure, protection, and support through text analysis and a modeling activity.
3. Students will be able to use the CER Framework to develop an explanation of how the muscular and skeletal systems work together (interact) to help the human body function through individual writing and group sharing.

2. Misconceptions:

- Body systems operate in isolation from one another (National Institutes of Health).
- Bones are not living things (National Institutes of Health).

- Muscles are only for physical movements like walking, throwing, and swimming (CK-12; National Institutes of Health).

3. Detailed Procedures:

ENGAGE: Let's Get Moving!

Guiding questions:
1. What makes the human body move?
2. What body parts are involved in moving?

"Simon Says" (Head, Shoulder, Knees, and Toes)

Play "Simon Says" with the students. For each direction, "Simon" will tell students to complete several physical movements. Following this activity, students will work in pairs to complete the Body Movement Table identifying which parts of the body are moving during each physical activity.

- Walk/jog in place
- Clap your hands
- Wave your arms
- Jump up and down
- Pretend to kick a ball
- Dance around

Body Movement Table

Physical activity	Body parts that were moving
1. Throwing a ball	
2. Jumping rope/jumping up and down	
3. Kicking a ball	
4. Bouncing a basketball	
5. Sitting on a chair	

Accommodations: Modeling the physical movements will help ELL students understand the rules of "Simon Says". Images on the Body Movement Table sheet will help ELL students visualize the movement. Pair ELL and non-ELL students together to complete the Body Movement Table.

EXPLORE: Building Body Concepts

Building Body Concepts through Text-Based Inquiry

Students will read about the muscular and the skeletal systems from the article "Learning how the bones and muscles work together". In groups of two, students will use what they read in the article to define and describe aspects of each of the two systems on the concept of definition maps.

What is it?

Involuntary

What is it?

Voluntary

System

Structures of the Muscular

Tendons-

Muscle fibers–

Muscular

System

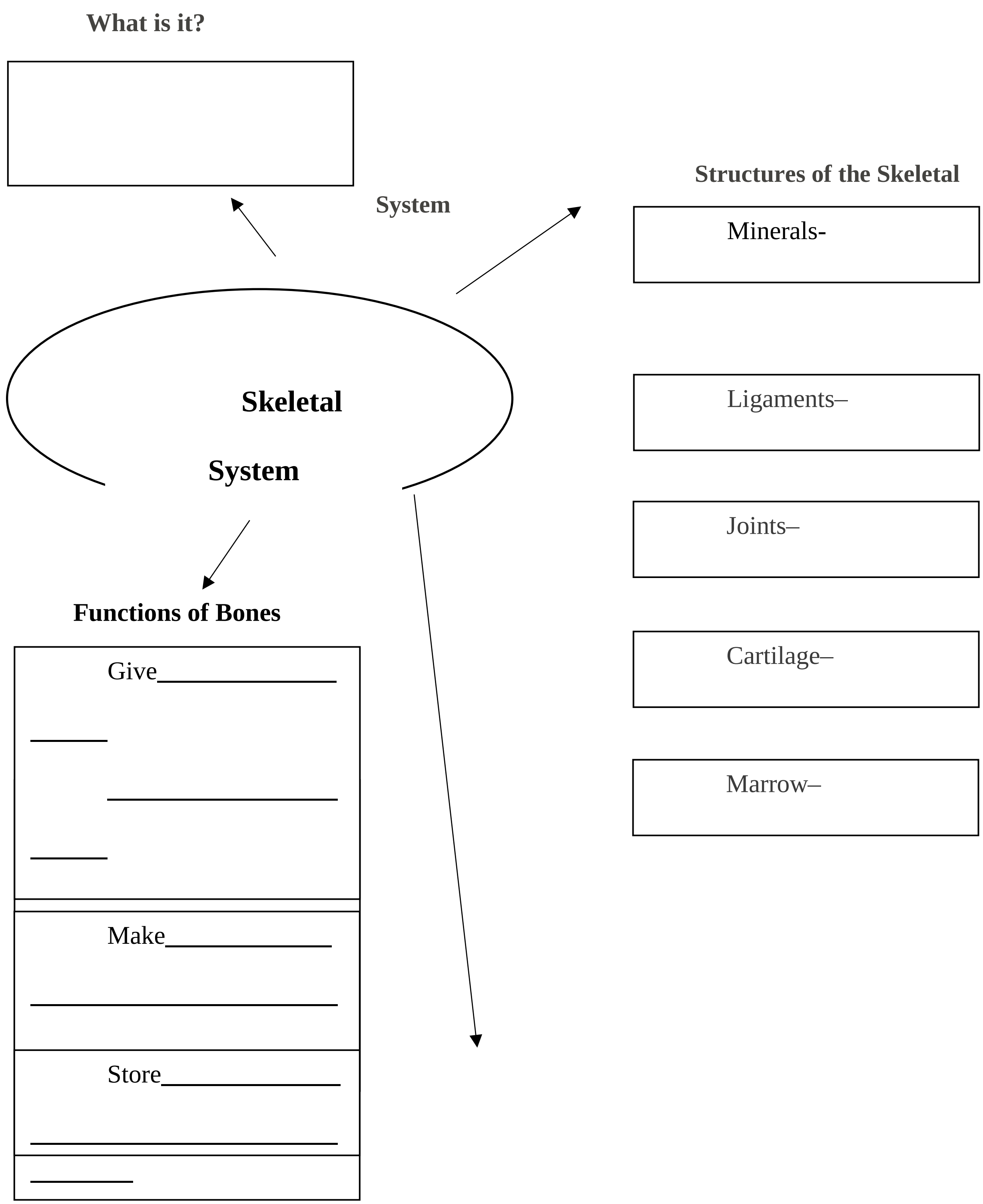
Types of Muscles

Skeletal muscle –

Smooth muscle-

Cardiac muscle –

What are examples (or drawings)?


What is it?
Structures of the Skeletal
System
Minerals-
Skeletal
System
Ligaments–
Joints–
Functions of Bones
Cartilage–
Give
Marrow–
Make
Store

What are examples (or drawings)?

Accommodations: ELL students may use a dictionary and work with partner to read the article. The graphic organizer handouts will help students define or describe the terms. Allow ELL students to use drawings or short phrases to complete the concept of definition maps.

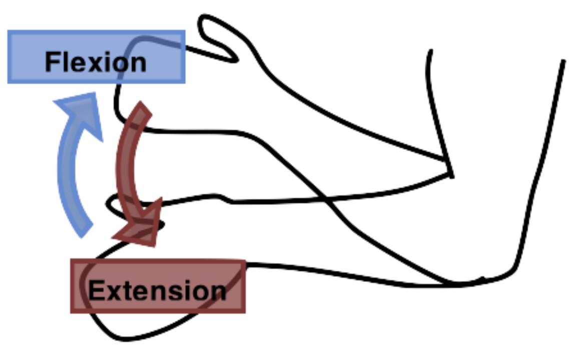
Building Body Concepts through Hands-on Inquiry: "Make a Muscle"

Pose this question for students to think about as they continue through the lesson: "How do the muscular and skeletal system **interact** (work together) to help the human body work?"

In this activity, student teams will use the following items to build a 3-D physical model of an arm, focusing on the structures of the muscles and bones. Have students extend and flex their arm (referencing the article). The arm models will need to move from an extended position to a flexed position as if "making a muscle". Students will need to label and identify the following five vocabulary terms on their model: **joints, ligaments, tendons, voluntary muscle,** and **skeletal muscle.** Students will use what they now know about how muscles and bones interact to build their arm model.

Materials

Rubber bands
Straws
Pipe cleaners
Balloons
Ziploc bags
Tape

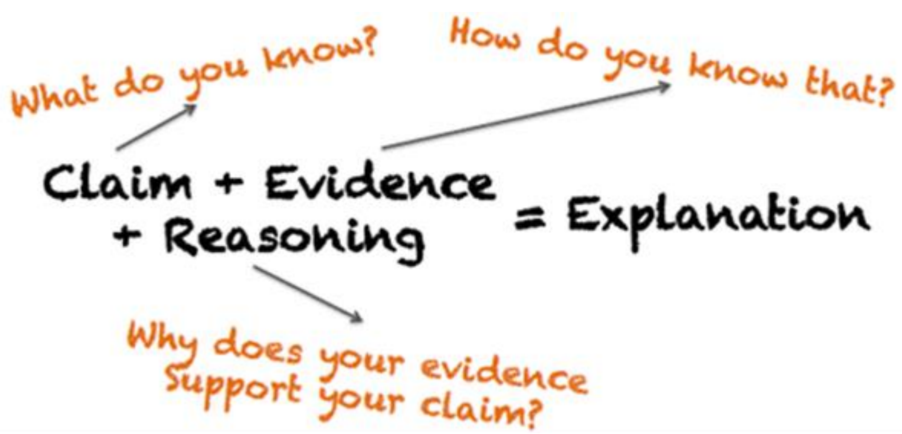


Accommodations: Modeling the flex and extend arm movement will help ELL students connect these terms to the physical movement. The images will help students understand what specific actions they are trying to model. Highlighting the key words from the concept of definitions maps will help them identify and label the specific structures on their arm model.

EXPLAIN: Using CER to Explain the Connection Between Systems

CER Framework

Read through and briefly describe the three components of the CER Framework. Students will formulate an explanation about the muscular and skeletal system utilizing the CER Framework to answer the question "What would happen to the human body if the muscular system or skeletal system did not function?". Write the prompt on the board and then read it aloud. Tell students to think silently for a few minutes about the question.



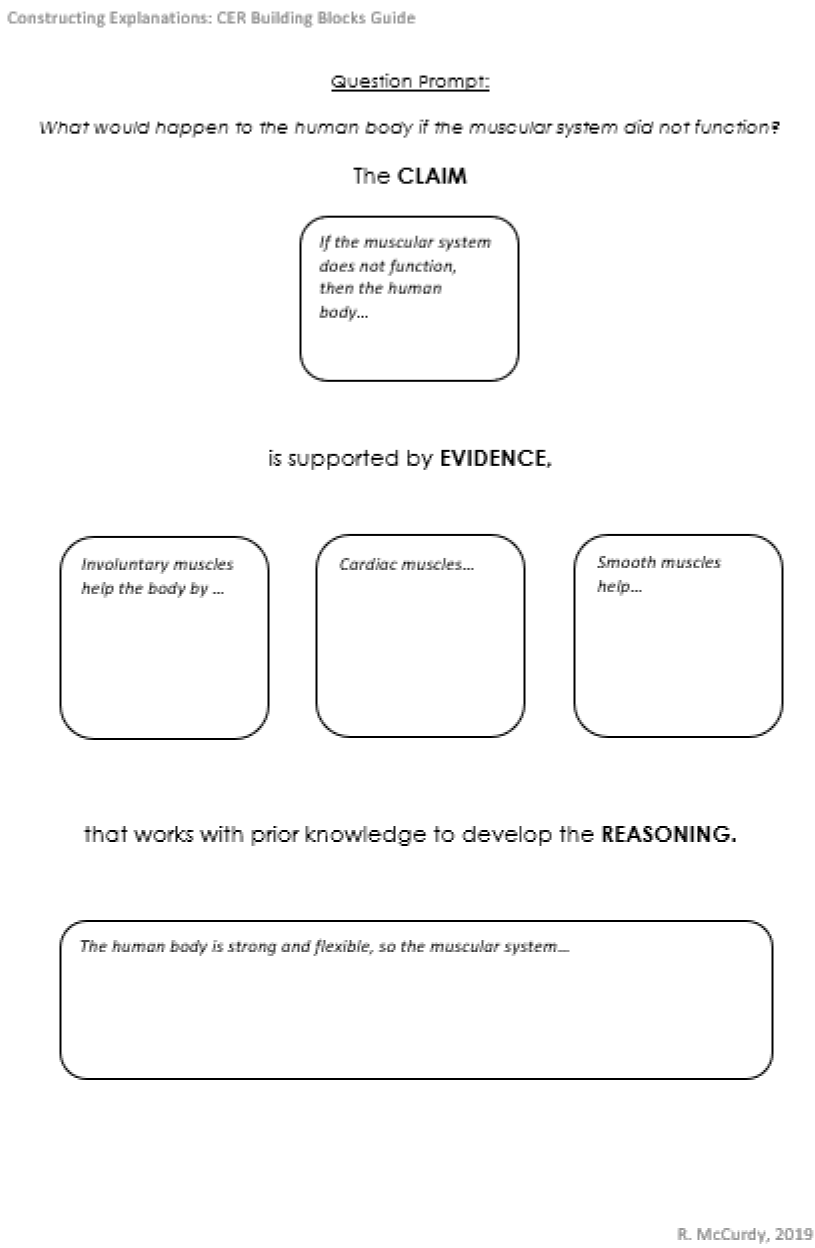
Muscle and Skeletal Teams: Divide the class into two different groups. One group will address the muscular system and one group will address the skeletal system. Divide each of these

groups into teams of three or four. Students will remain in these teams throughout the remainder of the lesson.

Constructing Explanations: CER Building Blocks Guide

Give each student a CER Building Blocks Guide. Read and identify each part of the graphic organizer. Explain that like the body systems of the human body, each part of CER supports each other to develop an explanation.

Each student will individually consider the question "If a scientist wanted to discuss this question with you, what claim would you make and what evidence would you present to support your claim?" Tell students that the prompts on the sheet will guide them in completing their claim, evidence, and reasoning statements. Students may use the article reading, Concept of Definition maps, their arm models, or other sources to gather and record evidence to support their claim. After each student has completed his/her CER Building Blocks Guide, team members share what they recorded to compare and develop consensus as a team.



Constructing Explanations: CER Building Blocks Guide

Question Prompt:

What would happen to the human body if the muscular system did not function?

The **CLAIM**

If the muscular system does not function, then the human body…

is supported by **EVIDENCE,**

Involuntary muscles help the body by …

Cardiac muscles…

Smooth muscles help…

that works with prior knowledge to develop the **REASONING.**

The human body is strong and flexible, so the muscular system…

R. McCurdy, 2019

Public Reasoning

Select one muscular system team and one skeletal system team to share their CER from their completed CER Building Blocks Guide aloud to the whole class. Direct the student audience to listen and critique the team's evidence and reasoning to determine if these components adequately support the team's claim and answer the question.

Accommodations: The teacher will remind students to use their arm model to help them visualize the how the two systems interact to help them understand the question. The sentence

starters and examples will help students answer the question. Students will work in teams of three or four to complete the CER Building Blocks Guide. The document camera will be used to present the team's CER statements. Presenters will point to each part of the graphic organizer when telling the class about their team's work. ELL students may use examples to present their evidence and reasoning statements.

ELABORATE/EXTEND: Rachel's Winning Toe?

Given the connection between the muscular and skeletal systems, consider this scenario:

Rachel is a soccer player. As she kicked the winning goal during the championship game, she also injured her toe. During the doctor's examination, the x-ray showed that her big toe was broken.

Team Talk

Tell students to discuss how Rachel's muscular and skeletal systems were affected by her injury. Encourage students to use the vocabulary terms from their Concept of Definition maps to specifically address the structures and functions of muscles and bones.

Challenge students to discuss other body systems that may be affected by Rachel's injury. Students can use the CER Building Blocks Guide to help them develop an explanation of how these systems may interact with the muscular and skeletal systems.

Accommodations: Allow ELL students to use the Concept of Definition maps, the CER Framework, and the CER Building Block Guide to help students speak and explain this real-life scenario. The team discussion helps students to understand and share examples and evidence of their explanations.

EVALUATE: Assessing Throughout the Lesson

The teacher ***evaluates*** students' understanding of the structures and functions of the muscular and skeletal systems throughout the ***engagement*** of students' prior knowledge and the ***exploration*** of the written text by gathering and recording information and through the hands-on modeling. Students were also evaluated by their utilization of the CER Framework and the CER Building Blocks Guide to develop an ***explanation*** of their claim. As students critiqued their peers' explanations and discussed the ***extension*** scenario in their teams, teachers evaluated students' understanding of the CER tools to develop evidence-based explanations.

4. Adaptations for ELLs

See the green highlighted adaptations throughout procedures.

5. Science Practices: Asking questions, carrying out investigating, analyzing and interpreting data, constructing explanations, engaging in argument from evidence, obtaining, evaluating, and communicating information

6. Materials: Rubber bands, straws, pipe cleaners, balloons, Ziploc bags, tape, interactive notebook, writing utensil

7. Safety:
There is no significant safety issue related to this lesson.

8. References:

CK-12. "The Muscular System". https://www.ck12.org/section/The-Muscular-System/

National Institutes of Health (US); Biological Sciences Curriculum Study. Bethesda (MD): National Institutes of Health (US); 2007. https://www.ncbi.nlm.nih.gov/books/NBK20361/#A760

APPENDIX I
PREVENTING SOIL EROSION LESSON PLAN

1. Rationale/Purpose:

Science Standards:

SC.4.E.6.4 Describe the basic differences between physical weathering (breaking down of rock by wind, water, ice, temperature change, and plants) and erosion (movement of rock by gravity, wind, water, and ice).

SC. 4. N.3.1 Explain that models can be 2D, 3D or a computer model

SC.4.N.1.4 : Attempt reasonable answers to scientific questions and cite evidence in support.

SC.4.N.1.7: Recognize and explain that scientists base their explanations on evidence.

SC.5.N.2.1: Recognize and explain that science is grounded in empirical observations that are testable; explanation must always be linked with evidence.

ELA Standards:

LAFS.4.RI.3.7 Interpret information presented visually, orally, or quantitatively (e.g., in charts, graphs, diagrams, time lines, animations, or interactive elements on Web pages) and explain how the information contributes to an understanding of the text in which it appears.

LAFS.4.L.3.6 Acquire and use accurately general academic and domain-specific words and phrases as found in grade level appropriate texts, including those that signal precise actions, emotions, or states of being (e.g., *wildlife*, *conservation*, and *endangered* when discussing animal preservation).

LAFS.4.SL.1.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade *4 topics and texts*, building on others' ideas and expressing their own clearly.

LAFS.4.SL.1.3 Identify the reasons and evidence a speaker provides to support particular points

English Language Development Standards:

ELD.K12.ELL.SC.1: English language learners communicate information, ideas and concepts necessary for academic success in the content area of Science.

Content Objectives:

1. Students will be able to distinguish between the processes of weathering and erosion based upon their features through a text-based inquiry.
2. Students will be able to examine the process and effects of erosion by rain (water) on a farmland model.
3. Students will be able to use data from a farmland model and the text to explain how to prevent soil erosion from rain (water) using CER Framework.

4. **Misconceptions**: (Fries-Gaither, 2008).

- Weathering and erosion mean the same thing.
- Erosion happens very quickly.
- Erosion is never a good thing.

2. Detailed Procedures:

Engagement: Disappearing Cliffs

Access prior knowledge by showing weathering and erosion video. In groups of four, have students discuss what they observed occurring to the cliff by asking the following questions:

1. What happened to the cliff over the course of the year?
2. What factors contributed to the cliff's structure over time?
3. What processes were involved?
4. Is there are pattern or cycle that you observed?

Discuss that what students observed are examples of weathering and erosion.

Accommodations:

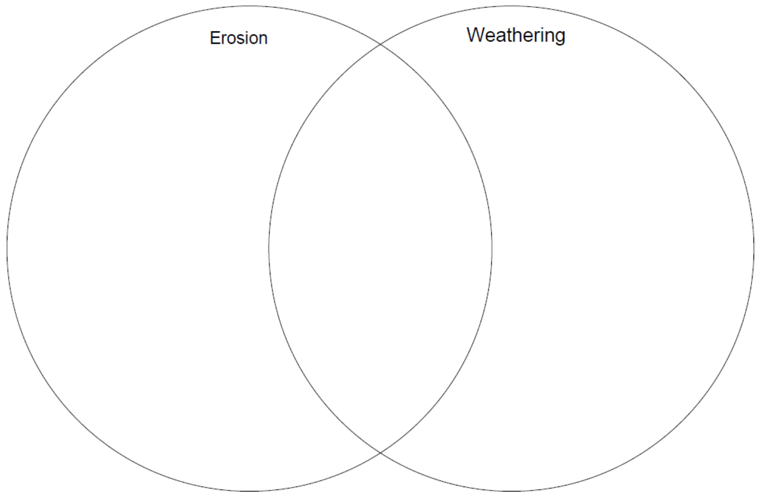
Beginning	Labeled visual images of the landforms will be presented and pointed out to the students. Questions about the weathering and erosion video will be simplified requiring only a "yes/no" response or one-word answers. ("Does the cliff look different now?" or "What made the cliff change?") Students will work in groups of two, pairing ELL students with non-ELL students.
Intermediate	Questions about the weathering and erosion video will be require students to provide a simple sentence response ("How does the cliff look at the end of the video?" or "How did the cliff change?") Teacher will check for comprehension and participation. Students will work in groups of two, pairing ELL students with non-ELL students.
Advanced	Students will work in groups of two, pairing ELL students with non-ELL students.

Explore: How Weathering and Erosion Work

Text-Based Inquiry—Break It, Move It"

Give each student the article "Break It, Move It". While reading in groups of two, students are to complete a Venn Diagram to compare and contrast the processes of "weathering" and "erosion". Indicate that students may use color-coded underlining/highlighting on the article to identify characteristics of each or both processes.

Venn Diagram Graphic Organizer



After students complete the Venn Diagram, allow them to complete the Semantic Feature Analysis using the Venn Diagram and their text as a guide to help them identify relationships between weathering and erosion as well as specific features of each process.

Erosion and Weathering Semantic Feature Analysis

Terms	Features							
	Breaks rocks into smaller pieces	Shapes Earth's surface	Moves rock to new places	Occurs by water, wind, and ice	Takes place first	Influenced by weather conditions	Occurs slowly over time	Slowed down or prevented by plants and their roots
Erosion								
Weathering								

Accommodations:

Beginning Students may use pictures to compare and contrast these processes on the Venn Diagram. The bold-faced terms in the article and the color-coded underlining/highlighting will help students focus on key words and ideas while reading the text. Students may work in pairs to complete the Semantic Feature Analysis. Students will work in groups of two, pairing ELL students with non-ELL students.

Intermediate Students may also use their color-coded article and Venn Diagram to help them complete the Semantic Feature Analysis. Students will work in groups of two, pairing ELL students with non-ELL students.

Advanced Students will work in groups of two, pairing ELL students with non-ELL students.

Hands-on Inquiry—Farmland Foundation Model

Tell students that they will design and build a model farmstead to explore how rain affects erosion on the land. Ask students, "What is a model?" and "What is the purpose of using a model?" After student responses, emphasize that a model is a representation of an object and that scientists use models to explain phenomena. Inform students that they will simulate a rain shower to explore rain's effect on the land.

Phase 1: Farmland on a Hill

a) Design a Blueprint: Students will draw a blueprint of a farmstead to help prevent erosion by rain. Use the materials listed to incorporate into your design.

b) Make a model :Using their blueprint, students will build a model of the farmland/farmstead and simulate erosion by rain (water). Provide each group of students with a plastic shoebox partially filled (two-thirds full) with moist sand (sand is easier to work with and easier to clean up than soil or potting material).

To test their design, students will place one end of their shoebox "farm" on a text book. The uphill end is where students will pour their "rainwater". Students will record the results of erosion of their farmland model in their science notebooks. Provide each group of students the following landscape objects:

- 5 Monopoly houses to represent different buildings on a farm
- 8 to 10 rocks of different sizes to represent boulders
- 2 to 3 pieces of Spanish moss
- 6-7 small trees/plants from plastic floral arrangements
- Water (500 mL)
- Cup
- Aluminum tray to catch water
- Paper towels for cleanup

Phase 2: A Better Farmland Design

a.) Design a Blueprint: Tell students that now their job is to protect the buildings and crops on the farm so that they are not flooded or washed away. Instruct students to think about which material would best protect their buildings and crops from washing away. Provide time for students to re-design their farmstead based upon other groups' success with their initial farmland. Students will draw a diagram of their design in their science journals prior to building. Students will make predictions of what will happen when water is poured. Ask, "What will stay where it is placed? What will move?"

b.) Make a model: Using their blueprint, students will build a new model of the farmland/farmstead and simulate erosion by rain (water).

c.) Test the Design: To test their design, students will place one end of their shoebox "farm" on a text book as in the first phase. The students will draw an "after" diagram of the farmstead in their science notebooks.

After students test their design, lead students to discuss what they believed worked and did not work. Tell students to describe their model and how each part helps prevent rain erosion of their farmland.

Accommodations:

Beginning Provide Power Point slides with the directions and read each step orally. Stop at key points when delivering directions, explanations, and instructions to determine student comprehension. Provide a copy of the directions for each group, using a visual key to identify what each item of the materials represents. Students will draw their designs in their science notebooks to share their ideas. Students will work in groups of two, pairing ELL students with non-ELL students.

Intermediate Ask questions about what she/he needs to do. Students can draw their designs in their science notebooks to share their ideas. Students will work in groups of two, pairing ELL students with non-ELL students.

Advanced Students will work in groups of two, pairing ELL students with non-ELL students.

Explain: Using CER to Explain Erosion

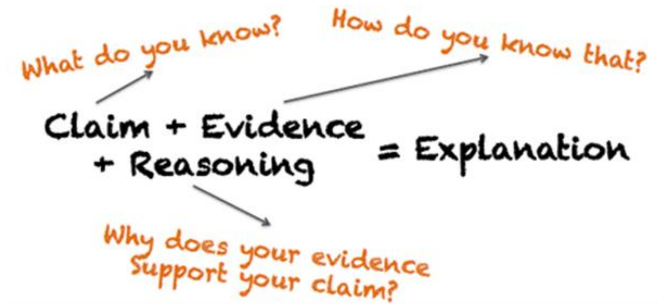
Ask students to describe what happened to the land when water was poured over their farmstead.

- What was the process that was modeled?
- What factor impacted the process and how?

Explain from the data they collected how the factor of rain impacted erosion.

Pose this question prompt to the students: "What is the best way to protect houses on the beach to prevent sand erosion?"

Visual Representation:



Constructing Explanations: CER Building Blocks Guide

Give each student a CER Building Blocks Guide. Read and identify each part of the graphic organizer. Tell students that the prompts on the sheet will guide them in completing their claim, evidence, and reasoning statements. Students may use information the article reading, the Venn diagram, the Semantic Feature Analysis, and the farmland model to gather and record evidence to support their claim. After each student completes his/her CER Building Blocks Guide, group members share what they recorded to compare and develop consensus as a group.

Protecting Houses on the Beach

Question Prompt:

"What is the best way to protect houses on the beach to prevent sand erosion?"

The **CLAIM**

(Ex. The best way to protect houses on this beach from sand erosion is to...)

is supported by **EVIDENCE,**

(Ex. Our farmland model showed...)

(Ex. Based upon the article...)

Provide an example from your own experiences.

that works with prior knowledge to develop the **REASONING.**

(Ex. Erosion refers to ___________. My evidence indicated _________. Therefore, the best way to prevent soil erosion because ____.)

McCurdy & Gao, 2019

Accommodations: Writing scaffolds utilizing the claim, evidence, and reasoning framework will be provided to support students in constructing their scientific explanations. In addition to providing writing scaffolds, a visual representation will be displayed for students to refer to as a reminder of how to construct a scientific explanation. These supports are especially helpful for supporting ELLs.

Public Reasoning

Select one student per group to share their CER from their completed CER Building Blocks Guide aloud to the whole class. Direct the student audience to listen and critique the group's evidence and reasoning to determine if these components adequately support the claim and answer the question.

Accommodations: The teacher will remind students to use article reading, the Venn diagram, the Semantic Feature Analysis, and the farmland model the help them provide evidence to support their claim. The sentence starters and examples will help students answer the question. Students will work in groups of three or four to complete the CER Building Blocks Guide. The document camera will be used to present the team's CER statements. Presenters will point to each part of the graphic organizer when telling the class about their team's work. ELL students may use examples to present their evidence and reasoning statements.

Elaborate/Extend: It's Not Just Raining Anymore!

Tell students to consider a similar scenario from their farmland simulation, except they need to add another weather factor (wind, hurricane, etc.) Tell students to think about and discuss these questions:

- How would this added factor affect their farmland?
- How does this factor affect the design of the farmland model they developed?

Allow the students to redesign their farmland models considering this new factor and conduct a simulation testing their new design. (A fan may be used to help develop windy conditions if needed.) In their interactive notebooks, students will record how they redesigned their farmland and the effects the new factor had on their farmland model.

Evaluation: Assessing Throughout the Lesson

Students are formatively assessed throughout each of the 5Es of the lesson. The teacher ***evaluates*** students' understanding of the weathering and erosion from the images and video used to ***engage*** *and access* students' prior knowledge and the ***exploration*** of the written text by gathering and recording information on the Venn Diagram and Semantic Feature Analysis and through the hands-on farmland simulation. Students were also formatively ***evaluated*** by their utilization of the CER Framework and the CER Building Blocks Guide to develop an ***explanation*** of their claim. As students critiqued their peers' explanations and discussed the

extension scenario in their groups, teachers evaluated students' understanding of the CER tools to develop evidence-based explanations.

Accommodations: Provide extended time to complete formative assessment, if needed. For example, students may be permitted to speak their responses into a recorder in lieu of providing a written response.

3. Adaptations for ELLs

See highlighted accommodations throughout procedures

4. Science Practices: Developing and using models, carrying out investigations, obtaining, evaluating, and communicating information

5. Materials:

For each student:

- "Break It and Move It" Article
- Semantic Features Analysis Sheet
- CER Building Blocks Guide

For each group:

- 4 to 5 Monopoly houses to represent different buildings on a farm
- 10 rocks of different sizes to represent boulders
- 2 to 3 pieces of Spanish moss
- 7 to 8 small trees from plastic floral arrangements
- 3 plastic toy farm animals
- 1 plastic shoebox filled with moist sand
- Water (500 mL)
- Tray to catch water
- Cup or container to hold water
- Paper towels for cleanup

6. Safety:

There is no significant safety issue related to this lesson.

7. References:

Fries-Gaither, J. (2008). "Common Misconceptions about Weathering, Erosion, Volcanoes, and Earthquakes". Beyond Penguins and Polar Bears. https://beyondpenguins.ehe.osu.edu/issue/earths-changing-surface/common-misconceptions-about-weathering-erosion-volcanoes-and-earthquakes

https://betterlesson.com/lesson/633928/erosion-and-deposition

APPENDIX J
GROUP TEACHING OBSERVATION SHEET

	Group ______	Group ______	Group ______
Teaching procedures tie to objectives of the lesson			
Discpline Literacy (e.g., CER framework, vocabulary teaching strategies…) in science teaching			
ELL Accommodations for teaching science			
Other			

APPENDIX K
PROFESSIONAL LEARNING TASKS

Week	Focus	Tasks to Be Completed	Course Implementation
Week 1 **Oct. 8 -12**	Integrating Disciplinary Literacy and Science	□ Online Professional Learning Module 1 □ Check-for-Understanding Task (Module 1)	-A focus on disciplinary literacy will be threaded throughout the entire intervention.
Week 2 **Oct. 15 - 19**	Connecting Science and Literacy through Scientific Explanation and Argument • Teaching Science as Argument Framework (TSAF) • C-E-R Framework	□ Online Professional Learning Module 2 □ Check-for-Understanding Task (Module 2)	-The TSAF will be used to will be used to guide PSTs' thinking about effective science teaching throughout the intervention. -During each of the three investigations, the CER Framework will be used to assist PSTs in constructing evidence-based explanations in both talk and writing. - After participating in each investigation, PSTs will analyze the lesson from a teacher's perspective using the TSAF. - PSTs will also use the TSAF to inform the development of their inquiry-based science lessons (see planning questions related to the TSAF)
Week 4 **Oct. 22 – Oct 26**	Supports for writing scientific explanations • Writing scaffolds Overview of Investigation #1	□ Online Professional Learning Module 3 □ Check-for-Understanding Task (Module 3)	-During each of the three investigations, the instructor will use writing scaffolds based on the CER Framework to help PSTs appropriately justify their claims in writing. -The instructor will also make explicit the importance of using writing scaffolds as an effective strategy for supporting ELLs.

Week	Focus	Tasks to Be Completed	Course Implementation
Week 4 **Oct. 29- Nov. 2**	Answer questions, clarify any missed items on the check-for-understanding tasks, and provide additional practice opportunities	□ Attend first interactive session with researcher either face-to-face or via Skype	
Week 5 **Nov. 5 - 9**	Scaffolds for supporting science talk • Teacher questioning • Teacher talk moves Overview of Investigation #2	□ Online Professional Learning Module 4 □ Check-for-Understanding Task (Module 4)	-During each of the three investigations, the instructor will use talk moves based on the CER Framework to scaffold PSTs' communication of scientific ideas and evidence in ways that reflect scientific discourse. The intent is to help PSTs recognize the importance of science talk as a forum for public reasoning and engagement in the language of science.
Week 6 **Nov. 12 - 16**	Answer questions, clarify any missed items on the check-for-understanding tasks, and provide additional practice opportunities	□ Attend second interactive session with researcher either face-to-face or via Skype	
Week 7 **Nov. 26 - 30**	Overview of Investigation #3 Overall Intervention Sequence and Timeline Pre & Post Intervention Assessments	□ Online Professional Learning Module 5 □ Check-for-Understanding Task (Module 5)	
Week 8 **Dec. 3 -7**	Answer questions, clarify any missed items on the check-for-understanding tasks, provide additional practice opportunities, and distribute any materials needed for the intervention	□ Attend final interactive session with researcher either face-to-face or via Skype	

APPENDIX L
OVERVIEW OF ONLINE MODULES

<u>Module 1</u>

- <u>Topic:</u> Integrating Disciplinary Literacy and Science
- <u>Objective(s)</u>:
    - Gain an understanding of the pedagogical basis for incorporating disciplinary literacy in the elementary science classroom.
    - Learn about five instructional and curricular features that can support students in developing literacy as they engage in scientific inquiry.
- <u>Content</u>:
    - What is disciplinary literacy?
        - The specialized skills and strategies needed for disciplinary learning:
            - Academic vocabulary
            - Kinds of text features
            - Ways of reading
            - Structure of information
            - What kind of evidence is privileged
    - Problem: Many activities in content area learning assume that students know the literacies that are specific to the discipline, such as:
        - Reading science text
        - Writing science text
        - Participating in science talk
        - Interpreting visual representations
    - Science texts often pose a variety of challenges for students. These challenges include:
        - Academic and scientific language
        - Logical connectives
        - Polysemy
        - Nominalization
        - Lexical Density
        - Multimodality
        - Passive Voice
    - Supporting Students in Developing Disciplinary Literacy in Science (see Krajcik & Sutherland, 2010)
        - Connect science ideas with students' everyday experiences and with previous classroom experiences
        - Pose questions that are meaningful and important to the lives of learners
        - Explicitly reference visual elements in written text, and teach students to use graphics and text to support meaning making
        - Provide students with time, opportunities, and guidance to apply science learning to new contexts

        - Engage students in constructing explanations and arguments, which are essential components of scientific discourse
    - Summary
        - Teachers must provide **explicit instruction** as well as **scaffolded opportunities** for practice in using disciplinary literacy skills!
        - Literacy should be positioned as a tool to support knowledge acquisition in science rather than as an independent curriculum goal.
        - Preservice teachers need opportunities to examine the texts of science, to plan instruction that integrates authentic uses of text into inquiry, and to learn how to teach students how to read, write, and communicate like scientists.
- Resources:
    - http://serpmedia.org/rtls/index.html
        - Project website on Reading to Learn in Science
    - http://scienceandliteracy.org/teachersupport/strategyguides
        - Link to 81 Elementary Strategy Guides (2-5) to accompany science texts
- Related Readings:
    - Pearson, D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in service of the other. *Science*, *328 (5977)*, 459-463.
    - Krajcik, J. & Sutherland, L. (2010). Supporting students in developing literacy in science. *Science*, *328* (5977), 456-459.
    - Cervetti, G. & Pearson, D. (2012). Reading, writing, and thinking like a scientist. *Journal of Adolescent & Adult Literacy*, *55*(7), 580-586.
- Check-for-Understanding:
    - This module discussed how connecting literacy activities to inquiry-based science instruction can enhance the learning of both by creating a meaningful and motivating context. Describe at least one way you can create this kind of connection within your science methods course for preservice elementary teachers.
    - What questions do you have about integrating disciplinary literacy and inquiry-based science?

Module 2

- Topic: Connecting Science and Literacy through Scientific Explanation and Argument
- Objective(s):
    - Gain an understanding of how to support students' science and literacy learning through scientific explanation and argument.
    - Learn about the role of the CER Framework in supporting students in constructing scientific explanations in both talk and writing.
- Content:

    - Science includes specialized ways of communicating, which can differ from students' everyday ways of talking and writing (Zembal-Saul, McNeil, & Hershberger, 2013).
    - Written and oral communication in the context of science inquiry depend on the use of data as evidence for explanation and argumentation (Krajcik & Sutherland, 2010).
- Benefits of Engaging Students in Scientific Explanation
    - Develops science content knowledge
    - Participation in scientific practices
    - Participation in the norms of science and scientific language
    - Improves understanding about the nature of science
- Duschl (2008) and Jimenez-Aleixandre (2008, 2014) argue that argumentation for school science should emphasize two related facets:
    - social negotiation (e.g., how to critique, debate, and evaluate an argument) and
    - epistemic understanding of argument (e.g., what counts as data, evidence, and claim, and the relationships between these components).
- Interplay between talk and writing
    - Talking and writing scientific explanations are complementary activities!
        - Examples –
            - Students talk about their ideas first (e.g., predictions) in preparation for an investigation in which they will record observations and data in their science notebooks, which will later serve as evidence for scientific claims.
            - Students attempt to identify patterns in evidence and/or draft an initial explanation in writing before engaging in a science talk in which students co-construct claims from evidence.
- A Framework for Explanation-Driven Science
    - The C-E-R framework can be used to support students in constructing scientific explanations in both talk and writing.
        - Claim
        - Evidence
        - Reasoning
    - Watch video clip 2.1 Introducing the CER Framework
- <u>Videos:</u> Video Clip 2.1 Introducing the CER Framework
    - In this video, Ms. Hershberger, a third-grade teacher, reviews the components of scientific explanation with students and supports them in constructing working definitions for each component. She then creates a poster using students' language for explanation, which is displayed in the classroom for the

rest of the year and used by the class as a reference when talking and writing scientific explanations.

- Related Readings:
    - Chen, Y., Hand, B., & Park, S. (2016). Examining elementary students' development of oral and written argumentation practices through argument-based inquiry. *Science & Education*, *25*, 277-320.
    - Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education*, *93*(4), 687–719.
- Check-for-Understanding:
    - In what ways does talk serve as a scaffold for younger children as they move towards writing scientific explanations?
    - What questions do you have about how engaging students in scientific explanation supports their literacy and science learning in tandem?

Module 3

- Topic: Scaffolds for supporting scientific writing
- Objective(s)
    - Learn how to use a variety of supports to help students in writing scientific explanations.
- Content
    - Written scaffolds and visual representations that utilize the CER Framework can be used to help students justify their claims in writing.
    - Writing scaffolds for scientific explanations include:
        - Sentence starters
        - Questions
        - Prompts
    - There are four characteristics to consider when designing writing scaffolds. These include:
        - General and content support
        - Detail and length
        - Fading
        - Structure (explanation, sentence starter, or question)
    - Watch video clip 4.1 Writing Explanations
    - Visual representations can help remind students how to construct a scientific explantion.
        - Include classroom poster examples
- Videos:
    - Video Clip 4.1 Writing Explanations
        - In this video, Mrs. Kur asks students to work in small groups to write claims and evidence based on data collected from an investigation. This video demonstrates how the progression from small-group writing to large

group discussion helped prepare students to come to the science talk ready to share their data and idea.

- <u>Check-for-Understanding</u>
    - What writing scaffolds or visual representations do you currently use during classroom instruction to help preservice teachers write scientific explanations?
    - What questions do you have about how to support students' communication of scientific ideas in writing?

<u>Module 4</u>

- <u>Topic:</u> Scaffolds for supporting science talk
- <u>Objective(s)</u>
    - Learn how to use talk moves to scaffold students' communication of scientific ideas and evidence in ways that reflect scientific discourse.
- <u>Content</u>
    - Science talks provide students with an opportunity to engage in scientific discourse, as well as receive oral support from their teacher and classmates.
    - Supporting Whole-Class and Small-Group Discussion
        - The talk moves that a teacher uses during class discussion can play an important role in supporting the explanation building process.
            - Examples include revoicing student ideas and asking questions that prompt students to include evidence
        - See talk moves outlined in *Ready, Set, Science!* (Michaels et al., 2008)
        - The CER framework can be used to guide teacher questions and supports in a number of ways.
            - Examples –
                - What patterns are you beginning to notice in your data?
                - What claim can you make based on the data you have so far?
        - Watch video clip 4.2 Talk Moves
    - Critique, Debate, & Co-Construction of Knowledge
        - Debating a peer explanation includes having students share their scientific explanations with the class, critique the different components of the explanations, and come to a consensus as a class on what should be included in the strongest explanation.
        - Engaging in this process can support students in improving the quality of their own scientific explanations.
        - Watch video clip 5.8 Critiquing Peer Explanation
- <u>Videos:</u>
    - Video Clip 4.2 Talk Moves
        - In this video, Ms. Hershberger, a third-grade teacher, gives a paper cup with six battery/bulb diagrams to her third-grade and fourth-grade students

and asks them to predict whether the diagram will work to light the bulb. The students discuss their ideas during whole-class discussion. Ms. Hershberger uses a series of talk moves to address multiple students and elicit their thinking.

- Video Clip 5.8 Critiquing Peer Explanation
  - In this video, Ms. Hershbergers' third-grade students work in small groups to collect data about different types of pulleys using force meters. Following the investigation, the children work in their groups to write claims and evidence based on their data. As the class gathers for a science talk, the students are asked to critique the claims and evidence written by others.

- <u>Related Readings</u>
  - Chen,Y., Hand, B. & Norton-Meir, L. (2017). Teacher roles of questioning in early elementary science classrooms: A framework promoting student cognitive complexities in argumentation. *Science Education*, *47*, 373-405.
  - Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287-312.
- <u>Check-for-Understanding</u>
  - What talk moves do you currently use during classroom instruction to facilitate preservice teachers' engagement in scientific explanation?
  - What questions do you have about how to scaffold students' communication of scientific ideas and evidence during whole-class and small-group discussion?

<u>Module 5</u>

<u>Topic</u>: Intervention Materials, Sequence, & Timeline

- Review the overall sequence, timeline, and format of the scientific explantion-based intervention
  - Three total inquiry experiences each consisting of two components:
    1. firsthand (hands-on) inquiry
    2. secondhand (text-based) inquiry
  - Each inquiry experience will involve:
    - Searching for evidence through firsthand experiences and text in order to construct a more accurate and complete understanding of the natural world
    - Engaging in written and oral discourse with the goal of communicating evidence-based explanations and evaluating and revising the explanations.
- Review the procedures and protocols for pretest administration
- Learn about how fidelity of implementation will be calculated.

APPENDIX M
CHECK-FOR-UNDERSTANDING TASKS

Module	**Topic**	**Check-for-Understanding**		
		Describe at least one way you can create this kind of connection within your science methods course for preservice elementary teachers.	*What questions do you have about integrating disciplinary literacy and inquiry-based science?*	
Module 1	**Integrating Disciplinary Literacy and Science**	Provide a science lesson in science methods course, which integrates science talk, reading science text, and writing in an inquiry-based activity based on a specific science content standard.	What are specific curriculum available for teachers to integrate disciplinary literacy in science teaching?	
		What are 3 interesting things from the module that stood out to you?	*What are 2 changes you will make within your science methods course?*	*What is 1 question you still have?*
Module 2	**Connecting Science and Literacy through Scientific Explanation and Argument**	1) The TESSA framework is intended to inform the user of activities associated with other 6 kinds of science practices listed in NGSS, from asking questions to obtaining, evaluating, and communicating information. 2) Questions Used by Preservice Teachers When Planning for Inquiry-Based Science Instruction 3) “Although the findings of Study 2 portrayed an encouraging picture of preservice teachers’ developing understandings of teaching science as argument, a number of limitations persisted.	1) Explicitly make connections between the TESSA framework with science practices and literacy practices. 2) Trying to develop modeling lesson using TESSA framework.	What do those three features look like in practice? For example, what does it look like when you use KLEW as an argument map to support argument construction?
Module 3	**Scaffolds for Supporting Scientific Writing**	*What are 3 interesting things from the module that stood out to you?*	*What are 2 changes you will make within your science methods course?*	*What is 1 question you still have?*

Module	Topic	Check-for-Understanding		
		No answer	No answer	I am unclear on some elements of the lesson plan. For example, I am not clear about how students will select evidence to support their claim.
		What are 3 interesting things from the module that stood out to you?	*What are 2 changes you will make within your science methods course?*	*What is 1 question you still have?*
Module 4	**Scaffolds for Supporting Scientific Talk**	1) Teachers lay multiple roles to tackle different situations by considering student ownership of ideas and activities 2) The relationships between the roles teachers adopt and students cognitive responses 3) Argument can be seen to take place as an individual activity, through thinking and writing, or as a social activity taking place within a group-a negotiated act within a specific community.	I might want to include two perspectives of defining argument, including individual activity and social activity.	When argument is seen as an individual activity, through thinking and writing, does it equal/ related to scientific explanation?
		What are 3 interesting things from the module that stood out to you?	*What are 2 changes you will make within your science methods course?*	*What is 1 question you still have?*
Module 5	**Intervention Materials, Sequence, & Timeline**	No answer	1) Incorporate concept mapping 2) Engage PSTs in text-based inquiry	What evidence will students use to support their claims in the erosion lesson?

APPENDIX N
FACE-TO-FACE MEETING ONE SUMMARY

Face-to-Face Meeting One

- **Model Inquiry-Based Lessons**
  - Discussed Goal of the Inquiry-Based Lessons: The goal is to engage preservice elementary teachers as learners to experience learning through scientific inquiry for themselves**.**
  - Three total investigations each consisting of two related components:
    1. firsthand (hands-on) inquiry
    2. secondhand (text-based) inquiry
  - Each investigation will be researcher-developed using the 5E Model.
    - Digestion & Body Systems Investigation (Life Science)
    - Oobleck Investigation (Physical Science)
    - Earth and Space Science?
  - Each inquiry experience will involve:
    - Searching for evidence through firsthand experiences and text in order to construct a more accurate and complete understanding of the natural world
    - Engaging in written and oral discourse with the goal of communicating evidence-based explanations and evaluating and revising the explanations using the CER Framework (i.e., claim, evidence, reasoning).
  - After each investigation, preservice teachers will be guided to unpack the lesson from the perspective of the teacher (using the three main features of the TSAF).
    - Teaching Science as Argument Framework (Zembal-Saul, 2009)
      - The Structure of Argument (claims, evidence, reasoning) for scaffolding explanation construction
      - Public reasoning (i.e., making thinking visible
      - Language of Science (i.e., norms of productive participation in scientific discourse)
    - Note – The preservice teachers will be introduced to the TSAF at the start of the intervention.
    - Discussed using the TSAF as a heuristic to analyze preservice teachers' written lesson plans at the end of the intervention.

Next Steps

- Complete remaining PD modules:
  - Module 3 – by 10/5
  - Module 4 – by 10/12
  - Module 5 – by 11/2
- Develop three inquiry-based investigations

APPENDIX O
FACE-TO-FACE MEETING TWO SUMMARY

Face-to-Face Meeting Two

- **Discussed Disciplinary Literacy (DL) Definition**
  - DL is engaging students "in not just learning about the discipline, but actually in **using** reading and writing in the same way the historian or scientist does."
  - In the context of science, this means learning to **read** like a scientist, **write** like a scientist, and **communicate** like a scientist.
- **Clarified Three Features of the TSAF**
  - The first important feature of the TSAF involves **using the structure of argument to guide students work to construct, communicate, and evaluate scientific explanations**. To illustrate this component, writing scaffolds and visual representations based on the CER argument structure will be used to assist students in appropriately justifying their evidence-based claims both in writing and orally.
  - The second important feature of the TSAF **is making thinking visible though public scientific reasoning**. To illustrate this component, each lesson will involve the course instructor facilitating a science talk in which PSTs will be encouraged to communicate their explanations and critique the claims of their peers. During these whole-class science talks, the course instructor will use a series of talk moves (e.g., "Would someone like to add to that?") to make PSTs' thinking visible while also fostering student-student interactions. These science talks will also provide PSTs with an opportunity to engage in classroom discussion that does not follow the traditional turn-taking format.
  - The third important feature of the TSAF is **authentic engagement with the language of science**. Science includes specialized ways of communicating, district from students' everyday ways of talking and writing. Thus, teachers must make efforts to model classroom norms of discourse and provide students with opportunities to practice using the language of science. To illustrate this feature of the TSAF, throughout each lesson, the course instructor will use productive questioning techniques (e.g., "Do you agree?";" What evidence helped you arrive at that conclusion?") to scaffold PSTs' communication of scientific ideas and evidence in ways that reflect scientific discourse.
- **Discussed How PTs Will Reflect After Each Inquiry-Based Lesson**
  - After engaging in each lesson as learners, PSTs will unpack the lesson plan from the perspective of the teacher (using the three core components of the TSAF as a heuristic). To do this, we can provide PSTs with a hard copy of the lesson plan and have them work in pairs to highlight aspects of the lesson as they relate to the three components of the TSAF (i.e., argument structure, making thinking visible, and the language of science). Once PSTs have had the opportunity to highlight the lesson plan, you can guide a whole-group discussion in which PSTs discuss how the lesson supports all students' in constructing, communicating, and debating evidence-based scientific claims.

APPENDIX P
FACE-TO-FACE MEETING THREE SUMMARY

Face-to-Face Meeting Three

- **Finalized Intervention Sequence and Timeline**
  - <u>Before Intervention:</u>
    - Pretest administration will take place in both conditions during the first two weeks of the science methods course.
  - <u>During Intervention</u> (Note: The Intervention does not actually begin until week 3 of the course.):
    - Phase 1 (weeks 3-4)
    - Phase 2 (weeks 5-10 of the course)
      - Lesson 1: *Oobleck: Solid or Liquid?*
      - Lesson 2: Making Explanations about Body Systems
        - Revisions needed!!
      - Lesson 3: *Preventing Soil Erosion*
    - Phase 3 (weeks 11-14 of the course)
  - <u>After Intervention</u>
    - After the intervention, the posttests will be administered in both conditions.
- **Reviewed Pretest Administration Protocols**
  - <u>Week 1</u> – Distribute *Explanation of Research* forms & provide very brief description of study
    - Administer Demographic Survey and NSAAQ (15 mins)
  - <u>Week 2</u>
    - Administer The Argumentation Test (15 mins)
  - <u>Week 3</u>
    - Administer the Written Scientific Explanation Assessment (15 mins)
  - <u>Week 4</u>
    - Pretest Measure Make-ups for Absent Participants

- **Developed Fundamental Lesson Principles**
  - Intended to provide more practical building blocks for PSTs' knowledge development
  - Suggestions:
    - Post in Webcourses as a constant reminder to students
    - Add to weekly PPTs (by Dr. Gao) as a continuous reminder
    - Add to the course syllabus for lesson plan assignment
    - List at the top of each model-inquiry based lesson plan
- **Discussed/Reviewed Three Model-Inquiry Based Lesson Plans (to be taught by GTA)**
  - Oobleck (Weeks 5-6)
    - Vocab Strategy: Frayer Model
  - Human body system (Weeks 7-8)

            - Semantic Feature Analysis
    - Soil Erosion (Weeks 9 & 11)
        - Vocab Strategy: Concept of Definition Map
- **Discussed Plan for Lesson Plan Reflection/Debrief**
    - After engaging in each model lesson, PSTs will work together to text-code a hard-copy of the lesson plan according to the *Questions Used by PSTs When Planning for Inquiry-Based Science Instruction*
    - Share instructor-coded lesson plan and lead whole-group discussion
- **Discussed Lesson Plan Rubric**
    - Must revise to incorporate lesson plan fundamentals
    - 10 categories at 3 pts. each
- **Fidelity of Implementation**
    - Researcher will attend each week in-person to take field notes and complete FOI checklists (phases 1-3).
    - GRA will also conduct FOI checks.
        - GTA is unable to attend in-person each week due to a course conflict.
            - For the weeks that GTA is unable to attend in-person, researcher will use phone to audio-record the session.
            - GTA will then use the audio-recording to complete the FOI checklists for those weeks.

<u>Next Steps</u>

- Design and print TSAF poster
- Make any final revisions to three inquiry-based investigations

APPENDIC Q
SEMESTER SCHEDULE

Please note that assignment formats, course readings and this outline may be adjusted over the course of the semester.

Week	Class Date	Topic	Assignment Due
1	1/9	Self-Introduction Syllabus Review APA format Demographic Survey NSAAQ (pretest)	APA
2	1/16	Science Teaching Standards The Argumentation Test (pretest)	Online reading response 1 Belief Paper
3	1/23	Concept map/misconception Vocabulary Teaching Written Scientific Explanation (pretest)	Online reading response 2 (Vocabulary Teaching) Resource Review 1
4	1/30	Ch. 1 Inquiy Ch. 3 Planning Units and Lessons TSAF Overview Presentation	Online reading response 3 Resource Review Presentation starts
5	2/6	Ch. 2 Science Practices and Inquiry Process Skills Physical Science Lesson (Oobleck) CER Framework	Online reading response 4 Resource Review 2
6	2/13	Ch. 11 Matter and Motion Oobleck (cont) Ch. 5 Assessment of Understanding and Inquiry Reflection and Practices	Online reading response 5
7	2/20	Ch. 10 The Human Body Life Science Lesson (Human body system) Teaching Disciplinary-Specific Literacy Reflection and Practice	Online reading response 6
8	2/27	Human body system lesson (Cont) Ch. 2 Science Practices and Inquiry Process Skills Reflection and Practice	Online reading response 7

9	3/6	Ch. 7 Earth and Space Science Earth/Space Sciences lesson (Preventing Soil Erosion) Teaching Disciplinary-Specific Literacy	Online reading response 8
10	3/11-3/16 Spring Break		
11	3/20	Preventing Soil Erosion (Cont)	Online reading response 9 Inquiry Lesson draft
12	3/27	Integrating Science and Engineering	Online reading response 10 **Inquiry Lesson Plan Due on Webcourses** Resource Review Presentation ends
13	4/3	Lesson Plan Review/Feedback	Revised Lesson Plan Due on Webcourses
14	4/10	Group Teaching Inquiry-based Lesson NSAAQ (Posttest) Argumentation Test (Posttest)	**Reflection on an Inquiry-Based Lesson Due on Webcourses** Science Notebook
15	4/17	Group Teaching Inquiry-based Lesson Written Scientific Explanation Assessment (Posttest)	
16	4/24	**Class ends (No class meeting)**	**Inquiry-based Lesson Plan and Reflection Due on Via (4/24)** **Final Paper (4/27)**

APPENDIX R
PROFESSIONAL LEARNING EVALUATION TOOLS

Appendix R1: Instructor Satisfaction Survey

Instructions: To what extent do you agree with the following statements? Please use the following scale:

4 = Strongly Agree **3 = Agree** **2 = Disagree** **1 = Strongly Disagree**

Level 1. Effective professional learning experiences

Item#	Statement	4	3	2	1
L1.1	The objectives of the professional development were clearly stated.				
L1.2	The professional development content was aligned to the stated objectives.				
L1.3	The professional development was appropriate given my previous level of knowledge.				
L1.4	The professional development delivery was engaging.				
L1.5	The professional development content was organized.				
L1.6	The professional development content was clearly delivered.				
L1.7	The professional development supported me to reflect on my own teaching practices as related to supporting PSTs' knowledge and practices for teaching science as explanation.				
L1.8	The time allotted for the professional development was sufficient.				

PLEASE CONTINUE ON THE BACK

Level 2. Essential participant knowledge and skills

Item#	Statement	4	3	2	1
L2.1	I have increased my understanding of the role of language and literacy in science.				
L2.2	I have increased my understanding of how to use the Teaching Science as Argument (TSAF) Framework in my science methods course to support PSTs' developing knowledge and practices related to scientific explanation.				
L2.3	I have increased my knowledge on how to use writing scaffolds to support PSTs in writing scientific explanations				
L2.4	I have increased my knowledge on how to use specific talk moves to scaffold PSTs' communication of scientific ideas and evidence in ways that reflect scientific discourse.				

Comments:

Thank you for completing the questionnaire!

Appendix R2: Social Validity Questionnaire

TSAF Social Validity Questionnaire **Rebeca Grysko, M.Ed.**	**Strongly Disagree**	**Disagree**	**Neither Disagree or Agree**	**Agree**	**Strongly Agree**
Instructions: Please circle one answer for each statement below.					
START HERE	**SD**	**D**	**N**	**A**	**SA**
1. The TSAF is appropriate for my students.	1	2	3	4	5
2. The TSAF is aligned with the current goals of my science methods course.	1	2	3	4	5
3. The TSAF improves my students' knowledge of the nature of science.	1	2	3	4	5
4. The TSAF improves my students' knowledge of argumentation.	1	2	3	4	5
5. The TSAF protocol procedures are appropriate for my science methods course.	1	2	3	4	5
6. The TSAF protocol procedures are easy to implement.	1	2	3	4	5
7. The TSAF protocol is an *effective* instructional tool.	1	2	3	4	5
8. The TSAF protocol is an *efficient* instructional tool.	1	2	3	4	5
9. I would use the TSAF protocol with my students.	1	2	3	4	5

10.	**I would participate in additional TSAF professional learning.**	1	2	3	4	5

11. How many years have you taught at the K-12 level? _________

____

12. How many years have you taught at the post-secondary level?

____

Please share any comments/feedback you may have in the box below.

Thank you for completing the questionnaire!

APPENDIX S
INSTRUMENTATION

Appendix S1: Demographic Information Survey

Name: ______________________________

Course/Instructor: ___________________

What is your major? ___________________

What is your gender?

☐ Female

☐ Male

Which best describe you? (Check all that apply)

☐ American Indian / Alaskan Native

☐ Asian

☐ Black / African American

☐ Caucasian / White

☐ Hispanic

☐ Native Hawaiian / Other Pacific Islander

☐ Other

What is your primary language?

☐ English

☐ Other ___________________

What is your student level?

☐ Junior

☐ Senior

Appendix S2: The Nature of Science as Argumentation Questionnaire

The Nature of Science as Argument Questionnaire (NSAAQ)

Directions: Read the following pairs of statements and then circle the number on the continuum that best describes your position on the issue described. The numbers on the continuum mean:

1 = I completely agree with viewpoint A and I completely disagree with viewpoint B
2 = I agree with both viewpoints, but I agree with viewpoint A more than I agree with viewpoint B
3 = I agree with both viewpoints equally
4 = I agree with both viewpoints, but I agree with viewpoint B more than I agree with viewpoint A
5 = I completely agree with viewpoint B and I completely disagree with viewpoint A

What is the nature of scientific knowledge?
When you think of the body of knowledge that has been generated by the work of scientists, how would you describe it? The statements below describe scientific knowledge from different viewpoints. Indicate which viewpoint you agree with the most using the scale below…

	Viewpoint A	A not B	A > B	A = B	B > A	B not A	Viewpoint B
1	Scientific knowledge describes what reality is really like and how it actually works.	1	2	3	4	5	Scientific knowledge represents only one possible explanation or description of reality.
2	Scientific knowledge should be considered tentative.	1	2	3	4	5	Scientific knowledge should be considered certain.
3	Scientific knowledge is subjective.	1	2	3	4	5	Scientific knowledge is objective.
4	Scientific knowledge does not change over time once it has been discovered.	1	2	3	4	5	Scientific knowledge usually changes over time as the result of new research and perspectives.
5	The concept of 'species' was invented by scientists as a way to describe life on earth.	1	2	3	4	5	The concept of 'species' is an inherent characteristic of life on earth; it is completely independent of how scientists think.
6	Scientific knowledge is best described as being a collection of facts about the world.	1	2	3	4	5	Scientific knowledge is best described as an attempt to describe and explain how the world works.

How is scientific knowledge generated?
When you think of what scientists do in order to produce scientific knowledge, how would you describe this process? The statements below describe different viewpoints for how scientific knowledge is generated. Indicate which viewpoint you agree with the most using the scale below…

	Viewpoint A	A not B	A > B	A = B	B > A	B not A	Viewpoint B
7	Experiments are important in science because they can be used to generate reliable evidence.	1	2	3	4	5	Experiments are important in science because they prove ideas right or wrong.
8	All science is based on a single scientific method	1	2	3	4	5	The methods used by scientists vary based on the purpose of the research and the discipline.
9	The methods used to generate scientific knowledge are based on a set of techniques rather than a set of values.	1	2	3	4	5	The methods used to generate scientific knowledge are based on a set of values rather than a set of techniques.

The Nature of Science as Argument Questionnaire (NSAAQ)

Directions: Read the following pairs of statements and then circle the number on the continuum that best describes your position on the issue described. The numbers on the continuum mean:

1 = I completely agree with viewpoint A and I completely disagree with viewpoint B
2 = I agree with both viewpoints, but I agree with viewpoint A more than I agree with viewpoint B
3 = I agree with both viewpoints equally
4 = I agree with both viewpoints, but I agree with viewpoint B more than I agree with viewpoint A
5 = I completely agree with viewpoint B and I completely disagree with viewpoint A

What is the nature of scientific knowledge?
When you think of the body of knowledge that has been generated by the work of scientists, how would you describe it? The statements below describe scientific knowledge from different viewpoints. Indicate which viewpoint you agree with the most using the scale below…

	Viewpoint A	A not B	A > B	A = B	B > A	B not A	Viewpoint B
1	Scientific knowledge describes what reality is really like and how it actually works.	1	2	3	4	5	Scientific knowledge represents only one possible explanation or description of reality.
2	Scientific knowledge should be considered tentative.	1	2	3	4	5	Scientific knowledge should be considered certain.
3	Scientific knowledge is subjective.	1	2	3	4	5	Scientific knowledge is objective.
4	Scientific knowledge does not change over time once it has been discovered.	1	2	3	4	5	Scientific knowledge usually changes over time as the result of new research and perspectives.
5	The concept of 'species' was invented by scientists as a way to describe life on earth.	1	2	3	4	5	The concept of 'species' is an inherent characteristic of life on earth; it is completely independent of how scientists think.
6	Scientific knowledge is best described as being a collection of facts about the world.	1	2	3	4	5	Scientific knowledge is best described as an attempt to describe and explain how the world works.

How is scientific knowledge generated?
When you think of what scientists do in order to produce scientific knowledge, how would you describe this process? The statements below describe different viewpoints for how scientific knowledge is generated. Indicate which viewpoint you agree with the most using the scale below…

	Viewpoint A	A not B	A > B	A = B	B > A	B not A	Viewpoint B
7	Experiments are important in science because they can be used to generate reliable evidence.	1	2	3	4	5	Experiments are important in science because they prove ideas right or wrong.
8	All science is based on a single scientific method	1	2	3	4	5	The methods used by scientists vary based on the purpose of the research and the discipline.
9	The methods used to generate scientific knowledge are based on a set of techniques rather than a set of values.	1	2	3	4	5	The methods used to generate scientific knowledge are based on a set of values rather than a set of techniques.

The Nature of Science as Argument Questionnaire (NSAAQ)

	Viewpoint A	A not B	A > B	A = B	B > A	B not A	Viewpoint B
10	Science is best described as a process of exploration and experiment.	1	2	3	4	5	Science is best described as a process of explanation and argument.
11	An experiment is used to test an idea.	1	2	3	4	5	An experiment is used to make a new discovery.
12	Within the scientific community, debates and discussions that focus on the context, processes, and products of inquiry are common.	1	2	3	4	5	Within the scientific community, debates and discussions that focus on the context, processes, and products of inquiry are rare.

What counts as reliable and valid scientific knowledge?
A central claim of science is that it produces reliable and valid knowledge about the natural world. The statements below describe different viewpoints about what counts as reliable and valid scientific knowledge. Indicate which viewpoint you agree with the most using the scale below…

	Viewpoint A	A not B	A > B	A = B	B > A	B not A	Viewpoint B
13	Scientific knowledge can only be considered trustworthy if the methods, data, and interpretations of the study have been shared and critiqued.	1	2	3	4	5	Scientific knowledge can be considered trustworthy if it is well supported by evidence.
14	The scientific method can provide absolute proof.	1	2	3	4	5	It is impossible to gather enough evidence to prove something true.
15	If data was gathered during an experiment it can be considered reliable and trustworthy.	1	2	3	4	5	The reliability and trustworthiness of data should always be questioned.
16	Scientists know that atoms exist because they have made observations that can only be explained by the existence of such particles.	1	2	3	4	5	Scientists know that atoms exist because they have seen them using high-tech instruments.
17	Biases and errors are unavoidable during a scientific investigation.	1	2	3	4	5	When a scientific investigation is done correctly errors and biases are eliminated.
18	A theory should be considered inaccurate if a single fact exists that contradicts that theory.	1	2	3	4	5	A theory can still be useful even if one or more facts contradict that theory.
19	Scientists can be sure that a chemical causes cancer if they discover that people who have worked with that chemical develop cancer more often than people who have never worked that chemical	1	2	3	4	5	Scientists can only assume that a chemical causes cancer if they discover that people who have worked with that chemical develop cancer more often than people who have never work that chemical.

The Nature of Science as Argument Questionnaire (NSAAQ)

What role do scientists play in the generation of scientific knowledge?
The statements below describe different viewpoints for what scientists do and what they are like. Indicate which viewpoint you agree with the most using the scale below…

	Viewpoint A	A not B	A > B	A = B	B > A	B not A	Viewpoint B
20	In order to interpret the data they gather scientists rely on logic and their creativity and prior knowledge.	1	2	3	4	5	In order to interpret the data they have gather scientists rely on logic only and avoid using any creativity or prior knowledge.
21	Scientists are influenced by social factors, their personal beliefs, and past research.	1	2	3	4	5	Scientists are objective, social factors and their personal beliefs do not influence their work.
22	Successful scientists are able to use the scientific method better than unsuccessful scientists.	1	2	3	4	5	Successful scientists are able to persuade other members of the scientific community better than unsuccessful scientists.
23	Two scientists (with the same expertise) reviewing the same data will reach the same conclusions.	1	2	3	4	5	Two scientists (with the same expertise) reviewing the same data will often reach different conclusions.
24	A scientist's personal beliefs and training influences what they believe counts as evidence.	1	2	3	4	5	What counts as evidence is the same for all scientists.
25	The observations made by two different scientists about the same phenomenon will be the same.	1	2	3	4	5	The observations made by two different scientists about the same phenomenon can be different.
26	It is safe to assume that a scientist's conclusions are accurate because they are an expert in their field.	1	2	3	4	5	A scientist's conclusions can be wrong even though scientists are experts in their field.

Appendix S3: The Argumentation Test

Name: ___________________________

Gender:______ Age: _______ Year in School:____________ Language Spoken at Home:______________

Part I: Making a Scientific Argument

Introduction: Once a scientist develops an explanation for why something happens, he or she must support their claim with some type of reason. The explanation and the supporting reason is called an argument. Scientists use arguments to convince others that their claim is indeed true. How do you think scientists create a convincing argument?

Directions: The first three questions are designed to determine what you think <u>counts</u> as a good *scientific* argument. In each question you will be given a claim. Following the claim are 6 different arguments. Your job is to rank the arguments in order using the following scale:

1 = This is the **most** convincing argument
2 = This is the **2nd most** convincing argument
3 = This is the **3rd most** convincing argument
4 = This is the **4th most** convincing argument
5 = This is the **5th most** convincing argument
6 = This is the **least** convincing argument

Your task is to rank the 6 different arguments in terms of how convincing <u>you think</u> they are. *Remember that you can only rank one argument as 1, one argument as 2, one argument as 3, and so on.*

Question #1. Objects sitting in the same room often feel like they are different temperatures. Suppose someone makes the following claim about the temperature of various objects sitting in the same room, which reason makes the most convincing argument?

Claim: Objects that are in the same room are the same temperature even though they feel different because…	**Your Ranking**
…when we measured the temperature of the table, it was 23.4^{O}C, the metal chair leg was 23.1^{O}C, and the computer keyboard was 23.6^{O}C.	__________
…good conductors feel different than poor conductors even though they are the same temperature.	__________
…objects that are in the same environment gain or lose heat energy until everything is the same temperature. Our data form the lab proves that point: the mouse pad and plastic desk were both 23^{O}C.	__________
…objects will release and hold different amounts of heat energy depending on how good of an insulator or conductor it is.	__________
…the textbook says that all objects in the same room will eventually reach the same temperature.	__________
…we measured the temperature of the wooden table and the chair leg and they were both 23^{O}C even though the metal chair leg feels colder. If the metal chair leg was actually colder it would have been a lower temperature when we compared it to the temperature of the table.	__________

Question #2. A pendulum is a string with a weight attached to one end of it. Suppose someone makes the following claim about pendulums, which reason makes the most convincing argument?

Claim: The length of the string determines how fast a pendulum swings back and forth regardless of the weight on the end of the string because…	**Your Ranking**
…the weight on the end of a long string has a longer distance to travel when compared to a weight on a short string. As a result, pendulums with shorter swings make more swings per second than pendulum with longer strings.	__________
…pendulums with different string length have different swing rates. We measured the swing rate of a pendulum with a 10 cm string and a pendulum with a 20 cm string, The 10 cm pendulum had swing rate of 2 swings per second and the 20 cm pendulum has a swing rate of 1 swing per second.	__________
…a pendulum with a 14 cm string had a swing rate of 1 swing per second and a pendulum with a 15 cm string had a swing rate of 1 swing per second.	__________
…a pendulum with a 10 cm string had a swing rate of 2 swings per second and a pendulum with a 15 cm string had a swing rate of 1 swing per second.	__________
…our textbook says that the weight on the end of the string has nothing to do with how fast a pendulum swings.	__________
…we tested the swing rate of three pendulums, one with a 10 gram weight and 10 cm string, one with a 10 gram weight and 20 cm string, and one with 20 gram weight and a 20 cm string. The two pendulums with the 20 cm string had the same swing rate (1 swing per second) and were slower the pendulum with the shorter string (2 swings per second). If the weight on the end of the string mattered these two pendulums would have had different swing rates but they were the same.	__________

Question #3. Scientists often use animals in their research. Suppose someone makes the following claim about the use of animals in scientific research, which reason makes the most convincing argument?

Claim: Scientists should be allowed to use animals for research because…	**Your Ranking**
…a computer or other non animal model can be used instead.	__________
…animals are susceptible to many of the same bacteria and viruses as people, such as anthrax, smallpox, and malaria. Even though animals differ from people in many ways, they also are very similar to people in many ways. An animal is chosen for research only if it shares characteristics with people that are relevant to the research.	__________
…public opinion polls have consistently shown that a majority of people approve of the use of animals in biomedical research that does not cause pain to the animal and leads to new treatments and cures.	__________
…animal research was essential in developing many life-saving surgical procedures once thought impossible. For example the technique of sewing blood vessels together was developed through surgeries on dogs and cats by Alexis Carrel, for which he was awarded a Nobel Prize in 1912.	__________
…infecting animals with certain microbes allows researchers to identify the germs that cause different types of diseases. Once discovered scientists can develop vaccines to test the effectiveness of these vaccines without harming any people in the process.	__________
…humans have 65 infectious diseases in common with dogs, 50 with cattle, 46 with sheep and goats, 42 with pigs, 35 with horses, and 26 with fowl.	__________

Part II. Challenging an Argument

Introduction: Once a scientist develops an explanation for why something happens, he or she must support the explanation with there reasons for why they think their explanation is correct. The explanation along with its supporting reasons is called an argument. Sometimes other scientists agree with the argument; sometimes they do not. When they disagree, they challenge the accuracy of the argument. How do you think scientists challenge the arguments of other scientists? The last three questions on this test are designed to determine what you think counts as a good <u>challenge</u> to a s*cientific* argument.

Directions: In each question you will be given an argument. Following the argument are 6 different challenges. Your job is to rank the challenges using the following scale:

1 = This comment is the **strongest** challenge to this argument
2 = This comment is the **2nd strongest** challenge to this argument
3 = This comment is the **3rd strongest** challenge to this argument
4 = This comment is the **4th strongest** challenge to this argument
5 = This comment is the **5th strongest** challenge to this argument
6 = This comment is the **weakest** challenge to this argument

Question #4—Jason, Angela, Sarah, and Tim are in physics class together. Their teacher asked them to design an experiment to determine if all objects in the same room are the same temperature even though they feel different. After they designed and carried out an experiment to answer this question on their own, they met in a small group to discuss what they have found out. Suppose Jason suggests that:

> *"I think that all objects in the same room are always different temperatures because they feel different and when we measured the temperature of the table, it was 23.4^{O}C, the metal chair leg was 23.1^{O}C, and the computer keyboard was 23.6^{O}C."*

Angela disagrees with Jason. Your task is to rank the 6 different challenges given by Angela in terms of how strong <u>you think</u> they are.

Angela: I disagree…	**Your Ranking**
…because your evidence does not support your claim. All of the objects that you measured were within one degree of each other. That small of difference is just measurement error.	______
…I think that all objects in the same room are the same temperature even though they feel different	______
…if those objects were really different temperatures their temperature would have been much different. For example, when I measured the temperature of my arm it was 37^{O}C while the temperature of the table was 23^{O}C that is a difference of 14 degrees. Everything else was right around 23^{O}C.	______
…I think all objects become the same temperature even though they feel different because objects that are good conductors feel colder than objects that are poor conductors because heat transfers through good conductors faster.	______
…because I know you always rush through labs and never get the right answer.	______
…I think all objects become the same temperature because the temperatures of all those objects you measured were within 1 degree.	______

Question #5—Tiffany, Steven, and Yelena are in the same science class. Their teacher asked them to design an experiment to determine what makes some objects floats and some objects sink. After they designed and carried out an experiment to answer this question on their own, they met in a small group to discuss what they have found out. Suppose Steven suggests that:

> *"I think heavy objects sink and light objects float. This is true because when I put the 10 gram plastic block in the tub of water it floated while the 40 gram metal block sank."*

Tiffany disagrees with Steven. Your task is to rank these 6 different challenges given by Tiffany in terms of how strong you think they are.

Tiffany: I disagree…	**Your Ranking**
…because Yelena is always right and she disagrees with you.	________
…because you did not test enough objects. How can you be sure that it is the weight of an object that makes it sink or float if you only tested two things?	________
…the metal block sank because it is very dense not because it is heavy and the plastic block floated because it has density that is less than water not because it is light.	________
…because light objects can sink too. A paper clip only weighs one gram and it sinks. According to you claim all light objects should float. How can a paper clip that is lighter than a piece of plastic sink while the heavier piece of plastic floats?	________
…The plastic block may have been lighter than the metal block but that is not why it floated. The metal block has a density of 2.5 g/cm^3, which is more than water so it sinks. The plastic block has a volume 16 cm^3 which means its density is .6 g/cm^3 which is less than water so it floats.	________
…I think objects that have a density greater than water sink and objects that have a density less than water float.	________

Question #6— Elana, Shauna, and Sam are in a science class together. At the beginning of class, their teacher poses the following question: *"Should scientists be able to use animals in medical research?"* The teacher then asked Elana, Shauna, and Sam to discuss what they think about the issue in a small group. Suppose Shauna begins the conversation by saying:

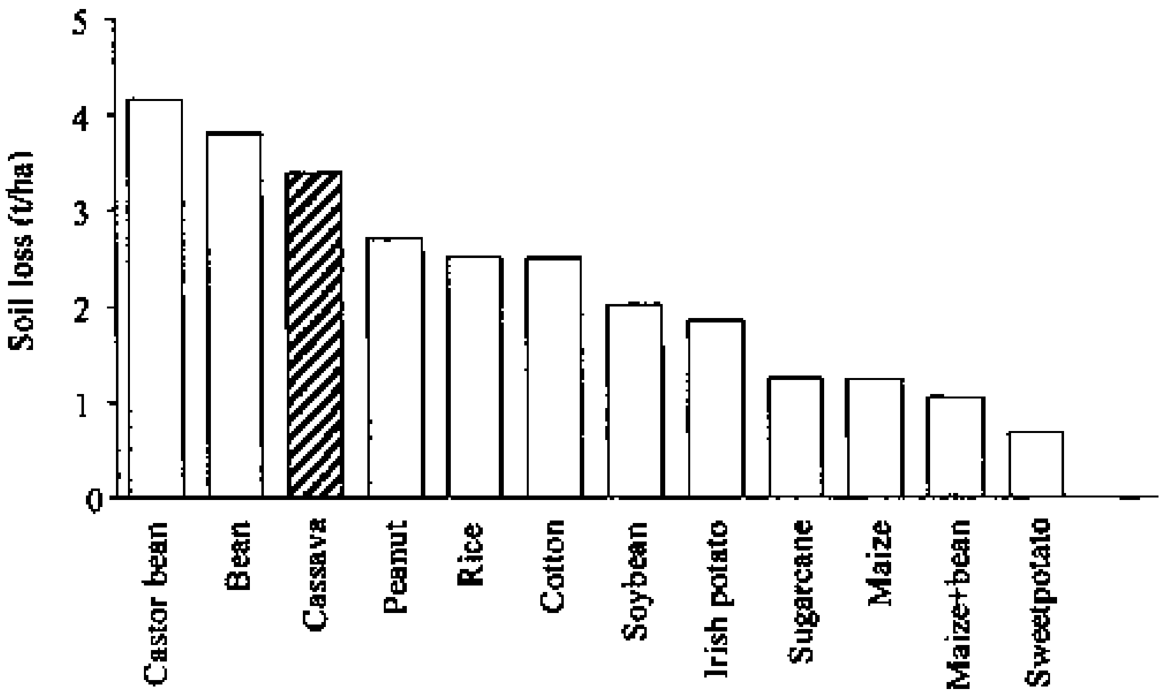
> *"I think using animals in medical is a bad idea because people and animals suffer from different disease and the bodies of animals and humans are completely different. So how can scientists justify performing painful experiments on animals if they are so different?'*

Sam disagrees with Shauna. Your task is to rank these 6 different challenges given by Sam in terms of how strong you think they are.

Sam: I disagree…	**Your Ranking**
…even though animal and human bodies are completely different like you say, I think using animals in medical research is a good idea because it would be impossible to prove that a specific germ is responsible for a disease without the use of laboratory animals.	________
…I think using animals in medical research is good idea and very useful.	________
…animals are not that different from humans. Animals and humans have similar organs and animals suffer from many of the same diseases that we do.	________
…because you don't know what you are talking about. You just care more about animals then you do about people.	________
…an animal is only chosen for research if it shares characteristics with people that are relevant to the research. For example; animals share many of the same organs as people so they can be used to develop new surgical techniques. Organ transplants, open heart surgery, and many other procedures that are common today were developed by experimenting with animals.	________
…how can using animals in research be a bad idea if it allows scientists to do research without having to conduct painful experiments on people?	________

Appendix S4: Written Scientific Explanation Assessment

Examine the following bar graph.



Write a **scientific explanation** that answers the question: Which crop is the most resistant to the effects of erosion?

Appendix S5: Scientific Explanation Base Rubric

Component	**Levels** 0	1	2
Claim *A statement or conclusion that answers the original question/problem.*	Does not make a claim, or makes an inaccurate claim.	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence *Scientific data that support the claim. The data need to be appropriate and sufficient to support the claim.*	Does not provide evidence, or only provides inappropriate evidence (evidence that does not support claim).	Provides appropriate but insufficient evidence o support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support claim.
Reasoning *A justification that connects the evidence to the claim. It shows why the data count as evidence by using appropriate and sufficient scientific principles.*	Does not provide reasoning, or only provides inappropriate reasoning.	Provides reasoning that connects the evidence to the claim. May include some scientific principles or justification for why the evidence supports the claim, but it is not sufficient.	Provides reasoning that connects the evidence to the claim. Includes appropriate and sufficient scientific principles to explain why the evidence supports the claim.

Source: McNeill, Lizote, Krajcik, & Marx (2006), p. 189

Appendix S6: Specific Rubric for Scientific Explanation Assessment

Component	Levels 0	1	2
Claim *A statement or conclusion that answers the original question/problem.*	Does not make a claim, or makes an inaccurate claim.	Does not apply to this assessment task.	Makes an accurate and complete claim.
Exemplars	"Castor bean is the most resisitant to the effects of erosion."		"Sweet potato is the most resistant to the effects of erosion."
Evidence *Scientific data that support the claim. The data need to be appropriate and sufficient to support the claim.*	Does not provide evidence, or only provides inappropriate evidence or vague evidence.	Provides appropriate, but insufficient evidence to support the claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support the claim. Includes no inappropriate evidence.
Exemplars	"The bar graph shows me it is true."	"The bar graph shows that sweet potato did not lose a lot of soil."	"The bar graph shows that sweet potato had the <u>least</u> amount of soil loss out of all the crops."
Reasoning *A justification that links the claim and evidence and includes appropriate and sufficient scientific principles to defend the claim and evidence.*	Does not provide reasoning, or only provides reasoning that does not link evidence to the claim.	Repeats evidence and links it to the claim. May include some scientific principles, but not sufficient.	Provides accurate and complete reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.
Exemplars	"Castor bean has the tallest bar on the bar graph."	"Since sweet potato had the least amount of soil loss, it is the most resisitant to the effects of erosion."	"Erosion is the movement of weathered rock and soil from one place to another. Since sweet potato had the least amount of soil loss out of all the crops, it is the most resisitant to the effects of erosion."

APPENDIX T
ADMINISTRATION SCRIPTS

Appendix T1: Script for the Demographic Information Survey and the NSAAQ

Cue

"You are going to complete two questionnaires today. The questionnaires have been stapled together to form one packet. I want to ensure you that your responses to these questionnaires will not affect your course grade in any way."

"You'll only need a pencil or pen. I'm going to hand out the questionnaire packets now. You may begin completing the *Demographic Information Survey* on the front page of the packet. However, please wait for me to explain the directions before you begin the other questionnaire in the packet.

Do

Pass out the questionnaire packets. Once all participants have a packet, say the following:

Cue

"After you complete the *Demographic Information Survey,* you will begin *The Nature of Science as Argument Questionnaire*. Please turn to page 2 in your packet as I explain the directions for completing this questionnaire.

"You will read the following pairs of statements and then circle the number on the continuum that best describes your position on the issue described. The numbers on the continuum mean:
1 = I completely agree with viewpoint A and I completely disagree with viewpoint B
2 = I agree with both viewpoints, but I agree with viewpoint A more than I agree with viewpoint B
3 = I agree with both viewpoints equally
4 = I agree with both viewpoints, but I agree with viewpoint B more than I agree with viewpoint A
5 = I completely agree with viewpoint B and I completely disagree with viewpoint A"

"Please circle only one number for each pair of statements. Remember to complete all 26 items as honestly as possible."

"You may get started now. Please remember to take your time, read each item carefully, and respond as honestly as possible. Once you're done, raise your hand and I'll come by and pick up your completed packet.

Do

When a participant is done, make sure that there is a first and last name on the first page of the packet, then review all the responses to make sure the participant hasn't missed any items. If there aren't any missing responses, put the completed packet into the original envelope. If there is a missing response, return it to the participant and ask them to complete the missing item(s).

Please list the names of any absent students here:

____

____

____

____

____

Appendix T2: Script for The Argumentation Test

Cue

“You are going to complete *The Argumentation Test* today. I want to ensure you that your responses to this assessment will not affect your course grade in any way.”

“You’ll only need a pencil or pen. I’m going to hand out the assessment now. Please write your first and last name on the front of the assessment. You may also fill in the demographic information, such as your gender, age, year in college, and primary language spoken. However, please wait for me to explain the directions before you begin the assessment.”

Do

Pass out the assessment. Once all participants have an assessment, say the following:
“Please follow along as I explain the directions for completing this assessment.”

Cue

“Part I is titled *Making a Scientific Argument*. The questions in this section are designed to determine what you think counts as a good *scientific*
argument. In the first three questions, you will be given a claim. Following the claim are 6 different arguments. Your job is to rank the arguments in order using the following scale:
1 = This is the **most** convincing argument
2 = This is the **2nd most** convincing argument
3 = This is the **3rd most** convincing argument
4 = This is the **4th most** convincing argument
5 = This is the **5th most** convincing argument
6 = This is the **least** convincing argument”

“For each question, you can only use each ranking once.”

“Part II is titled Challenging Arguments. The questions in this section are designed to determine what you think counts as a good *challenge* to a scientific argument. In questions 4-6, you will be given a claim supported by an argument. Following the claim are 6 different challenges. Your job is to rank the arguments in order using the following scale:
1 = This comment is the **strongest** challenge to this argument
2 = This comment is the **2nd strongest** challenge to this argument
3 = This comment is the **3rd strongest** challenge to this argument
4 = This comment is the **4th strongest** challenge to this argument
5 = This comment is the **5th strongest** challenge to this argument
6 = This comment is the **weakest** challenge to this argument”

Again, for each question, you can only use each ranking once.”

"You may get started now. Please remember to take your time, read each item carefully, and respond as honestly as possible. Once you're done, raise your hand and I'll come by and pick up your completed assessment.

Do

When a participant is done, make sure that there is a first and last name on the first page of the assessment, then review all the responses to make sure the participant hasn't missed any items. If there aren't any missing responses, put the completed packet into the original envelope. If there is a missing response, return it to the participant and ask them to complete the missing item(s).

Please list the names of any absent students here:

____

____

____

____

____

Appendix T3: Script for the Written Scientific Explanation Assessment

Cue

"You are going to complete a *Written Scientific Explanation Assessment* today. I want to ensure you that your performance on this assessment will not affect your course grade in any way."

"You'll only need a pencil or pen. I'm going to hand out the assessment now. Please write your first and last name on the top and then wait for me to review the directions before you get started."

Do

Pass out the assessment. Once all participants have a packet, say the following:

Cue

"This assessment consists of one open-ended items. You will examine the secondhand data displayed and then write a scientific explanation to answer the question presented."

"You may get started now. Please remember to take your time, read the item carefully, and write as neatly as possible. Once you're done, raise your hand and I'll come by and pick up your assessment."

Do

When a participant is done, make sure that there is a first and last name on the first page of the packet and place the completed assessment into the original envelope.

Please list the names of any absent students here:

____

____

____

____

____

APPENDIX U
FIDELITY OF IMPLEMENTATION

Appendix U1: Phase 1 Fidelity Checklist

TSAF Implementation

Phase 1 Fidelity Checklist

Instructor name:

Weeks 4 5 6 7 8 9 11 12 13 14 15

Reviewer name: **Date Began:** **Date Completed:**

PFS: **PF%:**

CUE		
Instructions: Please check "Yes" or "No" for the following components and then score each section. Yes = 1 No = 0 Points		
	YES	**NO**
Bridged from previous class session		
Oriented PSTs to current lesson (i.e., introduced topic, accessed/reviewed prior knowledge)		
Shared learning goal(s)/objective(s)		
Section score: /3		

DO		
	YES	**NO**
Instructor provided PPT overview of importance/benefits of engaging elementary students in scientific explanation		
Instructor provided PPT overview of the connections between literacy and science		
Instructor provided PPT overview of the TSAF, including examples of how each of the three components can be employed during classroom instruction		
Instructor provided PPT overview of the CER Framework		
Instructor distributed CER handout to be used by PSTs as a reference for the remainder of the semester		
Instructor distributed and provided an overview of the scientific explanation base rubric		
Instructor guided PSTs in the process of critiquing three sample explanations using the base rubric		

Instructor discussed how the samples ranged in complexity, from simple (claim + 1 piece of evidence) to complex (claim + multiple pieces of evidence + reasoning)		
Section score: /8		

REVIEW/REFLECT		
	YES	**NO**
Instructor reviewed the three features of the TSAF (i.e., argument structure, making thinking visible, and language of science)		
Instructor reviewed components of CER Framework (i.e., claim, evidence, and reasoning)		
Instructor reviewed the role of explanation in science		
Section score: /3		

SALIENT FEATURES AND ESSENTIAL COMPONENTS		
	YES	**NO**
Made explicit connections between literacy and science		
Made connections to elementary students and/or classroom practice		
Emphasized the nature of science (i.e., makes explicit what scientists do and why, talks about the work of real scientists)		
Section Score: /3		

ADDITIONAL INFORMATION

Weekly Fidelity Score (WFS):
Cue _______ + Do _______ + Review _______ + Salient _______ = _______ / 17

PFS ________ /17 = _______ PF %

Total time of instruction:

Reviewer comments:

Appendix U2: Phase 2 Fidelity Checklist

TSAF Implementation

Phase 2 Fidelity Checklist

Instructor name: **Weeks** 4 5 6 7 8 9 11 12 13 14 15

Reviewer name: **Date Began:** **Date Completed:**

Investigation 1 2 3 **PFS:** **PF%**

CUE		
Instructions: Please check "Yes" or "No" for the following components and then score each section. Yes = 1 No = 0 Points		
	YES	**NO**
Bridged from previous class session		
Oriented PSTs to current lesson (i.e., introduced topic, accessed/reviewed prior knowledge)		
Shared learning goal(s)/objective(s)		
Section score: /3		

DO		
	YES	**NO**
Instructor encouraged PSTs to pursue testable questions		
Instructor provided opportunities for PSTs to read about the phenomena under study		
Instructor engaged PSTs in an academic vocabulary building strategy (e.g., Frayer Model, Concept of Definition Map, Semantic Feature Analysis)		
Instructor provided opportunities for PSTs to engage firsthand with the phenomena under study		
Instructor engaged PSTs in the process of collecting, recording, and representing data		
Instructor encouraged PSTs to identify patterns in their data (i.e., *What claim can you make based on the evidence?)*		
Instructor reviewed the three components of scientific explanation (i.e., claim, evidence, and reasoning)		

Instructor displayed visual representation of CER Framework		
Instructor provided writing scaffolds to assist PSTs in constructing a scientific explanation		
Instructor used a series of talk moves (e.g., *Would someone like to add to that?*) to make PSTs' thinking visible and foster peer interactions.		
Instructor used productive questioning techniques (e.g., *What evidence helped you arrive at that conclusion?)* to scaffold PSTs' communication of scientific ideas and evidence in ways that reflect scientific discourse.		
Instructor made connections to the big idea/science concept		
Section score: /12		
REVIEW/REFLECT		
	YES	**NO**
PSTs were provided with an opportunity to unpack lesson from the perspective of the teacher (using the three features of the TSAF as a heuristic).		
PSTs discussed how the lesson supports <u>all</u> students in constructing, communicating, and debating evidence-based scientific claims.		
Instructor reviewed components of CER Framework		
Instructor reviewed the role of explanation in science		
Section score: /4		
SALIENT FEATURES AND ESSENTIAL COMPONENTS		
	YES	**NO**
Made explicit connections between literacy and science		
Made connections to elementary students and/or classroom practice		
Emphasized the nature of science (i.e., makes explicit what scientists do and why, talks about the work of real scientists)		
Placed attention on developing academic vocabulary		
Engaged PSTs in science reading, writing, and talk		
Several talk turns between PSTs not directly involving instructor during whole-group discussion		
Section Score: /6		

ADDITIONAL INFORMATION	
Weekly Fidelity Score (WFS): **Cue _______ + Do _______ + Review _______ +** **Salient _______ = _______ / 25**	**PFS ________ /25 = _______ PF %**

Reviewer comments:

Appendix U3: Phase 3 Fidelity Checklist

TSAF Implementation **Phase 3 Fidelity Checklist**		
Instructor name:	**Weeks** 5 6 7 8 9 11 12 13 14 15	
Reviewer name:	**Date Began:**	**Date Completed:**
	PFS:	**PF%:**
CUE		
Instructions: Please check "Yes" or "No" for the following components and then score each section. Yes = 1 No = 0 Points		
	YES	**NO**
Shared rationale for lesson plan assignment (i.e., to provide PSTs an opportunity to apply their developing understandings of the TSAF when planning for science instruction)		
Distributed and discussed planning questions related to the TSAF		
Reviewed/discussed lesson plan rubric		
Section score: /3		
DO		
	YES	**NO**
Instructor provided in-class time for PSTs to work on their group lesson plans		
Instructor provided support during the planning process (i.e., referred to the planning questions to help PSTs negotiate the content and sequencing of their lessons)		
Instructor engaged PSTs in the process of reviewing other groups' lesson plans (using the TSAF as a heuristic) and to offer suggestions for improvement		
Instructor allowed PSTs to revise their group lessons based on peer suggestions		

Instructor provided class time for each group to present their final inquiry-based science lesson		
Section score: /5		
REVIEW/REFLECT		
	YES	**NO**
Instructor engaged PSTs in self-reflection of their own lessons (using the three features of the TSAF as a heuristic)		
PSTs reflected upon how their lesson supports <u>all</u> students in constructing, communicating, and debating evidence-based scientific claims.		
Instructor reviewed the role of explanation in science		
Section score: /3		

SALIENT FEATURES AND ESSENTIAL COMPONENTS		
	YES	**NO**
Made explicit connections between literacy and science		
Made connections to elementary students and/or classroom practice		
Emphasized the nature of science (i.e., makes explicit what scientists do and why, talks about the work of real scientists)		
Provided targeted feedback to each collaborative group		
Section Score: /4		

ADDITIONAL INFORMATION	
Weekly Fidelity Score (WFS): **Cue _______ + Do _______ + Review _______ +** **Salient _______ = _______ / 15**	**PFS ________ /15 = _______ PF %**
Reviewer comments:	

Appendix U4: Instructor Fidelity Worksheet

TSAF Implementation

Instructor Fidelity Worksheet

Teacher name: **TFS:** **TF %:**

Reviewer name: **Worksheet completion date:**

INTERVENTION PHASE 1

P1 FS ________ /17 = _______ PF %

INTERVENTION PHASE 2

P2 FS (Investigation 1) ________ /25 = _______ PF %
P2 FS (Investigation 2) ________ /25 = _______ PF %
P2 FS (Investigation 3) ________ /25 = _______ PF %
P2 Total FS = Investigation 1 _______+ Investigation 2 _______+ Investigation 3 _______= / 75

INTERVENTION PHASE 3

P3 FS ________ /15 = _______ PF %

TOTAL FIDELITY SCORES

Total Fidelity Score (TFS): P1 FS _________ + P2 Total FS _________ + P3 FS _________ = / 107

Total Fidelity %: TFS ___________ / 107 = __________ TF%

APPENDIX V
INTERRATER RELIABILITY

Appendix V1: Assessment Interrater Reliability Worksheet

Rater Name: Date:

NSAAQ PRETEST		
Participant Code	Score 1	Score 2

NSAAQ POSTTEST		
Participant Code	Score 1	Score 2

THE ARGUMENTATION PRETEST		
Participant Code	Score 1	Score 2

THE ARGUMENTATION POSTTEST		
Participant Code	Score 1	Score 2

SCIENTIFIC EXPLANATION PRETEST		
Participant Code	Score 1	Score 2

SCIENTIFIC EXPLANATION POSTTEST		
Participant Code	Score 1	Score 2

Appendix V2: Interrater Reliability Instructor Fidelity Worksheet

P1 Fidelity Score: ________ /17	**P1 FS: ________ /17 = _______ PF %**
P1 Interrater Score: ________ /17	**P1 FS: ________ /17 = _______ PF %**
INTERVENTION PHASE 2	
Investigation 1	
P2 Fidelity Score: __________ /25	**Investigation 1 FS: _______ /25 = _______ PF %**
P2 Interrater Score: ________ /25	**Investigation 1 FS: _______ /25 = _______ PF %**
Investigation 2	
P2 Fidelity Score: __________ /25	**Investigation 1 FS: _______ /25 = _______ PF %**
P2 Interrater Score: ________ /25	**Investigation 1 FS: _______ /25 = _______ PF %**
Investigation 3	
P2 Fidelity Score: __________ /25	**Investigation 1 FS: _______ /25 = _______ PF %**
P2 Interrater Score: ________ /25	**Investigation 1 FS: _______ /25 = _______ PF %**
P2 Total FS = **Investigation 1 ______+ Investigation 2 ______+ Investigation 3 ______= / 75**	
P2 Interrater Total FS = **Investigation 1 ______+ Investigation 2 ______+ Investigation 3 ______= / 75**	
INTERVENTION PHASE 3	
P3 Fidelity Score: __________ /15	**P3 FS: ________ /15 = _______ PF %**
P3 Interrater Score: ________ /15	**P3 FS: ________ /15 = _______ PF %**
TOTAL FIDELITY SCORES	
Total Fidelity Score (TFS): P1 FS _________ + P2 Total FS _________ + P3 FS _________ = / 107	
Interrater TFS: P1 FS _________ + P2 Total FS _________ + P3 FS _________ = / 107	
Total Fidelity %: TFS ___________ / 107 = __________ TF%	
Interrater Total Fidelity %: TFS ___________ / 107 = __________ TF%	

APPENDIX W
COPYRIGHT PERMISSIONS

Appendix W1: John Wiley and Sons Permission

**JOHN WILEY AND SONS LICENSE
TERMS AND CONDITIONS**

May 22, 2019

This Agreement between Rebeca Grysko ("You") and John Wiley and Sons ("John Wiley and Sons") consists of your license details and the terms and conditions provided by John Wiley and Sons and Copyright Clearance Center.

License Number	4556590782914
License date	Mar 26, 2019
Licensed Content Publisher	John Wiley and Sons
Licensed Content Publication	Science Education
Licensed Content Title	Learning to teach elementary school science as argument
Licensed Content Author	Carla Zembal-Saul
Licensed Content Date	Apr 27, 2009
Licensed Content Pages	33
Type of use	Dissertation/Thesis
Requestor type	University/Academic
Format	Print and electronic
Portion	Figure/table
Number of figures/tables	2
Original Wiley figure/table number(s)	Figure 1 and Table 1
Will you be translating?	No
Title of your thesis / dissertation	Using Argument as a Bridge Between Literacy and Science: An Intervention Study in a Science Methods Course for Elementary Preservice Teachers
Expected completion date	Jun 2019
Expected size (number of pages)	300
Requestor Location	Rebeca Grysko 13207 Charfield St. WINDERMERE, FL 34786 United States Attn: Rebeca Grysko

Appendix W2: Harvard Education Publishing Group Permission

Dear Rebeca Grysko,

Greetings from the office of Harvard Education Publishing Group. My name is Laura and I assist the editors with rights and permissions. I am in touch with you today on behalf of HEPG, regarding your request to include a figure from Harvard Educational Review in your doctoral dissertation.

In reply to your request of March 26, 2019, I am pleased to grant permission to reprint the following material for use in your doctoral dissertation. Permission is granted for non-exclusive, non-transferable use, in print and electronic media, in English, for scholarly purposes only. Any other uses will require an additional request.

Please give credit to the authors and the Review in this, or a similar, manner on all copies made: Figure 1, page 44, from "Teaching Disciplinary Literacy to Adolescents: Rethinking Content-Area Literacy" by T. Shanahan, C. Shanahan, 2008, Harvard Educational Review, 78(1), pp. 40-59. Copyright © President and Fellows of Harvard College. All rights reserved. Used with permission.

We waive our customary fee for this purpose.

Please let me know if you have any questions or if I may assist you in any way.

With all best wishes,

Laura Clos
Rights and Permissions
Harvard Education Publishing Group
A part of the President and Fellows of Harvard College
Laura Clos
Harvard Education Publishing Group
8 Story Street, 1st Floor, Cambridge, MA 02138 USA
617-495-3432 (ph)
617-384-7257 (vm)
617-496-3584 (fax)
laura_clos@harvard.edu
www.hepg.org

Appendix W2: NSAAQ and The Argumentation Test Permission

DEPARTMENT OF CURRICULUM AND INSTRUCTION
THE UNIVERSITY OF TEXAS AT AUSTIN

1 University Station D5700 • Austin, TX 78712
(512) 471-5942 • http://ci.edb.utexas.edu

December 4, 2018

Dear Researcher:

You have my permission to use The Nature of Science as Argument Questionnaire and/or The Argumentation Test in your research. Copies of the instruments are included. Request for any changes or alterations to the instrument should be sent via email to victor.sampson@utexas.edu. When using the instrument please use the following reference:

Sampson, V. and Clark, D. (2006, April). The development and validation of the Nature of Science as Argument Questionnaire (NSAAQ). Paper presented at the 2006 International Conference of the National Association of Research in Science Teaching (NARST). San Francisco, CA.

Clark, D. and Sampson, V. (2006, June). Evaluating argumentation in science education: New assessment tools. Presentation given as part of the symposium, "Argumentative Knowledge Construction in CSCL" at the 7th International Conference of the Learning Sciences (ICLS). Bloomington, Indiana.

Respectfully,

Victor Sampson, Ph.D.
Associate Professor of STEM Education
Fellow, Elizabeth Massey Chair in Education
Department of Curriculum and Instruction
College of Education
The University of Texas at Austin
victor.sampson@utexas.edu

REFERENCES

Abd-El-Khalick, F., & Lederman, N.G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, *22*, 665–701.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: A project 2061 report*. New York: Oxford University Press.

Anderson, R. (1984). Some reflections on the acquisition of knowledge. *Educational Researcher*, *13*(9), 5–10.

Anderson, R. C., Hiebert, E. H., Scott, J. A., & Wilkinson, I. A. G. (1985). *Becoming a nation of readers: The report of the commission on reading*. Washington, DC: National Academy of Education, National Institute of Education & Center for the Study of Reading.

Anderson, R. C., & Pearson, P. D. (1984). A schema-theoretic view of basic processes in reading comprehension. In P. D. Pearson (Ed.), *Handbook of reading research* (Vol. 1, pp. 255–291). New York: Longman.

Association, I. L. (2018). Literacy Glossary. Retrieved August 11, 2018, from https://www.literacyworldwide.org/get-resources/literacy-glossary

Aydeniz, M., & Ozdilek, Z. (2015). Assessing pre-service science teachers' understanding of scientific argumentation: What do they know about argumentation after four years of college science? *Science Education International* , *26*(2), 217–239.

Aydeniz, M., Pabuccu, A., Cetin, P. S., & Kaya, E. (2012). Argumentation and students' conceptual understanding of properties and behaviors of gases. *International Journal of Science and Mathematics Education*, *10*(6), 1303–1324. https://doi.org/10.1007/s10763-012-9336-1

Bandura, A. (1997). *Self efficacy: The exercise of control*. New York, NY: W.H. Freeman.

Barreto-Espino, R., Avraamidou, L., & Zembal-Saul, C. (2014). Prospective elementary teachers' knowledge of teaching science as argument: A case study. *School Science and Mathematics*, *114*(2), 53–64. https://doi.org/10.1111/ssm.12052

Bell, P., & Linn, M. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education*, *22*, 797–817.

Benus, M. J., Yarker, M. B., Hand, B. M., & Norton-Meier, L. (2013). Analysis of discourse practices in elementary science classrooms using argument-based inquiry during whole-class dialogue. In M. S. Khine & I. M. Saleh (Eds.), *Approaches and strategies in next generation science learning* (pp. 224–245). Hershey, PA: Information Science Reference.

Beyer, C., & Davis, E. (2008). Fostering second graders' scientific explanations: A beginning elementary teacher's knowledge, beliefs, and practice. *Journal of the Learning Sciences*, *17*(3), 381–414. https://doi.org/10.1080/10508400802222917

Biological Sciences Curriculum Study. (1989). *New designs for elementary school science and*

health: A cooperative project of Biological Sciences Curriculum Study (BSCS) and International Business Machines (IBM). Dubuque, IA: Kendall/Hunt.

Boyer, E. (2016). Preservice elementary teachers' instructional practices and the teaching science as argument framework. *Science & Education*, *25*(9–10), 1011–1047. https://doi.org/10.1007/s11191-016-9864-0

Brandt, D., & Clinton, K. (2002). Limits of the local: Expanding perspectives on literacy as a social practice. *Journal of Literacy Research*, *34,* 337–356.

Brent, R., Wheatley, E., & Thomson, S. (1996). Videotaped microteaching: Bridging the gap from the university to the classroom. *The Teacher Educator*, *31*(3), 238–247.

Brookfield, S. (1995). *Becoming a critically reflective teacher*. San Francisco, CA: Jossey Bass.

Bruner, J. (1983). *Child's talk*. New York, NY: Norton.

Bulgren, J. A., & Lenz, B. K. (1996). Strategic instruction in the content areas. In D. D. Deshler, E. S. Ellis, & B. K. Lenz (Eds.), *Teaching adolescents with learning disabilities: Strategies and methods* (pp. 409–473). Denver, CO: Love Publishing.

Cavagnetto, A. (2010). Argument to foster scientific literacy: A review of argument interventions in K–12 science contexts. *Review of Educational Research*, *80*(3), 336–371.

Cervetti, G. N., Hiebert, E. H., Pearson, P. D., & McClung, N. A. (2015). Factors that influence the difficulty of science words. *Journal of Literacy Research*, *47*(2), 153–185.

Chen, Y.-C., Hand, B., & Norton-Meier, L. (2017). Teacher roles of questioning in early elementary science classrooms: A framework promoting student cognitive complexities in argumentation. *Science Education*, *47*, 373–405.

Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching*, *44*, 815–843.

Clark, D., & Sampson, V. (2006). Evaluating argumentation in science education: New assessment tools. Presentation given as part of the symposium, "Argumentative Knowledge Construction in CSCL" at the 7th International Conference of the Learning Sciences (ICLS). Bloomington, Indiana.

Creech, J., & Hale, G. (2006). Literacy in science: A natural fit. *The Science Teacher*, *73*(2), 22–27.

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

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks: CA: Sage.

Croninger, R., Li, M., Cameron, C., & Murphy, K. (2018). Classroom discussions: Building the foundation for productive talk. In *Classroom discussions in education* (K.P. Murph, pp. 1–29). New York: NY: Routledge.

Davis, E., & Bricker, L. (2011). Science and literacy in teacher education: What do preservice

teachers need to know and be able to do? Retrieved from http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_086022.pdf

Davis, E., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research*, *76*(4), 607–651.

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process*. Boston, MA: Heath.

Dillman, D., Smyth, J., & Christian, L. M. (2014). *Internet, mail, and mixed mode surveys: The tailored design method* (4th ed.). Hoboken, NJ: Wiley.

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

Durlak, J. A., & DuPre, E. P. (2008). Implementation matters: A review of research on the influence of implementation on program outcomes and the factors affecting implementation. *American Journal of Community Psychology*, *41*, 327–350.

Duschl, R. (2000). Making the nature of science explicit. In R. Millar, J. Leach, & J. Osborne (Eds.), *Improving science education: Contributions from research* (pp. 187–206). Philadelphia: PA: Open University Press.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*, 39–72.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grade K-8*. Washington, DC: National Academy Press.

Edmonds, A., & Kennedy, T. (2013). *An applied reference guide to research designs: Quantitative, qualitative, and mixed methods*. Thousand Oaks, CA: Sage.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPing into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education*, *88*, 915–933.

Fang, Z. (2004). Scientific literacy: A systemic functional linguistics perspective. *Science Education*, *89*(2), 335–347.

Fang, Z. (2006). The language demands of science reading in middle school. *International Journal of Science Education*, *28*(5), 491–520.

Fang, Z., Lamme, L., & Pringle, R. (2010). *Language and literacy in inquiry-based science classrooms, Grades 3-8*. Thousand Oaks: CA: Corwin.

Fang, Z., Lamme, L., Pringle, R., & Abell, S. (2010). *Language and literacy in inquiry-based science: Classrooms, Grades 3-8*. Thousand Oaks: CA: Corwin.

Fang, Z., & Schleppegrell, M. (2010). Disciplinary literacies across content areas: Supporting secondary reading through functional language analysis. *Journal of Adolescent & Adult Literacy*, *53*(7), 587–597.

Fang, Z., & Wei, Y. (2010). Improving middle school students'science literacy through reading infusion. *The Journal of Educational Research*, *103*, 262–273.

Frankel, K., Becker, B., Rowe, M., & Pearson, D. (2016). From “what is reading?” to what is literacy? *Journal of Education*, *196*(3), 7–17.

Freeman, G., & Taylor, V. (2006). *Integrating Science and Literacy Instruction: A Framework for Bridging the Gap*. Lanham, MD: Rowman and Littlefield Education.

Gast, D. L. (2010). *Single subject research methodology in behavioral sciences*. New York and London: Routledge Taylor & Francis Group.

Gee, J. P. (1999). Critical issues: Reading and the new literacy studies: Reframing the national academy of sciences report on reading. *Journal of Literacy Research*, *31*(3), 355–374.

Gee, J. P. (2004). Language in the science classroom: Academic social languages as the heart of school-based literacy. In W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory into practice* (pp. 13–32). Newark, DE: International Reading Association.

Gess-Newsome, J., & Lederman, N. . (1995). Biology teachers' perceptions of subject matter structure andits relationship to classroom practice. *Journal of Science Teaching*, *32*, 301–325.

Gillis, V. (2014). Disciplinary Literacy: Adapt not adopt. *Journal of Adolescent & Adult Literacy*, *57*(8), 614–623.

Glaser, B., & Strauss, L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago, IL: Aldine Publishing Company.

Goldschmidt, P., & Jung, H. (2011). *Evaluation of seeds of science/roots of reading: Effective tools for developing literacy through science in the early grades - light energy unit*. Los Angelos, CA: National Center for Research on Evaluation, Standards, and Student Testing (CRESST).

Grubbs, F. (1969). Procedures for detecting outlying observations in samples. *Technometrics*, *11*(1), 1–21.

Guskey, T. R. (2000). *Evaluating professional development*. Thousand Oaks, CA: Corwin Press.

Guthrie, J., Anderson, E., Alao, S., & Reinhart, J. (1999). Influences of concept-oriented reading instruction on strategy use and conceptual learning from text. *The Elementary School Journal*, *99*(4), 343–366.

Guthrie, J., Wigfield, A., Barbosa, P., Perencevich, K., Taboada, A., Davis, M., … Tonks, S. (2004). Increasing reading comprehension and engagement through concept-oriented reading instruction. *Journal of Educational Psychology*, *96*(3), 403–423.

Halliday, M. A. K. (1994). *Introduction to functional grammer* (2md ed.). London: Edward Arnold.

Hand, B., Alvermann, D., Gee, J., Guzzetti, B., Norris, S., & Phillips, L. (2003). Guest editorial:

Message from the “Island Group”: What is literacy in science literacy? *Journal of Research in Science Teaching*, *40*(7), 607–615.

Hapgood, S., Magnusson, S. J., & Palincsar, A. S. (2004). A very science-like kind of thinking: How young children make meaning from first- and second-hand investigations. *Journal of Learning Sciences*, *13*(4), 455–506.

International Literacy Association. (2012). *Adolescent literacy (Position statement, Rev. 2012 ed.).* Newark, DE: Author.

Jimenez-Aleixandre, M. P., & Erduran, S. (2007). Argumentation in science education: An overview. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 3–28). Dordrecht, Netherlands: Springer.

Kolb, S. (2012). Grounded theory and the constant comparative method: Valid research strategies for educators. *Journal of Emerging Trends in Educational Research and Policy Studies*, *3*(1), 83–86.

Krajcik, J. S., & Sutherland, L. . (2010). Supporting students in developing literacy in science. *Science*, *328*(5977), 456–459.

Kuhn, D. (1993). Science as argument: implications for teaching and learning scientific thinking. *Science Education*, *77*(3), 319–337.

Kutluca, A. Y., & Aydin, A. (2017). Changes in pre-service science teachers’ understandings after being involved in explicit nature of science and socioscientific argumentation processes. *Science & Education*, *26*, 637–668.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, England: Cambridge University Press.

Lederman, N. (1992). Students’ and teachers’ conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*, 331–359.

Lee, C. D., & Smagorinsky, P. (2000). Constructing meaning through collaborative inquiry. In C. D. Lee & P. Smagorinsky (Eds.), *Vygotskian perspectives on literacy research*. Cambridge, England: Cambridge University Press.

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Norwood, NJ: Ablex Publishing Corporation.

Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives onscience education. *Journal of Research in Science Teaching*, *38*, 296–316.

Lomax, R. G., & Hahs-Vaughn, D. L. (2012). *An introduction to statistical concepts. (3rd ed.)*. New York, NY: Routledge/Taylor Francis.

Martella, R., Nelson, R., Morgan, R., & Marchand-Martella, N. (2013). *Understanding and interpreting educational research*. New York, NY: Guilford Press.

McDonald, C. (2010). The influence of explicit nature of science and argumentation instruction

on preservice primary teachers' views of nature of science. *Journal of Research in Science Teaching*, *47*(9), 1137–1164. https://doi.org/10.1002/tea.20377

McKeown, M. G., Beck, I. L., & Blake, R. G. K. (2009). Rethinking reading comprehension instruction: A comparison of instruction for strategies and content approaches. *Reading Research Quarterly*, *44*(3), 218–252.

McNeill, K. L. (2011). Elementary students' views of explanation, argumentation and evidence and abilities to contruct arguments over the school year. *Journal of Reseach in Science Teaching*, *48*, 793–823.

McNeill, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on k–12 teachers. *Science Education*, *97*, 936–972.

McNeill, K. L., & Krajcik, J. S. (2007). Middle school students' use of appropriate and inappropriate evidence in writing explanations. In M. Lovett & P. Shah (Eds.), *Thinking with data* (pp. 233–265). New York: Taylor & Francis.

McNeill, K. L., & Krajcik, J. S. (2008). Scientific explantions: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching*, *45*(1), 53–78.

McNeill, K. L., & Krajcik, J. S. (2012). *Supporting grade 5-8 students in constructing explanations in science: The claim, evidence, and reasoning framework for talk and writing*. Boston, MA: Pearson.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006a). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of Learning Sciences*, *15*(2), 153–191.

McNeill, K. L., Lizotte, D. J., Krajcik, J. S., & Marx, R. W. (2006b). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of Learning Sciences*, *15*(2), 153–191.

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education*, *94*(2), 203–229.

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

Moje, E. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent & Adult Literacy*, *52*(2), 96–107.

Moje, E. (2015). Doing and teaching disciplinary literacy with adolescent learners: A social and cultural enterprise. *Harvard Educational Review*, *85*(2), 254–278.

National Assessment Governing Board, U. S. D. of E. (2014). *Science framework for the 2015 National Assessment of Educational Progress*. Retrieved August 26, 2018, from https://www.nagb.gov/content/nagb/assets/documents/publications/frameworks/science/2

015-science-framework.pdf

National Center for Educational Statistics. (2012). *NAEP achievement levels*. Retrieved from https://nces.ed.gov/nationsreportcard/achievement.aspx

National Center for Educational Statistics. (2015). *The nation's report card: Science 2015*. Washington, DC: Author. Retrieved from www.nationsreportcard.gov

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core State Standards for English language arts and literacy in history/social studies, science, and technical subjects*. Washington, DC: Author.

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

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

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

Nelson, V. (2010). Learning English, learning science: How science notebooks can help English language learners with two subjects. *Science and Children*, *3*, 48–51.

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, *21*, 553–576.

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

Norris, S., & Phillips, L. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240.

Ogunniyi, M. B. (2006). Using an argumentation-instrumental reasoning discourse to facilitate teachers' understanding of the nature of science. Paper Presented at the Annual Meeting of the National Association for Research in Science Teaching (NARST), San Francisco, CA.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, *328*(5977), 463–466.

Osborne, J., & Patterson, A. (2011). Scientific arguement and explanation: a necessary distinction? *Science Education*, *95*(4), 627–638.

Palincsar, A. S., & Brown, A. (1984). Reciprocal teaching of comprehension-fostering and comprehension monitoring activities. *Cognition and Instruction*, *1*(2), 117–175.

Palincsar, A. S., Collins, K., Marano, N., & Magnusson, S. J. (2000). Investigating the engagement and learning of students with learning disabilities in guided inquiry science teaching. *Language, Speech, and Hearing Services in Schools*, *31*, 240–251.

Pearson, D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. *Science, 328*, 459–463.

Pearson, P. D., Hiebert, E. H., & Kamil, M. L. (2007). Vocabulary assessment: What we know and what we need to learn. *Reading Research Quarterly*, *42*(2), 282–296.

Perry, K. (2012). What is literacy? - A critical overview of sociocultural perspectives. *Journal of Language & Literacy Education*, *8*(1), 50–71.

Phillips, L., & Norris, S. (2009). Bridging the gap between the language of science and the language of school science through the use of adapted primary literature. *Research in Science Education*, *39*, 313–319.

Piaget, J. (1969). *The psychology of intelligence*. Patterson, NJ: Littlefield, Adams.

Pressley, M., Wood, E., Woloshyn, V. E., Martin, V., King, A., & Menke, D. (1992). Encouraging mindful use of prior knowledge: Attempting to construct explanatory answers facilitates learning. *Educational Psychologist*, *27*(1), 91–109.

Provasnik, S., Malley, L., Stephens, M., Landeros, K., Perkins, R., & Tang, J. H. (2016). *Highlights from TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context (NCES 2017-002)*. U.S. Department of Education, National Center for Education Statistics. Washington, DC.

RAND Reading Study Group. (2002). *Reading for understanding: Toward an R & D program in reading comprehension*. Washington, DC: Office of Education Research and Improvement, U.S. Department of Education.

Robertshaw, B., & Campbell, T. (2013). Constructing arguments: Investigating pre-service science teachers' arguments in a socio-scientific context. *Science Education International*, *24*(2), 195–211.

Romance, N., & Vitale, M. (1992). A curriculum strategy that expands time for in-depth elementary science instruction by using science-based reading strategies: Effects of a year-long study in grade four. *Journal of Research in Science Teaching*, *29*, 545–554.

Romance, N., & Vitale, M. (2001). Implementing an in-depth expanded science model in elementary schools: Multi-year findings, research issues, and policy implications. *International Journal of Science Education*, *23*, 272–304.

Romance, N., & Vitale, M. (2017). Implications of a cognitive science model integrating literacy in science on achievement in science and reading: Direct effects in grades 3–5 with transfer to grades 6–7. *International Journal of Science and Mathematics Education*, *15*, 979–995.

Sadler, T. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*, 513–536.

Sadler, T. (2006). Promoting discourse and argumentation in science teacher education. *Journal of Science Teacher Education*, *14*(4), 323–346.

Sampson, V. (2009). Science teachers and scientific argumentation: Trends in practice and beliefs. In *Paper presented at the 2009 International Conference of the National*

Association of Research in Science Teaching. Garden Grove, CA.

Sampson, V., & Blanchard, M. (2012). Science teachers and scientific argumentation: Trends in views and practice. *Journal of Research in Science Teaching*, *49*, 1122–1148.

Sampson, V., & Clark, D. (2006). *The development and validation of the Nature of Science as Argument Questionnaire (NSAAQ)*. Paper presented at the 2006 International Conference of the National Association of Research in Science Teaching (NARST). San Francisco, CA.

Sandoval, W. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences*, *12*, 5–51.

Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction*, *23*(1), 23–55.

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

Schleppegrell, M. (2004). *The language of schooling: A functional linguistics perspective*. Mahwah, NJ: Lawrence Erlbaum.

Schwartz, R., & Raphael, T. (1985). Concept of defintion: A key to improving students' vocabulary. *Reading Teacher*, *39*, 198–203.

Shanahan, C., & Shanahan, T. (2014). Does disciplinary literacy have a place in elementary school? *The Reading Teacher*, *67*(8), 636–639.

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content- area literacy. *Harvard Educational Review*, *78*(1), 40–59.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 4–14.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, *28*, 235–260.

Street, B. V. (2003). What's "new" in New Literacy Studies? Critical approaches to literacy in theory and practice. *Current Issues in Comparative Education*, *5*(2), 77–91.

Tabachnick, B. G., & Fidell, L. S. (2014). *Using multivariate statistics (6th ed.)*. Essex, UK: Pearson.

Toulmin, S. E. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

Trygstad, P. J. (2013). *2012 National Survey of Science and Mathematics Education: Status of elementary school science*. Chapel Hill, NC: Horizon Research.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wang, J., & Herman, J. (2005). *Evaluation of seeds of science/roots of reading project:*

Shoreline science and terrarium investigations. Los Angeles, CA: National Center for Research on Evaluation, Standards, and Student Testing (CRESST).

Warwick, P., Stephenson, P., & Webster, J. (2003). Developing pupils' written expression of procedural understanding through the use of writing frames in science: Findings from a case study approach. *International Journal of Science Education*, *25*(2), 173–192.

Wellington, J., & Osborne, J. (2001). *Language and literacy in science education*. Philadelphia: PA: Open University Press.

Wolf, M. M. (1978). Social validity: The case for subjective measurement or how applied behavior analysis is finding its heart. *Journal of Applied Behavior Analysis*, *11*, 203–214.

Wright, T., & Domke, L. (2019). The role of language and literacy in k-5 science and social studies standards. *Journal of Literacy Research*, *51*(1), 5–29.

Yore, L., Bisanz, G., & Hand, B. M. (2003). Examining the literacy component of science literacy: 25 years of language and science research. *International Journal of Science Education*, *25*(6), 689–725.

Yore, L., & Treagust, D. (2006). Current realities and future possibilities: Language and science literacy - empowering research and informing instruction. *International Journal of Science Education*, *28*(2–3), 291–314.

Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education*, *93*(4), 687–719. https://doi.org/10.1002/sce.20325

Zembal-Saul, C., Munford, D., Crawford, B., Friedrichsen, P., & Land, S. (2002). Scaffolding preservice science teachers' evidence-based arguments during an investigation of natural selection. *Research in Science Education* , *32*(4), 437–463.

Zohar, A. (2008). Science teacher education and professional development in argumentation. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 245–268). Dordrecht, Netherlands: Springer.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Reseach in Science Teaching*, *39*, 35–62.

Zygouris-Coe, V. (2012). Disciplinary literacy and the common core state standards. *Topics in Language Disorders*, *32*(1), 35–50.

Zygouris-Coe, V. (2015). *Teaching discipline-specific literacies in grades 6-12*. New York, NY: Routledge.