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Understanding the Role of Science-Specific Literacy Strategies in Supporting Science Teaching and Student Learning: A Case Study of Preservice Elementary Teachers in a Science Methods Course that Integrated a Disciplinary Literacy Framework

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ABSTRACT

The shift to student engagement in scientific and engineering practices to learn science provides opportunities for science learning and language learning to occur in tandem. These opportunities also pose new challenges for elementary pre-service teachers (PSTs) since literacy methods courses have been presented separately from science methods courses. We integrated a disciplinary literacy framework in a science methods course to help elementary PSTs understand the synergistic connections between literacy and science teaching. The purpose of this study was to examine elementary PSTs' understanding of the use of science-specific literacy strategies to support science teaching and learning through three points of observation. Findings from three data sources indicated that PSTs showed a developing understanding of the role of disciplinary literacy in supporting student engagement in science practices and learning disciplinary core ideas. Implications for future uses of a disciplinary literacy framework for teaching and learning science and elementary PSTs' science preparation are presented.

Keywords: science methods course, elementary pre-service teachers, disciplinary literacy, science-specific literacy, teacher preparation, lesson planning

Introduction

The Next Generation Science Standards (NGSS) provide three dimensions to cultivate K-12 students' scientific habits of mind, develop their capability to engage in scientific inquiry, and teach them how to reason in a scientific context (National Research Council [NRC], 2012; NGSS Lead States, 2013). The NGSS call for sense-making through engaging students in science and engineering practices (SEPs) and learning disciplinary core ideas and crosscutting concepts (NGSS Lead States, 2013). SEPs involve making sense of the world (Schwarz et al., 2017) and require students to shift between everyday language and specialized language in science (Lee et al., 2013; NRC, 2012; Schwarz et al., 2017). Participation in language-intensive SEPs relies on science-specific literacy skills such as using technical vocabulary of science (Fang, 2004), comprehending scientific texts (Alvermann & Wilson, 2011; Sinatra & Broughton, 2011), and writing scientific explanations (Norris & Phillips, 2003). To support students' engagement in these practices, teachers need to understand how language and literacy practices support students in constructing and communicating meaning in science (Lee et al., 2013).

Elementary teachers typically teach science as part of an integrated language arts block. However, teacher education program structures often isolate literacy and science preparation (Pearson et al., 2010). Many elementary pre-service teachers (PSTs) take several literacy methods courses and a separate science methods course (Wallace & Coffey, 2019). This is not an ideal teacher preparation structure for facilitating PSTs' integration of science and literacy. To address this issue, elementary PSTs need to learn how to bridge science and literacy. They need to support students' use of science-specific language to participate in SEPs (Howes et al., 2009; Lemke, 1990). However, research showed that even though elementary teachers understood the importance of engaging students in scientific practices, they needed support in engaging their students in those practices (Bismack et al., 2014).

Disciplinary literacy is different from general literacy. It focuses on the language and literacy practices that members of academic disciplines use to produce and construct knowledge within each community (Zygouris-Coe, 2015; Rainey et al., 2017; Shanahan & Shanahan, 2008). This perspective could help elementary teachers understand the connections between science-specific literacy and science teaching. For example, this perspective could show how science-specific literacy instructional tools can scaffold students' participation in SEPs and help them make sense of science (Lee et al., 2013; Wright & Gotwals, 2017). In this study, a disciplinary literacy perspective was used to guide PSTs' lesson planning and reflection practices in an elementary science methods course.

Lesson plans are an essential part of teaching and in most teacher preparation programs. They are a means of gauging PSTs' pedagogical content knowledge (i.e., integration of science, pedagogy, student characteristics, and learning environment) (Cerbin & Kopp, 2006; Richards & Rogers, 2014; Shulman, 1986). Lesson planning has also has been documented as a significant area for examining PSTs' understanding of content and pedagogical strategies (Clark & Dunn, 1991; Clark & Peterson, 1986). Reflecting on the roles literacy plays in supporting, rather than competing, with science instruction is also critical for elementary teachers (Grysko & Zygouris-Coe, 2020). The purpose of this study was to examine elementary PSTs' understanding of the use of science-specific literacy strategies to support science teaching and learning through three points of observation within a disciplinary literacy integrated elementary science methods course. Specifically, our research questions (RQ) are as follows:

- RQ1: What specialized literacy practices of science do PSTs know at the beginning of the semester as demonstrated in their belief paper?
- RQ2: How did PSTs incorporate science-specific literacy strategies in their group lesson plans to support science teaching and learning?
- RQ3: What understanding do PSTs demonstrate in their reflection paper about the roles of the science-specific literacy strategies in supporting science teaching and learning?

Conceptual Framework

Two conceptual frameworks were used in this study. The frameworks guided an elementary science methods course design to develop PSTs' understanding of teaching science and literacy in tandem.

Engaging Students in Language Intensive SEPs

Research suggests that science teaching must reflect the natural inquiry of children's learning (Bransford et al., 2000) and promote students' engagement in SEPs (Sinatra et al., 2015). These SEPs include: (a) asking questions, (b) developing and using models, (c) planning and conducting investigations, (d) analyzing and interpreting data, (e) using mathematical thinking, (f) constructing explanations, (g) developing evidence-based arguments, and (h) obtaining, evaluating, and communicating information. The NGSS emphasize guidance of science teachers' teaching practices and are essential for several reasons (NGSS Lead States, 2013; NRC, 2012). First, engaging in these practices allows students to understand how scientific knowledge develops and applies to their local context. Using these practices also helps them appreciate the diverse approaches used to create this knowledge (NRC, 2012). Second, being involved in these practices helps students understand science's crosscutting concepts and disciplinary core ideas (NGSS Lead States, 2013). Third, it helps students' science knowledge become more integrated, instead of viewing science as isolated fact-based knowledge. Fourth, engaging in science or engineering can evoke students' curiosity and motivate their further learning (NRC, 2012). This conceptual perspective guided the design of interventions in an elementary science methods course to develop PSTs' understanding of SEPs. The eight SEPs were also used to analyze PSTs' understanding of science teaching and student learning in their lesson plans and reflection papers.

The SEPs offer rich opportunities and substantial demands for language learning while advancing science learning for all students (Lee et al., 2013). Engagement in these practices is language-intensive and requires specialized literacy skills, such as reading scientific texts and writing scientific explanations. A disciplinary literacy perspective offers science-specific pathways to teachers and students.

Disciplinary Literacy

Disciplinary literacy refers to 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. 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 (NRC, 2012). Through a disciplinary literacy lens, elementary students learn how to read the texts of science, use the norms and conventions of science, form scientific explanations, and engage in scientific investigations (Zygouris-Coe, 2015; Moje, 2007; Schleppegrell, 2004, 2007; Shanahan & Shanahan, 2008, 2012, 2014). In this study, we integrated a disciplinary literacy perspective in a science methods course. We engaged PSTs in using science-specific literacy strategies that reflect how science experts use language and literacy to do the following: build and use models; make sense of science concepts; construct scientific explanations; and develop, evaluate, and communicate knowledge. We also used this framework to analyze PSTs' lesson plans for identifying science-specific literacy strategies for science teaching and reflections on the roles of the science-specific literacy strategies in supporting science teaching and student learning.

Literature Review

Disciplinary Literacy in Science Teaching

Integrating literacy in science teaching and learning is not a new phenomenon (Krajcik & Sutherland, 2010; Lemke, 1990; Osborne, 2002; Townsend et al., 2018; Wellington & Osborne, 2001; Yore et al., 2003). Elementary teachers spend considerably less time on science instruction than on mathematics or language arts (Bassok et al., 2016; Duke, 2000, 2019). In many cases literacy strategies have been used in science teaching to engage students in the process of attending to text ideas, monitoring their understanding of concepts, and making connections between new content and prior knowledge (McKeown et al., 2009; Palinscar & Brown, 1984; Pressley et al., 1992).

What is new is the call for students to receive explicit instruction in science-specific literacy practices (NGSS Lead States, 2013; NRC, 2012). New educational standards call for a need to re-conceptualize literacy in science instruction for improving all students' preparation for both the academic and the literacy demands of science (Zygouris-Coe, 2012; Lee et al., 2013). Reading, writing, reasoning, and communicating are authentic components of learning and doing science. In the discipline of science, students need to develop literacy skills in science relevant ways to build their understanding of disciplinary core ideas, engage in SEPs, and apply crosscutting concepts (Fang & Wei, 2010; Krajcik & Sutherland, 2010; NGSS, 2013; Pearson et al., 2010). Disciplinary literacy offers a different instructional and learning framework in the content areas. 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 learn how to construct scientific explanations, they will also learn about scientific discourse and develop scientific knowledge (Osborne, 2010). However, few empirical studies addressed how to prepare elementary teachers to teach science by integrating disciplinary literacy in science teaching.

Teacher Preparation for Supporting All Students' Science and Literacy Learning

The NGSS emphasize the need to support students' science and literacy learning in tandem and the elementary teachers' roles in teaching both content areas (NGSS Lead States, 2013). To meet this objective, some language arts and science teacher educators have investigated how methods courses can help elementary PSTs learn to integrate science and literacy in meaningful ways and optimize instructional time for teaching both areas. Researchers have found the following: (1) encouraging PSTs' to use language arts methods in science teaching contributes to their recognition of language as a tool for science learning and seeing the possibility to include science teaching as part of a language arts curriculum (Akerson & Flanigan, 2000); (2) introducing PSTs to an interdisciplinary model in a scientific classroom has the potential to improve PSTs' confidence to implement an inquiry-based science teaching approach (Lewis et al., 2014); and (3) matching similar cognitive skills for both literacy and science learning through planning a science lesson helps PSTs understand the connections between scientific practices and the associated reading comprehension skills (Wallace & Coffey, 2019).

Akerson and Flanigan (2000) explored how a language arts methods course helped elementary PSTs improve their science teaching using language arts methods. Analysis of 23 PSTs' written journal entries revealed that they came to recognize language as a tool for teaching science content. They felt more confident in their abilities to deliver effective science instruction. Over half of PSTs chose to plan and conduct a science lesson during their in-class presentations in the language arts methods course. Two language arts tools, Know-Want to Know-Learned (KWL) graphic organizer and journals, were modeled in the methods course and commonly adopted by PSTs while they taught science lessons. However, PSTs also reported some difficulties with meeting science objectives using the methods they gained through the language arts methods course. The science methods instructor was not agreeable to coordinating efforts for instruction. These authors proposed the need for collaboration between literacy and science methods course faculty to help elementary PSTs address both discipline standards.

In another study, Lewis et al. (2014) explored how using an interdisciplinary model within a five-week summer elementary science methods course improved PSTs' knowledge and self-efficacy toward teaching science. The interdisciplinary model was focused on scientific classroom discourse to connect science and language arts. The academic language development strategies, such as using science notebooks, were also explicitly highlighted in the course. Analysis of 16 participants' post-course questionnaires, their final papers about their beliefs of science teaching, and transcripts from focus group interviews revealed that PSTs came to view interdisciplinary instruction as an effective way to create connections between science and literacy. PSTs began to see the potential integration of literacy tools, such as using science notebooks, as a more effective teaching approach. All 16 PSTs recognized the importance of adopting an inquiry-based approach to teaching science. Inquiry-based science lesson planning was a major component in the science methods course. Most of the PSTs worked with a partner to design a science lesson using the engage, explore, explain, elaborate, and evaluate (5E) instructional model (Bybee & Fuchs, 2006). However, this study did not use the analysis of the PSTs' lesson plans to disclose what literacy tools or strategies were incorporated into their science lesson. Also, this study did not discuss specific connections they made between science teaching and the use of literacy tools.

Most recently, Wallace and Coffey (2019) investigated elementary PSTs' use of an integrated science and literacy instructional model in their science methods course to design a lesson plan by providing a template focused on making meaning for hands-on science activities along with appropriate fiction or nonfiction texts. For example, while elementary students engage in a hands-on activity focused on making inferences by observing fossils, PSTs might choose a reading passage describing fossils and their environment to direct students to explain how the fossils might have been formed. Analysis of 35 integrated lesson plans written or co-written by 45 PSTs revealed that most participants demonstrated proficiency in incorporating strategies to promote reading comprehension and sense-making in science by matching similar "scientific thinking skills" and "reading skills" within a science lesson. PSTs were able to show their understanding of connecting the scientific practice with the associated reading comprehension skills from the text. This could potentially strengthen both science learning and reading comprehension of elementary students.

The reviewed studies focus on integrating general literacy strategies in science to augment elementary students' understanding of science concepts and science practices. These general literacy strategies include those that can be used across all content areas (e.g., KWL graphic organizers, notebook, and organization of ideas from texts). However, Shanahan and Shanahan (2008) argued that general literacy strategies are not enough for preparing students to meet the specialized demands of a discipline such as science. The above review of the literature supports the need for research investigating the preparation of elementary PSTs through collaboration between science and literacy teacher educators. It also demonstrates a need to integrate a disciplinary literacy framework to help elementary PSTs understand the roles of science-specific literacy strategies to support elementary students' science learning through lesson planning and reflection. The current study was designed to address these needs.

Methodology

A qualitative exploratory case study research design (Creswell, 1998) was used to examine our three research questions. This case study helped build an in-depth and contextualized understanding (Yin, 2003) of elementary PSTs' learning about using science-specific literacy strategies to support science teaching and student learning. This occurred through collecting, describing, and interpreting (Yin, 2006) three data sources from PSTs' individual and group work within a disciplinary literacy integrated elementary science methods course. The data collection process followed the learning activities PSTs engaged in within the science methods course (Koro-Ljungberg et al., 2009; Tellis, 1997).

Context

Interdisciplinary Collaboration

This study took place at a large metropolitan university in the Southeastern United States, in a state that has not adopted the NGSS. During the 15-week spring semester of 2018, 31 elementary education PSTs (8 juniors and 23 seniors) participated in a science methods course before starting their senior clinical internships in elementary classrooms. The course instructors, who are also researchers of this study, included two faculty members from science education and literacy education with their respective two doctoral students who were teaching assistants. A two-faculty member collaboration resulted from professional discussions and a common interest in the role of literacy in science teaching and learning. Faculty collaboration was based on a voluntary commitment and was not part of a faculty workload. Two faculty members met for 12 weeks before the beginning of the course, shared readings, pedagogical ideas, and research plans. The interdisciplinary faculty collaboration resulted in a plan of action for a science methods course that included presentations and informal co-teaching by the literacy faculty and a literacy doctoral student. Another outcome of the collaboration included changes made on the original science methods course syllabus, lesson plan assignment, rubric for the lesson plan, belief paper, and reflections.

Science Methods Course

In the elementary education program, the science methods course was the only course focusing on teaching science. It was designed to prepare PSTs to incorporate the state science teaching standards and implement them in elementary classroom settings.

Instructors started this course by eliciting PSTs' background knowledge of literacy in science at the beginning of the semester. Then PSTs were engaged in different experiences to help them understand the roles of the science-specific literacy strategies in supporting science teaching and student learning. After introducing science standards in the state and general lesson planning procedures, most course time was devoted to adopting a disciplinary literacy approach to science teaching guided by our second conceptual perspective starting from the fourth week of the course (see Table 1). The co-teaching conducted by both the science and literacy teacher educators took place for 12 weeks. The significant content implemented through co-teaching included (1) an overview of literacy and challenges related to students' literacy needs in science; (2) an introduction of disciplinary literacy in science (Zygouris-Coe, 2015); (3) engagement with scientific texts (McKeown et al., 2009) and a presentation of reading tools (Zygouris-Coe, 2015) and science vocabulary; and (4) engagement in three model science lessons.

Three model lessons were structured by the 5E instructional model (Bybee & Fuchs, 2006) and were designed to situate PSTs as elementary students. PSTs were engaged in SEPs to support their science and literacy learning based on specific state science standards. The two NGSS dimensions, disciplinary core ideas and science practices, were addressed in the three model lessons. The NGSS dimension, crosscutting concepts, was not covered because the state science standards did not incorporate them. Simultaneously, science-specific literacy strategies were integrated into these lessons to support students in making sense of science concepts and participating in science practices. For example, in a physical science lesson, PSTs investigated the physical properties of Oobleck (a non-Newtonian fluid) during the exploration phase. Then they exchanged scientific arguments on the state of the matter by using the pieces of evidence they collected. The Claim-Evidence-Reasoning (CER) framework (McNeill & Krajcik, 2011) was introduced to support their practice of argumentation. Another life science lesson (Hall et al., 2017) focused on how to develop and use scientific models to explain the process of photosynthesis and cell respiration. Specific sentence frames and a review of vocabularies (such as chloroplast) helped PSTs write and tell their scientific explanations. In an earth science lesson, the instructor used science talk to engage PSTs in communicating their ideas about water erosion effects on land. PSTs were also guided to use a graphic organizer to compare similarities and differences of some science-specific concepts (i.e., weathering, erosion, deposition).

Table 1

Relative Activities and Curriculum Materials in the Science Methods Course

Activity	Curriculum Materials
Discuss teaching standards	The purpose of science teaching and guided questions - CCSS, NGSS, state standards, and school district planning
Lesson planning, write objectives based on state standards.	Planning to teach science, lesson plan template, and criteria
Discuss science practices and 5E instructional model, teach science through a disciplinary literacy lens	Inquiry and science teaching, NGSS (SEPs), science text ("Issue Overview: Fracking") from Newsela
Experience and reflect on a physical science lesson focusing on *scientific argument*	Science lesson 1, scientific argument using CER (McNeill & Krajcik, 2011)
Experience and reflect on a life science lesson focusing on the *explanatory model*	Science lesson 2, cell modeling
Experience and reflect on an earth science lesson focusing on *vocabulary instruction* and communicating like scientists	Science lesson 3, erosion
Make explicit connections to supporting all students learning science and literacy in tandem.	Lesson plan template and rubric
Design an inquiry-based science lesson	NGSSS standards, lesson plan template and rubric
Reflect on the lesson planning process	Reflection framework

Data Sources

For this study, we focused on the analysis of three data sources (belief papers, lesson plans, and reflection papers) from three learning activities PSTs engaged in within the science methods course. First, an individual belief paper from each PST was collected. This assignment was guided by five questions related to PST's prior knowledge of science instruction. Only responses to one question (see data analysis section) in PSTs' belief papers were chosen to answer our first research question. Second, the key assignment of the science methods course was a lesson plan. PSTs were asked to use a 5E instructional model (Bybee & Fuchs, 2006) to plan an inquiry-based science lesson to support elementary students' science learning. Eight groups of three or four PSTs worked on this assignment since the second week of the semester and each group submitted one lesson plan at the end of the semester. Each lesson plan included eight components, such as the following: state science standards and objectives; detailed procedures structured by a 5E instructional model (Bybee & Fuchs, 2006); SEPs; a materials list; and safety precautions. One component in the lesson plan rubric was to ask PSTs to include a variety of practices that support students' science-specific literacy development. PSTs were not limited to any specific strategies in their lesson plan and could incorporate science-specific literacy strategies in any phases of their lesson based on their understanding of the roles of science-specific literacy in science teaching and learning. The lesson plan was a culminating assignment that showed how groups of PSTs constructed meaning of how science teaching and disciplinary literacy could be implemented in tandem. Third, PSTs were asked to write a reflection paper at the end of the semester. The reflection paper was guided by five questions focusing on participants' individual thoughts related to the planning and learning process. For this study, only responses to one question (see data analysis section) in PSTs' written reflection papers were chosen to answer our third research question.

Data Analysis

To answer R1, PSTs' responses to a question in their individual belief paper, "What specialized literacy practices of science have you learned to promote students' science and literacy learning? Please provide a brief explanation", were analyzed. An inductive analytical approach (Miles & Huberman, 1994) allowed codes to emerge from the data. During the initial coding process, responses to the question of the belief and reflection papers were read, and the following question was considered: "What is the major idea brought out in this sentence or paragraph?" (Strauss & Corbin, 1998, p. 120). An initial code was assigned to segments of the text based on the answer to this question. Initial codes were then grouped into categories grounded on similarities in their properties and dimensions. For example, the initial codes of using graphic organizers and discussing vocabulary were grouped under "Examples of literacy strategies" (see examples in Table 2). Initial themes were then identified due to consistency in the data among participants. These themes indicated PSTs' understanding of the specialized literacy practices of science at the beginning of the semester.

Table 2

Sample of the Coding System for PSTs' Belief Paper

Category	Subcategories	Codes	Quotes
Examples of literacy strategies	Graphic organizers	KWL chart	"I have observed this in the classroom, where the students made a KWL chart with the teacher."
	Discussing vocabulary	Word analysis in class	"Word analysis and discussing vocabulary could be used in a science classroom."

To answer RQ3, a similar approach was used to analyze PSTs responses to a question in the written reflection paper, "How do science literacy strategies facilitate the process of inquiry and the development of students' scientific knowledge?" Examples of categories, codes, and quotes are presented in Table 3 below. Specific themes with examples are described within the findings section in detail.

Table 3

Sample of the Coding System for PSTs' Reflection Paper

Categories	Subcategory	Codes	Quotes
Explanation of how science-specific literacy strategies support science learning	Scaffold	Vocabulary and Concepts/misconceptions	"in an inquiry-based lesson plan the teacher starts with a question, students can discuss the topic/answer the question to the best of their knowledge. Using questioning as a scaffold, students will use science specific vocabulary and determine misconceptions."
		SEPs	"They support inquiry and problem solving by allowing students to be engaged enough to ask questions, make predictions, find answers, and make inferences based on their findings."

To address RQ2, PSTs' lesson plans were analyzed using a constant comparative approach (Glaser & Strauss, 2017). The constant comparative method involves dividing the data into discrete "incidents" and coding them into categories. The initial coding scheme consisted of three categories (disciplinary core ideas, SEPs, and crosscutting concepts) to align with the three dimensions of science teaching in the NGSS. While analyzing PSTs' lesson plans, there were no literacy or strategies identified related to the development of students' crosscutting concepts. This was not surprising, since crosscutting concepts were not part of the state science standards. Thus, the crosscutting concepts category was excluded from the final coding scheme. Table 4 presents the final coding scheme for the types of science-specific literacy strategies PSTs incorporated in their lesson plans to support elementary students' science and literacy learning in tandem.

During the data analysis process, the first and second author coded data independently and achieved initial inter-rater reliability greater than 85%, and after discussion, reached 98% agreement.

Table 4

Coding System for Types of Science-Specific Literacy Strategies PSTs Incorporated in Their Lesson Plans

Categories	Codes	Examples
SEPs	Engaging students in science-specific writing supported by evidence	Using content-specific language to write a paragraph explaining erosion and its' effects
	Engaging students in explanation using the CER framework	Requiring students to construct an explanation to explain why particular objects sink and others float
	Providing sentence frames for scaffolding students' science writing	Provide sentence frames based on the CER framework to help students construct a written scientific explanation
	Helping students record and organize information/data	Having students record their observations in a science notebook
	Guiding students in using multiple sources of information	Using the internet and texts to research the functions of different organs
	Communicating scientific information	Having students explain their findings to the teacher and their peers
Disciplinary Core Ideas (DCIs)	Using text to build background knowledge to stimulate interest, introduce vocabulary, etc.	Having students use nonfiction text to research one of the human organs
	Teaching science-specific vocabulary	Explicitly teach terms related to the classification of rocks (e.g., sedimentary, igneous, and metamorphic)
	Developing concept knowledge by exploring relationships between vocabulary	Leading a discussion on the relationships between the following vocabulary words: seasons, sun, Earth, equator, and revolution.

Findings

Overall, findings indicated that through participation in an integrated disciplinary literacy science methods course co-designed and co-taught by science and literacy teacher educators, elementary PSTs began to develop their understanding of literacy in science teaching and student learning. First, at the beginning of the semester, while most PSTs had never heard about science-specific literacy strategies, they demonstrated their understanding of general literacy practices in science. Second, PSTs incorporated science-specific literacy strategies within their inquiry-based lesson plans to facilitate students' development of disciplinary core ideas and engagement in SEPs. Third, in their written reflection paper, PSTs showed more developed knowledge than their belief papers on the role of science-specific literacy in science teaching and student learning within four categories.

Table 5

PSTs' Understanding of Science-Specific Literacy as Demonstrated in Their Belief Paper

Category	Subcategory	Codes	Quotes (Samples)	Themes
Examples of literacy strategies	Graphic organizers discussing vocabulary	KWL	"I have observed this in the classroom, where the students made a KWL chart with the teacher."	PSTs mentioned general literacy strategies
	Reading different types of texts	Vocabulary	"Word analysis and discussing vocabulary Could be used in science classroom."	
		Read storybooks, fiction, nonfiction, trade book	"The teacher first read a book about butterflies and listed the stages of the butterfly. The students were also given a worksheet to fill out and label each stage."	
Conceptualization of specialized literacy practices of science	Connection to science	Never heard of disciplinary literacy	"I have never learned a specialized literacy practice of science to promote science and learning. This has not been a discussion in any of my courses."	Some conceptualized literacy as scientific methods while others could not position literacy in science teaching and learning.
		Scientific methods	"By making their observations, asking questions, making predictions, searching for information to test those predictions, and summarize their findings, this makes the Scientific Method a highly effective literacy practice used in science."	
	Relationship between literacy and science learning	Reciprocal relationship	"Science and literacy go hand in hand. To complete the experiments requested students need to be able to read the instruction and explain what they are observing."	Only 2 PSTs referred to the reciprocal relationship of science and literacy learning explicitly while one student viewed literacy and science as two separate subjects.
		Two subjects	"I love science but literacy was not my favorite topic to learn. I am looking forward to learning how teachers get their students to enjoy the two subjects."	

RQ1. What Specialized Literacy Practices of Science do PSTs Know at the Beginning of the Semester as Demonstrated in Their Belief Paper?

Most of PSTs had never heard about a science-specific literacy approach (i.e., disciplinary literacy). PSTs had different experiences with, and general prior understanding of the specialized literacy demands of science and how they relate to students' science and literacy learning. The themes under two categories were described below.

Examples of Literacy Strategies

Most PSTs mentioned some general literacy tools when they talk about literacy strategies being used in science classrooms. These examples include graphic organizers (e.g., KWL), discussing vocabulary in class, reading different types of texts (e.g., storybooks, fiction, nonfiction, trade book). See the belief paper excerpts in Table 5.

Conceptualization of Literacy in Science

Very few students explicitly talked about how they viewed the relationship between science and literacy in general. As shown in Table 5, only two PSTs referred to the reciprocal relationship between science and literacy learning, while one PST viewed literacy and science as two separate subjects. Two PSTs used "hand in hand" to describe the importance of literacy in science practices. For example, one of them mentioned that, "To complete the experiments requested students need to be able to read the instructions and explain what they are observing." However, one PST viewed literacy and science as almost two competing subjects. A statement was made in this PST's belief paper that "I, as a student, love science but literacy was not my favorite topic to learn. I am looking forward to learning how teachers get their students to enjoy the two subjects."

Some PSTs made connections between literacy and scientific methods and practices in science. For example, one PST wrote in the belief paper that:

> . . . a specialized literacy practice of science in the classroom I know of is the Scientific Method. By making their observations, asking questions, making predictions, searching for information to test those predictions, and summarizing their findings, this makes the Scientific Method a highly effective literacy practice used in science.

R2: How Did PSTs Incorporate Science-specific Literacy Strategies in Their Group Lesson Plans to Support Science Teaching and Learning?

Analysis of PSTs' lesson plans revealed that all eight groups incorporated various science-specific literacy strategies to support two dimensions of science teaching and learning in the NGSS (see Tables 6 and 7). These two dimensions were disciplinary core ideas and engagement in SEPs.

Table 6

Science-specific Literacy Strategies Incorporated to Support Students' Development of Disciplinary Core-ideas

Group	Type of Strategy	5E Phase	Excerpt from PST Group Lesson Plan
1	Teaching science-specific vocabulary	Explain	"To define wind and water erosion, students will be shown a PowerPoint presentation directed by the teacher defining content specific vocabulary and describing the differences between weather and erosion."
2	Teaching science-specific vocabulary	Engage	"Introduce flashcards (word on front, picture on back) for the following key terms: season, sun, Earth, equator, and revolution."
3	Developing concept knowledge by exploring relationships between vocabulary	Explore	"Allow students to work together to observe and distinguish the three types of rocks in their own way. In each students' science notebook, they will make a chart that they will use to sort each rock."
4	Developing concept knowledge by exploring relationships between vocabulary	Evaluation	"Students will have an end of the lesson assignment that will include riddles for their friends or family about body parts. A human body riddle book in which they create one question for each organ or body part specifying the functions and characteristics."
5	Teaching science-specific vocabulary	Engage	"The class will discuss what they already know about the organs in the human body and what they want to know using the science-specific terms (brain, heart, lungs, stomach, skeleton, and muscles)."
6	Developing concept knowledge by exploring relationships between vocabulary	Elaborate	"Students will create their own riddle flip book that includes the 6 major body parts (brain, heart, lungs, stomach, muscles, and skeleton)."
7	Using text to build background knowledge, stimulate interest, and introduce vocabulary	Engage	"Read the story *What Floats in a Moat* by Lynne Berry. During the reading students are to keep note of the objects that sank or floated in the story."
8	Developing concept knowledge by exploring relationships between vocabulary	Elaborate	"Students will write three sentences per topic for the assignment portion of this activity. The first topic will consist of a proper understanding recognizing that solids have a definite shape and that liquids and gases take the shape of their container."

Note: Find a more comprehensive table https://drive.google.com/file/d/13O3WaPDE-FPTG7LVWD8PSrMRJs_XFGj8/view?usp=sharing

First, to support students' development of disciplinary core ideas, PSTs incorporated three science-specific literacy strategies. These strategies included: (1) using science text to build background knowledge, stimulate interest, introduce vocabulary, etc.; (2) teaching science-specific vocabulary; and (3) exploring relationships between vocabulary to help students make sense of science concepts. Each group chose different strategies and incorporated them in different phases of the 5E instructional model from the list for different purposes. While three groups (group 4, 6, and 7) incorporated all three science-specific literacy strategies in their lesson plan, one group (group 5) only incorporated the second strategy focusing on teaching scientific vocabulary. Other groups incorporated two science-specific literacy strategies in their lesson plan.

For example, Group six included a read-aloud of the expository science text, *Me and My Amazing Body* by Joan Sweeney and Annette Cable (1999), to introduce students to various body parts and their basic functions (excerpts found in Tables 6 and 7). PSTs of this group planned that students would indicate the functions of organs to learn science-specific vocabulary. Their lesson plan also incorporated students creating riddle books to develop relationships between organs (science-specific vocabulary). Group five included one science-specific strategy, teaching science-specific vocabulary. In their lesson plan, students would engage in building a KWL chart to begin learning about parts of the body (science-specific vocabulary).

Second, six science-specific literacy strategies were identified in PSTs' lesson plans that showed how they planned to support students' engagement in SEPs. These science-specific literacy strategies included the following: (1) helping students record and organize info/data during an investigation, (2) communicating scientific information, (3) engaging students in science-specific writing supported by evidence, (4) guiding students in using multiple sources of information, (5) engaging students in scientific explanation using the CER framework, and (6) providing sentence frames for scaffolding students' science writing. Table 5 displays the specific types of science-specific literacy strategies found in each coding category per participant group. While one group (group four) did not use these strategies to engage students in SEPs in their lesson plan, other groups incorporated at least two science-specific literacy strategies. Most groups incorporated science-specific literacy strategies to support recording and organizing information/data and communicating scientific information. However, some groups provided more scaffolding, such as the CER framework or sentence frames. For example, in the Evaluation phase of their lesson plan, group seven included an opportunity for students to construct a scientific explanation, explaining why particular objects sink or float using the CER framework.

Out of the three dimensions of science teaching and learning, PSTs mainly incorporated science-specific literacy strategies to support students' engagement in science sense-making and science practices. PSTs did not include any science-specific literacy strategies focusing on the development of students' crosscutting concepts. This is not surprising given that the state has not adopted the NGSS and crosscutting concepts are not included in science standards.

RQ3: What Understanding do PSTs Demonstrate in Their Reflection Paper About the Roles of the Science-specific Literacy Strategies in Supporting Science Teaching and Learning?

In their reflection paper at the end of the semester, PSTs showed a more advanced knowledge of the role of science-specific literacy in science teaching and learning than understanding demonstrated in their belief papers. They showed their understanding in the following four categories: Explanation of how science-specific literacy strategies support science teaching and learning, Examples of science-specific literacy strategies to support science learning, Comparing science-specific literacy strategies to general literacy strategies, and the Relationship between literacy and science

Table 7

Science-Specific Literacy Strategies Incorporated to Support Students' Engagement in SEPs

Group	Type of Strategy	5E Phase	Excerpt from PST Group Lesson Plan
1	Communicating scientific info	Evaluation	"Students will turn to a shoulder partner and quickly discuss with each other what they learned about wind erosion and what it does."
2	Engaging students in explanation using the CER framework	Elaborate	"Students will complete a C-E-R framework on which location will make the best destination for their specified time of year."
3	Helping students record and organize info/data	Explore	In each students' science notebook, they will make a chart that they will use to sort each rock. They will have to write down common characteristics of the different rocks."
4	No strategies identified		
5	Guiding students in using multiple sources of information	Explore	"Students will work in groups to research each body part using the resources provided to them."
6	Providing sentence frames for scaffolding students' science writing	Explain	"Students will individually record in their science notebooks the function of each major organ using the following sentence structure: The ____ function is______."
7	Helping students record and organize info/data	Engage	"Pass out the Sink or Float table with the seven experimental objects listed. Explain to students that they will be filling out the first blank column with their predictions of what objects will sink or float. Display the items for the students to see and to record their answer."
8	Engaging students in explanation using the CER framework	Explain	"Claim: Write a sentence that states if a cup holds more or less or the same amount of liquid than cup ____. Cup __ holds ____(more or less or the same amount)."

Note: Find a more comprehensive table https://drive.google.com/file/d/13O3WaPDE-FPTG7LVWD8PSrMRJs_XFGj8/view?usp=sharing

Most PSTs provided explanations about how science-specific literacy strategies support the process of inquiry and the development of students' scientific knowledge. Specifically, PSTs identified three areas that science-specific literacy have been used in science teaching and learning. These areas include the following: learning scientific vocabulary, learning science concepts, and engagement in practices of science. Three excerpts below demonstrate PSTs' understanding of the role of science-specific literacy strategies in supporting science teaching and learning in the areas mentioned above, respectively:

> PST 1: These strategies motivate students to think and engage in inquiry-based, discovery science. They support inquiry and problem solving by allowing students to be engaged enough to ask questions, make predictions, find answers, and make inferences based on their findings.
> PST 2: Science is about more than just exploring facts. It is about exploring, going through the process of inquiry, and how students are able to uncover facts and theories. None of these

> steps would be possible without the development of scientific literacy. As a final thought, scientific literacy can also help students develop knowledge in ways outside of inquiry or experimentation. Students often will obtain scientific information through reading. If students are unable to read like a scientist, not able to comprehend science-specific texts, or not understanding tier-three vocabulary associated with the subject, it will be impossible for them to gain any new knowledge from a nonfiction text related to the subject area of science.
> PST 3: In an inquiry-based lesson plan the teacher starts with a question, students can discuss the topic/answer the question to the best of their knowledge. Using questioning as a scaffold, students will use science specific vocabulary and determine misconceptions.

PSTs' provided more examples of science-specific literacy strategies to support students' vocabulary learning, conceptual understanding, and engagement in SEPs (e.g., CER, science nonfiction texts, vocabulary strategies). Examples from PSTs' reflection paper are presented in Table 8.

Some PSTs believed there were no differences in literacy strategies across the subject areas. For example, one PST mentioned that "science literacy strategies for teaching are the same as other literacy strategies because they both involve comprehending and becoming more knowledgeable in a certain subject area." Others believed that science-specific literacy strategies differ from other literacy strategies "because they focus on science concepts, and vocabulary, and help students learn how to think like scientists." Other examples are shown in Table 8.

Most PSTs viewed the roles that literacy, especially science-specific literacy, plays in science teaching and learning. One PST who initially viewed science and literacy as separate subjects started to increase their understanding of the specialized literacy demands of science. In the reflection paper, the following statement was documented to represent this perspective, "Students need to be actively reading their textbook to learn science; the science is not only learned from the experiments they learn about." However, PSTs did not explicitly specify how inquiry-based science teaching supported students' development of their literacy and language proficiency.

Table 8

PSTs' Understanding About the Roles of the Science-Specific Literacy Strategies in Supporting Science Teaching and Student Learning in Their Reflection Paper

Category	Codes	Quotes (samples)	Theme
Explanation of how science-specific literacy strategies support science learning	Vocabulary	"In an inquiry-based lesson plan the teacher starts with a question . . . "	More PSTs provided explanations about how science-specific literacy strategies support the process of inquiry, and the development of students' scientific vocabulary, making sense of concepts, and engagement in SEPs.
	Concepts	"Using questioning as a scaffold, students will use science specific vocabulary and determine misconceptions."	
	SEPs	"They support inquiry and problem solving by allowing students to be engaged enough to ask questions, make predictions, find answers, and make inferences based on their findings."	
Examples of Science-specific literacy strategies to support science learning	C-E-R science nonfiction texts Using diagrams to compare and contrast concepts Vocabulary strategies		PSTs' provided more examples of science-specific literacy strategies to support students' vocabulary learning, conceptual understanding, and engagement in SEPs
Compare science-specific literacy strategies to general literacy strategies	No difference	"Science literacy strategies for teaching are the same as other literacy strategies."	Some believed there were no differences in literacy strategies across the subject areas. Others believed that science-specific literacy strategies differ from other literacy strategies
	Difference	"Because they focus on science concepts, and vocabulary, and help students learn how to think like scientists." "The difference between science literacy strategies is that they are presented in another form or way that enhances that specific subject of learning ability."	
Relationship between literacy and science	Hand-in-hand	"They are Hand-in-Hand. Inquiry becomes a way to engage students in learning vocabulary; learning vocabulary makes science learning easier and helps further inquiry."	There were differences in the ways PSTs conceptualized the relationship between science-specific literacy and science teaching and learning.

Discussion

The purpose of this study was to examine elementary PSTs' understanding of the use of science-specific literacy strategies to support science teaching and learning through three points of observation**.** This was in the context of a disciplinary literacy integrated elementary science methods course. Our findings indicate that elementary PSTs benefited from the lesson planning process by integrating disciplinary literacy in the elementary science methods course. Major findings from this study are discussed in this section.

First, this study provided empirical evidence of PSTs' understanding of the roles of literacy in science when they entered a science methods course. Even though most PSTs mentioned that they had never heard about science-specific literacy, their understanding of specialized literacy practices of science was demonstrated based on their different prior learning experiences (e.g., service-learning and literacy methods courses). PSTs were able to list some general literacy tools used in science teaching, such as KWL, reading fiction, or nonfiction text. These examples reflected PSTs' perceptions of the literacy demands of science and connections to students' science learning. This finding echoes some challenges of the traditional elementary teacher education programs, in which the science methods course was separated from literacy methods courses (Grysko & Zygouris-Coe, 2020; Pearson et al., 2010) and how literacy has been presented to teachers (Moje et al., 2010). PSTs lack opportunities to learn how to read, write, speak, and think in ways that reflect how knowledge is developed in science. For example, very few PSTs in their belief papers made connections between literacy and scientific methods and practices. One PST explicitly viewed literacy and science as separate subjects which could compete with each other for instruction.

Second, an encouraging finding of this study is that PSTs worked within groups and incorporated at least two science-specific literacy strategies in each inquiry-based lesson plan to support two dimensions (disciplinary core ideas and SEPs) of science learning. Although PSTs incorporated these science-specific literacy strategies in different phases of the 5E instructional model for different purposes, and some groups incorporated more strategies than others, the major roles of these strategies, as demonstrated in the lesson plans, were consistent. These roles include engagement in SEPs and sense-making of disciplinary core ideas (NGSS Lead States, 2013). For example, one group incorporated a read-aloud of an expository science text to teach body parts and functions. Another group planned to use the CER framework to scaffold students in constructing scientific explanations. This finding is different from other studies (Akerson & Flanigan, 2000; Lewis et al., 2014; Wallace & Coffey, 2019) that focused more on general literacy strategies' integration in science. Therefore, it enriches this research line by adding analysis of science-specific strategies in the lesson plans of PSTs to demonstrate how PSTs perceive the roles of science-specific literacy strategies in supporting elementary students' sense-making of disciplinary core ideas and engagement in SEPs. Integrating a disciplinary literacy framework in a science methods course through a collaboration of science and literacy education faculty made it possible for PSTs to start paying more attention to science-specific literacy strategies, instead of general literacy strategies for supporting elementary students' science learning. This is especially important because it provided empirical evidence of the outcomes of the collaboration between instructors of science and literacy methods courses to meet science standards as recommended (Akerson & Flanigan, 2000).

Third, an important finding from this study is that PSTs demonstrated their developing understanding of the role of science-specific literacy in science teaching and learning through their written reflection paper at the end of their science methods course. PSTs were able to specify three areas (i.e., vocabulary, learning science concepts, and engagement in science practices) that science-specific literacy supports in science teaching and student learning. Different examples (e.g., CER framework) were used to explain how they could be used for different purposes. It is important to note that although the role of literacy in science teaching and student learning has been documented in the literature (Krajcik & Sutherland, 2010; Sutherland, 2008), many studies on preparing elementary PSTs for integrating literacy in science teaching focus on general literacy strategies. These studies either see the possibility of including science teaching as part of a language arts curriculum (Akerson & Flanigan, 2000) or optimizing instructional time for elementary teachers to teach both areas (Lewis et al., 2014; Wallace & Coffey, 2019). Our current finding extended this research line by focusing on preparing elementary PSTs to explicitly reflect on comparing science-specific literacy strategies and general literacy strategies. The fact that PSTs made these critical connections in their reflections is notable because they demonstrated their conceptualizations of the role of science-specific literacy strategies as tools for supporting students' engagement in SEPs and learning disciplinary core ideas (NGSS Lead States, 2013). This is different than viewing them as stand-alone, literacy activities (Moje et al., 2010).

Furthermore, this finding is also formative regarding what science educators need to address in teacher preparation courses to develop better PSTs' knowledge of science and science-specific literacy strategies. For example, the findings indicated that PSTs just started identifying the roles of science-specific literacy strategies in science teaching and student learning. At the same time, they did not have enough opportunities to reflect on how science learning and inquiry-based science teaching serve as opportunities and contexts for elementary students to develop their science-specific literacy proficiency, such as ". . . the ability to read and comprehend a wide range of science texts, knowledge of the specialized vocabulary of science, and habits of mind that are inherent to learning and doing science" (Grysko & Zygouris-Coe, 2020, p. 497). This study provided empirical evidence to identify the areas teacher educators need to continue to work on through university coursework and future research to promote teaching science and science-specific literacy in tandem.

Limitations

Case study designs allow for limited generalizations because of the restricted sample size and bounded context of the study (Creswell, 2013). More research needs to be conducted to examine PSTs' understanding in other elementary teacher education program contexts. Two limitations of the study are presented before discussing the implications of the study. First, this study used a purposive, convenience sample in a state that did not adopt the NGSS, so different PSTs populations may be unaccounted for in this study. Second, the reflection paper was guided by the questions that researchers were interested in, and this might have led the participants to answer questions towards a researcher-oriented perspective. Despite these limitations, this study carries implications for the potential design of science methods course and future research (Cervetti et al., 2015).

Implications

This case study presented initial results from an interdisciplinary collaboration between science and literacy teacher educators who co-designed and co-taught an elementary science methods course. Science and literacy teacher educators should continue to seek more ways to collaborate and reform literacy and science methods courses. Such collaborations would better prepare elementary PSTs to teach science and meet the new science standards (NGSS Lead States, 2013). This also could begin the development of resources to prepare PSTs in several ways. First, a disciplinary literacy framework needs to be further integrated into the science methods course curriculum to deepen PSTs' understanding of science and literacy knowledge in tandem. For example, a disciplinary literacy framework could be integrated with the crosscutting concepts in science since this connection was missing in the current study. Second, reflections on using literacy for science teaching could be more meaningful if PSTs are provided opportunities to implement their lesson plans in elementary classroom settings. At the same time, in order to encourage elementary teachers to teach science and science-specific literacy in tandem, PSTs should be guided to reflect on if and how inquiry-based science teaching contributes to developing elementary students' proficiency in science-specific literacy. Third, instructors of science methods courses need professional development that facilitates collaboration with disciplinary literacy experts to co-construct new knowledge about 21st-century elementary teachers' needs in science and literacy.

Follow up research is needed to explore and examine the following areas: (1) how science and literacy educators can continue to support elementary PSTs consistently after science methods courses and in other learning contexts (i.e., pre-service teacher clinical internships), and (2) how to explicitly connect university courses to teaching practices in classrooms (Janzen, 2008). Besides science methods courses, it is necessary to monitor PSTs' progress during their clinical internship experiences through their first year of teaching to investigate and support their instructional and pedagogical needs.

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