Preparing Secondary Science Pre-Service Teachers to Teach in Linguistically Diverse Classrooms

A Dissertation Presented to

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By

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Abstract

As United States classrooms become increasingly linguistically diverse and national reform documents call for a greater focus on language use in the science classroom, it is becoming critical that pre-service science teachers are prepared to teach language- and literacy-integrated science in linguistically diverse classrooms. The three studies presented in this dissertation seek to build on a nascent field of research addressing how to best prepare secondary science pre-service teachers for linguistically diverse science classrooms through the implementation and analysis of a language- and literacy-integrated science intervention grounded in current research in the fields of English language development, K-12 science education, and teacher preparation. Analyses of secondary science pre-service teachers' instructional planning for and implementation of language- and literacy-integrated science instruction, as well as analysis of contextual factors that support or constrain such implementation, provide a window into how science teacher educators and researchers can better support secondary science pre-service teachers in implementing science instruction that is truly designed for all students.

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APPROVAL OF THE DISSERTATION

This dissertation, *Preparing Secondary Science Pre-Service Teachers to Teach in Linguistically Diverse Classrooms*, has been approved by the Graduate Faculty of the Curry School of Education in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Dedication

To my village, who carried me through every step of this journey.

To Gebrehiwot, whose curious mind and love of STEM sent me on this journey in the first place.

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Preparing Secondary Science Pre-Service Teachers to Teach in Linguistically Diverse Classrooms: Linking Document

The increasing linguistic diversity in K-12 science classrooms in the United States (National Center for Education Statistics, 2019), coupled with recent reforms in science education that forefront language as a key component of science instruction (National Research Council, 2012; NGSS Lead States, 2013), have led to a need for a new way of teaching in United States' science classrooms. In particular, research supports the integration of language and literacy into science instruction, a step that has proven to be beneficial for all students, but particularly for students classified as English Learners (e.g., Shaw, Lyon, Stoddart, Mosqueda, & Menon, 2014; Tong, Irby, Lara-Alecio, & Koch, 2014). Yet, while much research supports language- and literacy-integrated science instruction, little is known about how to best prepare pre-service teachers (PSTs) to teach language- and literacy-integrated science in linguistically diverse classrooms. That is, while it is known that language- and literacy-integrated science instruction is beneficial for students, how to ensure that teachers are teaching in this manner is still up for debate (Buxton & Lee, 2014).

The purpose of this dissertation was to investigate and add to the field of research on preparing PSTs to teach in linguistically diverse secondary science classrooms. I chose this area of study for my dissertation for two reasons: First, it combined my two research interests, English language development and science teacher education. Second, the nascency of the field means that there is still much to be learned about preparing PSTs for linguistically diverse secondary science classrooms. In this way, my studies have the potential to add to a field where research is very needed.

The three manuscripts for this study include a literature review and two empirical studies. I am the primary author on all three manuscripts and completed a majority of the design, implementation, and analysis for each manuscript. Each manuscript informs the others in a progression from literature review (Manuscript 1) to PST implementation through instructional planning (Manuscript 2) to PST instruction in the classroom (Manuscript 3). These manuscripts are linked conceptually by their focus on pre-service science teacher preparation for linguistically diverse students. The two empirical studies are further linked by the conceptual framework I developed for language- and literacy-integrated science instruction, which I call the Teaching English Learners Language- and literacy-integrated Science (TELLIS) instructional framework. The TELLIS framework was developed based on the findings from the literature review (Manuscript 1), as well as literature on preparing PSTs for linguistically diverse classrooms and science classrooms, distinctly. The TELLIS framework guided not only the structure and analysis of the empirical studies, but also the intervention as a whole. Thus, it was at the heart of both empirical studies.

In aggregate, the three manuscripts of this dissertation seek to summarize and add to the research on preparing PSTs for teaching in linguistically diverse science classrooms. I provide a brief overview of each manuscript, below.

Manuscript 1: Preparing Pre-Service Teachers to Teach Science to English Learners: A Review

The first manuscript of the three-manuscript dissertation is a literature review of extant research on preparing PSTs for linguistically diverse science classrooms. In particular, the research questions this study sought to answer are:

1. What are the variations in the structure of interventions designed to prepare PSTs for language- and literacy-integrated science instruction, and to what extent do they support PSTs' beliefs about and understanding and implementation of language- and literacy-integrated science?
2. What are the variations in the tasks for learning outlined in interventions designed to prepare PSTs for language- and literacy-integrated science instruction and to what extent do they support PSTs' beliefs about and understanding and implementation of language- and literacy-integrated science?

The purpose of this manuscript was to take a pulse on the slowly emerging research for preparing PSTs to teach science in linguistically diverse classrooms.

Though originally intended to focus solely on secondary science PST preparation, a dearth of studies at the secondary level necessitated casting a broader net to include studies in elementary settings. In sum, 12 interventions were identified as described by 14 studies (i.e., two interventions had more than one research study assessing outcomes). Each study was reviewed for structural and task-oriented components outlined in the literature as important for teacher development and operationalized in a researcher-created theoretical framework. The results of this review not only provided a broader understanding of the emerging field but also served as guide for the development of my own intervention. Though the guidance of both Dr. Mumba and Dr. Kibler was instrumental to the completion of this manuscript, I am the primary author. At the time of submission, this manuscript had been accepted to the *Journal of Research in Science Teaching*.

Manuscript 2: Developing Secondary Pre-Service Science Teachers' Instructional Planning Abilities for Language- and Literacy-Integrated Science Instruction in Linguistically Diverse Classrooms

The second manuscript of the three-manuscript dissertation is the first of two empirical studies. Informed by findings from Manuscript 1, both of the empirical studies were based on PSTs' participation in two language- and literacy-integrated science methods courses and were meant to add to the research on preparing PSTs to teach in linguistically diverse classrooms. In these studies, language- and literacy-integrated science instruction was operationalized by the self-created TELLIS framework. The TELLIS framework is grounded in sociocultural theories of learning (Duff, 2007; Duff & Talmy, 2011; Vygotsky, 1978) and informed by research on strategies for language and science integration (e.g., Lee & Buxton, 2013) and similar instructional frameworks (e.g., Lyon, Stoddart, Bunch, Tolbert, Salinas, & Solís, 2018; Stoddart, Bravo, Mosqueda, & Solís, 2013) that were highlighted in Manuscript 1. The TELLIS framework was integrated into science instructional methods throughout both secondary science methods courses.

In Manuscript 2, I investigated how, if at all, the instructional planning of 11 secondary science PSTs changed following their participation in the two language- and literacy-integrated science teaching methods courses. Specifically, my research questions were:

1. To what extent, if at all, did PSTs' instructional planning for language- and literacy-integrated science change following their participation in two semester-long language- and literacy-integrated science teaching methods courses?

2. In what ways, if at all, did the nature of PSTs' instructional planning for language- and literacy-integrated science change following their participation in two semester-long language- and literacy-integrated science teaching methods courses?

Data sources for this manuscript included lesson plans that were developed before and after the intervention, as well as post-intervention interviews. Results suggest that, following participation in the courses, more PSTs integrated the components of the TELLIS framework into their lesson plans than before participation in the courses. The nature of implementation also changed for some practices.

At the time of submission, Manuscript 2 was under review for publication in the *Journal of Science Teacher Education*.

Manuscript 3: Examining Secondary Science Pre-Service Teachers' Implementation of Language and Literacy Integrated Science Instruction Through a Cultural Historical Activity Theory Lens

Manuscript 3 is the second of the two empirical studies. Building on the prior manuscript focusing on PSTs' instructional planning, in Manuscript 3 I assessed PSTs' implementation of language- and literacy-integrated science instruction in linguistically diverse secondary science classrooms. I also investigated what factors of PSTs' student teaching placements, which I framed as activity systems through Cultural Historical Activity Theory (CHAT), might be associated with PSTs' uptake of the targeted instructional practices. Thus, Manuscript 3 focused on the following research questions:

1. To what extent do secondary science PSTs enact language- and literacy-integrated science instruction during their student teaching experiences?

2. How is PSTs' participation in different student teaching activity systems associated with their enactment of language- and literacy-integrated science instruction during their student teaching experiences?
3. In what ways do the mediating elements (i.e., tools, division of labor, rules, and community) of the student teaching activity systems operate within the system to support or constrain implementation of language- and literacy-integrated science instruction?

For this study, PSTs' implementation of language- and literacy-integrated science instruction was assessed through analysis of video-recorded lessons using a researcher-created rubric. With activity theory as a guiding framework, interviews with both the PSTs and their mentor teachers, as well as reflections PSTs completed throughout their student-teaching field experiences, were analyzed to better understand the contexts of the PSTs' instructional implementation. Results indicated that PSTs were able to implement all targeted instructional strategies to some extent in their student teaching placements, but that the extent to which they implemented each practice was related to the mediating elements of their student teaching activity systems.

This manuscript will be submitted to *Science Education*.

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Manuscript 1

Preparing Pre-Service Teachers to Teach Science to English Learners: A Review

Abstract

Despite growing numbers of English Learners (ELs) in United States science classrooms and recent science education reforms calling for language and literacy integrated science instruction, research is just beginning to address how to prepare pre-service teachers (PSTs) to teach science to ELs. Using a framework highlighting key structural and task-related components for preparing PSTs to teach science to ELs, we systematically examined interventions designed to prepare PSTs to teach in linguistically diverse science classrooms for variations in their structures and tasks for learning, and for outcomes. Results indicate that interventions for preparing PSTs to teach science to ELs ranged from parts of science methods courses to integrated programs spanning both science methods courses and field experiences. Most interventions addressed language and literacy integrated instruction, field experiences, skills for language-integrated science instruction, and identification and use of students' funds of knowledge in the classroom. Integration of language and literacy into science methods instruction, cohesion across program components, instructor modelling of targeted instructional strategies, and opportunities to practice targeted instructional strategies in K-12 classrooms were found to be common contributing factors to intervention success. However, the studies highlighted difficulties in PSTs' ability to transfer understanding to instruction and integrate students' funds of knowledge into instruction. Further, other parts of the framework, including asking PSTs to examine their beliefs about learners and science learning in linguistically diverse classrooms and development of PSTs' science content knowledge, were under-studied. Implications for science teacher preparation, science teaching and learning, and future research are discussed.

Introduction

In the United States, the linguistic diversity in science classrooms is rapidly growing. In the fall of 2016, nearly one in 10 public school students was classified as an English Learner (National Center for Education Statistics, 2017). In this paper, we define English Learners (ELs) as students who are classified by federally-mandated, standardized K-12 language proficiency assessments as learning English as an additional language in schools. We choose this term because of its ubiquity in EL research and policy. In the past, ELs may have been taught in separate, pull out classrooms focused primarily on English acquisition. However, recent, more inclusive placement practices (Villegas, SaizdeLaMora, Martin, & Millis, 2018), coupled with shortages in teachers specially trained in Teaching English to Speakers of Other Languages (TESOL) or bilingual education (Cross, 2017), mean that more science teachers have the opportunity to teach in linguistically diverse classrooms (i.e., classrooms with EL and non-EL-classified students). With this opportunity comes the need for teacher educators to prepare the rising science teacher workforce to teach in linguistically diverse classrooms, yet research on science teacher preparation for classrooms inclusive of ELs is just beginning to emerge. Thus, this review examines the extant studies addressing how science teacher preparation programs are preparing pre-service teachers (PSTs) to teach in linguistically diverse science classrooms.

Language and Literacy Integrated Science

As K-12 science classrooms are becoming more linguistically diverse, science education research and the Next Generation Science Standards (NGSS) are also highlighting the role of language in science learning. Indeed, the NGSS science and engineering practices necessitate the use of language, with developing and using models, forming explanations, engaging in argumentation, and communicating information identified as particularly rich opportunities for language use and development (Quinn, Lee, & Valdés, 2012). Research on integrating language and literacy, the latter defined in this paper as reading and writing, with science instruction has found that teaching language in the context of science can lead to greater language and literacy growth and science content acquisition than when language and content are taught separately (e.g., Lara-Alecio, Tong, Irby, Guerrero, Huerta, & Fan, 2012; Lee, Deaktor, Hart, Cuevas, & Enders, 2005; Tong, Irby, Lara-Alecio, & Koch, 2014). Indeed, numerous federally funded interventions that focus on integrating science and language instruction have shown improvements in ELs' science and literacy achievement (e.g., Lee, Maerten-Rivera, Penfield, Leroy, & Secada, 2008; Stoddart, 2005), especially in the context of inquiry instruction (Amaral, Garrison, & Klentschy, 2002; Stoddart, Pinal, Latzke, & Canaday, 2002). As such, it is now widely agreed that effective instruction for ELs' science and language learning requires the integration of science content and practices with a focus on science-centered language use and literacy development (Buxton & Lee, 2014; Stoddart et al., 2002).

Preparing Teachers to Teach Language and Literacy Integrated Science

Although there is relative agreement about the need to integrate language and literacy into science instruction for linguistically diverse classrooms (Buxton & Lee, 2014), how to support science teachers in doing so is less clear. The studies above provide insight into effective instruction *within* the K-12 classroom but do not address how these skills and practices can be corralled into teacher training, particularly within the context of teacher education programs.

This is an important area for science education research. Training that specifically addresses how to teach language and literacy integrated science in linguistically diverse classrooms is absent from or underdeveloped in many states' teaching license requirements (NASEM, 2018) and therefore in many teacher preparation programs (Tolbert, Stoddart, Lyon, &

Solís, 2014). As a result, many PSTs do not feel well-prepared to teach language learners in their content area classrooms (Durgunoglu & Hughes, 2010). This may be especially true at the secondary level, where teachers tend to see themselves as teachers of content, not language (Stoddart et al., 2002).

The research community is taking notice of this gap in science teacher education. Studies are emerging that address how to prepare teachers to instruct ELs in linguistically diverse science classrooms. While some literature reviews have synthesized research on PST training for teaching content to ELs that is *inclusive* of science (e.g., Janzen, 2008; Villegas et al., 2018) and others have summarized the research on preparing *in-service* teachers to teach science to ELs (e.g., Lee, 2005), none have looked at research specifically addressing preparing PSTs to teach ELs in science settings. This is important for two reasons: first, integrating language and literacy into science requires attention to specific disciplinary practices and discourses that move beyond general EL instructional strategies (Solís & Bunch, 2016). While discipline-inclusive preparation such as multilingual methods courses are important for developing PSTs' understanding of second language development theories and instructional strategies, they do not focus on how language and literacy can be integrated into science specifically (Bunch, 2010). This leaves PSTs to reconcile and integrate their learning on their own, which can be challenging (Bravo, Solís, & Mosqueda, 2011). Second, while research on preparing in-service teachers to teach language and literacy integrated science to linguistically diverse classrooms can provide valuable insights for PST preparation, professional development for in-service teachers is inherently different from preparation for PSTs due to differences in classroom experience, access to students, and learning agendas and schedules. Thus, an explicit focus on how to best prepare PSTs is important for furthering the research field and improving instructional practice (Faltis & Valdés, 2016).

Unfortunately, little is known about the nature of interventions designed to train PSTs to teach language and literacy integrated science in linguistically diverse classrooms, and in what ways the structure of and focal tasks for learning evident in the interventions contribute to their outcomes. Thus, this review seeks to answer the following research questions:

1. What are the variations in the structure of interventions designed to prepare PSTs for language and literacy integrated science instruction, and to what extent do they support PSTs' beliefs about and understanding and implementation of language and literacy integrated science?
2. What are the variations in the tasks for learning outlined in interventions designed to prepare PSTs for language and literacy integrated science instruction, and to what extent do they support PSTs' beliefs about and understanding and implementation of language and literacy integrated science?

Theoretical Framework

Preparing PSTs to teach language and literacy integrated science in linguistically diverse classrooms occurs at the unique cross-section of language, science, and teacher preparation. While other frameworks have addressed PST preparation generally (e.g., Feiman-Nemser, 2001) or PST preparation for linguistically diverse classrooms (e.g., Lucas & Villegas, 2013), none have considered how this preparation should be manifested within the unique context of science teacher preparation (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). Further, these frameworks have focused particularly on the tasks that PSTs should be able to accomplish, but fail to address important structural components of teacher preparation programs, such as duration, the role of field experiences, and coursework integration. As such, this review was guided by a framework we developed for preparing PSTs to teach science in linguistically diverse classrooms (see Figure 1) that builds on this prior scholarship in teacher preparation generally (i.e., Feiman-Nemser, 2001) and for linguistically diverse classrooms specifically (i.e., Lucas & Villegas, 2013) and takes into consideration some key structural components of teacher preparation that might support PSTs' development as language and literacy integrated science teachers.

In the framework, the inner circle represents the tasks we suggest PSTs should be able to accomplish for adequate preparation to teach science to linguistically diverse populations, while the outer circle outlines some of the key structural components of PST preparation that can support science teacher preparation. Each section of the framework is described next.

---Insert Figure 1 here---

Structural Components for PST Preparation for Linguistically Diverse Science Classrooms

The outer circle of our framework represents three key structural components that are important to attend to when considering how to prepare PSTs to teach in linguistically diverse science classrooms. These components include attention to intervention *duration, coursework integration, and field experiences and mentoring*. While we recognize that there are other structural components that may impact PST uptake of targeted instructional practices, we highlight these practices as those that are consistently identified as important to teacher preparation and professional development (e.g., Garet, Porter Desimone, Birman, & Yoon, 2001; NASEM, 2018; Valdés, Bunch, Snow, & Lee, 2005). We describe each component, next.

Duration. Research identifies sufficient duration, inclusive of both hours engaged in professional development (PD) and time span over which PD occurs, as a key component of effective PD (Garet et al., 2001). While there is no exact number of hours identified as a minimum for effective PD, research suggests that sustained PD tends to be more effective (Desimone, 2009; Johnson, Kahle, & Fargo, 2007).

In PST preparation, where training programs can vary from one to five years and are usually divided into semester-long courses and field experiences, extended duration of an intervention might require cohesion across program components. Program cohesion has been identified as a critical aspect of effective teacher preparation generally (Darling-Hammond, Hammerness, Grossman, Rust, & Shulman, 2005) and for teaching ELs specifically (Athanases & deOliveira, 2011) and allows for PSTs to engage with and revisit key concepts over the course of their teacher training. Next, we address two components of teacher preparation programs that can support this cohesion: integrated coursework and field experiences and mentoring.

Integrated coursework. In order for PSTs to teach language and literacy integrated science, they must learn the methods for teaching language, literacy, and science in an integrated manner. That is, language and literacy teaching methods should be taught within the context of science methods courses rather than as a stand-alone course (NASEM, 2018; Valdés et al.,2005). Doing so allows PSTs to make the natural connections between language and science teaching theory and practice, something that can be challenging to identify when language and science methods are taught in isolation (Bravo et al., 2011). Further, by teaching language and literacy as a part of science methods, language is positioned as a central component of what it means to do science (Valdés, Capitelli, & Quinn, 2018), aligning with the heightened attention to language in the NGSS (Quinn et al., 2012) and providing a focus on language and literacy in science that is beneficial for *all* students (Valdés et al., 2005).

Field experience and mentoring. Programmatic cohesion also extends to the field experiences in which PSTs engage during their teacher training. Indeed, in a recent, comprehensive report on ELs in STEM Subjects (NASEM, 2018), opportunities to engage in field experiences “that align with and support the practices that preservice teachers learn in their coursework” was emphasized as a key component of PST preparation (p. 169). This highlights two important implications for teacher preparation programs. First, programs should provide PSTs with the opportunity to practice language and literacy integrated science instruction with linguistically diverse students by forging partnerships with linguistically diverse school districts (Athanases & deOliveira, 2011; García, Arias, Harris Murri, & Serna, 2010). Second, PSTs should have the opportunity to engage in science instruction in K-12 classrooms where classroom instruction by mentor teachers (i.e., practicing teachers serving as hosts to PSTs) supports and reinforces the targeted instruction, particularly because field experiences and interactions with mentor teachers can have a significant impact on PSTs’ beliefs and practices (Clarke, Triggs, & Nielsen, 2014). In this way, teacher preparation programs can avoid the dissonance that occurs when PSTs are asked to implement reform-based practices in classrooms where more traditional instruction is present (Cochran-Smith, Villegas, Abrams, Chavez-Moreno, Mills, & Stern, 2015; Thompson, Windschitl, & Braaten, 2013).

Tasks for Learning to Teach in Linguistically Diverse Science Classrooms

While attention to the structural components of teacher preparation programs are important, how PSTs are prepared within these frameworks is of equal importance, though oftentimes less researched (Faltis & Valdés, 2016). Feiman-Nemser identified five central tasks for learning, which represent what PSTs “need to know, care about, and be able to do in order to promote substantial learning for all students” (2001, p. 1016). Lucas & Villegas (2013) built on Feiman-Nemser’s framework to include elements of linguistically responsive teaching, thus highlighting required tasks for preparing PSTs to teach linguistically diverse students. The inner circle of our framework expands this work even further by mapping on recent science reform documents (National Research Council [NRC], 2012) and ambitious science teaching practices (Windschitl, Thompson, & Braaten, 2018) to identify the tasks for learning that are beneficial for preparing PSTs for the unique confluence of language and literacy and science in linguistically diverse science classrooms (NASEM, 2018). The result is five key tasks for learning to teach in linguistically diverse science classrooms which we suggest are necessary to address when preparing PSTs to teach in these settings.

Analyzing beliefs and forming new visions of science instruction and linguistic diversity. Past schooling experiences (Feiman-Nemser, 2001; Wong & Luft, 2015) and PSTs' cultural, racial, ethnic, and social class backgrounds (NASEM, 2018) can affect how PSTs conceptualize and implement instruction in their classrooms. In a linguistically diverse science classroom, this means that teachers need to not only examine their rationale for science teaching and their beliefs about effective science instruction with respect to how instruction meets the needs of linguistically diverse students, but to also examine their beliefs about linguistic diversity, their roles as advocates for ELs, and their understandings of sociolinguistic factors of learning language in the science classroom. With regard to language and literacy integrated science instruction, this analysis extends to PSTs' beliefs about the role of language and literacy integration in the science classroom, especially because PSTs may hold strong beliefs about ELs and the relationship between language and content instruction (Lucas & Villegas, 2013; Pinnow & Chval, 2015). It is important, then, that preparation programs provide PSTs with opportunities to critically examine their beliefs about effective instructional practices in linguistically diverse science classrooms to determine in what ways those practices align with ambitious, language and literacy-integrated science instruction that is accessible to all students. Further, PSTs need to be exposed to and engage with plausible, intelligible, and fruitful alternative conceptions of what effective instruction looks like for linguistically diverse science classrooms (Pintrich, Marx, & Boyle, 1993) to support conceptual change and the formation of new visions of language and literacy integrated science instruction.

Developing scientific knowledge and understanding language demands. In linguistically diverse classrooms, science teachers need not only an understanding of science concepts, theories, explanatory frameworks, and rules for evidence and proof (i.e., subject matter knowledge for science; Feiman-Nemser, 2001), but also knowledge of the role language plays as students participate in scientific processes and engage with the big ideas of science (i.e., subject matter knowledge for language in science; Lucas & Villegas, 2013). In other words, secondary science teachers need to understand how language is used for *doing* science (Valdés et al., 2018).

At the same time, it is not enough to know of the science concepts and processes and linguistic features of science instruction if teachers do not know how to teach these things. PSTs need the pedagogical content knowledge necessary to effectively teach science (Shulman, 1986), as well as disciplinary linguistic knowledge, or "the knowledge base needed to facilitate ELLs' understanding of oral and written discourse within a discipline and their accurate use of language to engage them in the disciplinary discourse" (Turkan, De Oliveira, Lee, & Phelps, 2014; pp. 1-2). Thus, preparation programs need to support PSTs in recognizing the unique linguistic features of scientific discourse (Lemke, 1990) and developing the skills necessary to help *all* students notice and use these features of science discourse as they engage in science (Valdés et al., 2018).

Forming understandings of diverse learners and science and language learning. In order to foster interest in and appreciation for science's applicability to their own lives, students need to be able to see the connections between science instruction and their life experiences and interests (NRC, 2012). PSTs must therefore learn how to “cultivate the tools and dispositions to learn about students, their families, and communities,” and to understand how to use that knowledge to inform instruction (Feiman-Nemser, 2001, p. 1018). These funds of knowledge (González, Moll, & Amanti, 2005) are particularly important to identify when students come from cultural backgrounds that do not align with the norms and expectations of Western science classrooms and practices (Lee & Fradd, 1998). In linguistically diverse science classrooms, teachers need to understand ELs’ past experiences with science, both formally and informally, and learn about their literacy skills and language use in English and in their preferred languages (Lucas & Villegas, 2013).

In addition to knowing about the learner, PSTs also need to understand how learning occurs. In the science classroom, this may include theories of learning such as constructivism (Tobin, 1993), but in linguistically diverse classrooms, this knowledge needs to extend to an understanding of theories of language acquisition and how they may inform student learning in the science classroom (Lucas & Villegas, 2013).

Growing a beginning repertoire for science instruction and linguistic support. PST preparation programs are designed to introduce PSTs to a variety of instructional models, curricular resources, and assessment approaches, with the goal of helping teachers determine the best time, place, and way to use each approach or resources in their teaching (Feiman-Nemser, 2001). In linguistically diverse science classrooms, teachers need to be familiar with a variety of student-centered, language and literacy-integrated science instructional methods, as well as ways to develop and adapt curricular resources to provide language-related scaffolding that supports ELs in participating in rigorous science activity (Lucas & Villegas, 2013). Opportunities for

PSTs to engage in, discuss, and approximate rigorous language and literacy integrated science instruction is important to help them gain experience with scaffolding language while maintaining the rigor of scientific practice and content learning (Windschitl et al., 2018).

Identifying tools to study science instruction and its impact on all students' learning. Feiman-Nemser (2001) suggests that to study teaching, PSTs need to be able to observe, interpret, and analyze a variety of student work, curricular materials, and student responses to instruction, as well as other practitioner's instructional decisions. For teachers in linguistically diverse classrooms, these skills encompass a teacher's ability to reflect on and critically analyze instruction, curricular decisions, and student outcomes with language opportunities and challenges in mind. Teacher preparation programs need to provide PSTs opportunities to hone the skills of such reflection and interpretation so they can make informed instructional decisions in their future classrooms.

Collectively, our research team believes the inner and outer circles represent the logistical, theoretical, and practical components of PST preparation for teaching science in linguistically diverse classrooms. We used this framework to guide our literature search, analysis, and organization of results, below.

Methods

To answer our research questions, a multistep review of literature was conducted. First, electronic searches were conducted using a combined search engine of standard educational research databases, including ERIC, Academic Search Complete, Education Full Text, PSYC Info, Education Research Complete, and Psychology and Behavioral Science Collection. Primary search terms included various forms of 'pre-service teacher education.' Secondary search terms included a comprehensive list of labels commonly applied to English learners, including 'English learner,' 'English language learner,' and 'emergent bilingual,' among others. Tertiary search terms included 'science' and the various subdisciplines of science (e.g., biology, physics). Initial searches using these terms yielded 286 results which were presented by the search engine in order of relevance. Titles and abstracts were reviewed for required criteria, as detailed below. If it was unclear if a study met requirements from the title and abstract alone, the manuscript was skimmed to determine inclusion or exclusion.

In order to be included in the literature review, studies needed to be empirical, peer reviewed, and conducted between 2000 and 2019, a time during which more inclusive placement practices has led to a greater presence of ELs in science classrooms (Villegas et al., 2018). While there is a large body of research describing interventions in K-12 classrooms that integrate science, language, and literacy and measure students outcomes (e.g., Shaw, Lyon, Stoddart, Mosqueda, & Menon, 2014; Tong et al., 2014), the focus of this review was interventions designed to prepare PSTs to teach science in linguistically diverse classrooms. As such, only studies in which interventions were focused on PST preparation with outcomes for PST learning or instruction were considered. Further, though other research has addressed content teacher preparation for linguistically diverse classrooms generally (e.g., Villegas et al., 2018), because integrating language and literacy and science requires attention to specific disciplinary practices and discourses (Solís & Bunch, 2016), only studies focused on preparing PSTs to teach *science* to ELs in K-12 settings were included.

While recognizing the important work that is being done in the fields of culturally relevant pedagogy, we chose to focus particularly on studies that address preparing PSTs for classrooms inclusive of ELs and the unique *linguistic* affordances and needs of such classrooms. Given the tightly integrated nature of language and science learning (NASEM, 2018), we felt this was important to ensure that language is placed in the forefront of instructional decisions. Thus, studies included in this paper focused on teacher preparation for teaching students who are concurrently developing their science knowledge and skills and language abilities in English. Finally, only studies that occurred in the United States (U.S.) and were written in English were reviewed. We chose to limit our search to U.S.-based settings because of the ways national education policies influence practice and research in different countries (Villegas et al., 2018).

Using these guidelines, the initial education database search resulted in 10 applicable studies. To further investigate possible research contributions, bibliographies of these research studies were mined for additional empirical articles and related reviews of literature, which in turn were reviewed for additional studies. The curriculum vitae of researchers involved in PST training for teaching science to ELs were also mined for additional sources. Finally, the research journals in which the identified studies were published were searched for additional relevant articles. From these searches emerged studies that were written as conference papers or published in edited books in addition to those in peer-reviewed journals. Because of the small number of studies available, the studies described in edited books and conference papers were also included to provide a broader picture of PST preparation interventions focused on teaching science to ELs in linguistically diverse classrooms. In total, 12 interventions, as described by 15 studies (i.e., some interventions were reviewed by more than one study), were identified for this review of literature.

Each applicable study was read through in its entirety and then reviewed for the structural components and tasks for learning to teach outlined in our framework. Tables were used to identify the presence of each component or task in a study and to record in what ways those components or tasks were manifested in the interventions. The table also included a column for study outcomes, both positive and negative, and researcher-suggested reasons for the outcomes. Results are categorized by framework component, below.

Results

The interventions for preparing PSTs to teach science in linguistically diverse classrooms that were identified for this review varied in structure, complexity, and focus, ranging from single courses, parts of courses, and workshops to integrated interventions that spanned methods courses and/or field placements (see Table 1). Half of the interventions included PSTs who were earning endorsements at the elementary level (Arreguín-Anderson & Alanis, 2017; Bravo, Mosqueda, Solís, & Stoddart, 2014; Gibbons, 2008; Hernandez, 2016; Jung & Brown, 2016; Stoddart, Bravo, Mosqueda, & Solís, 2013; Stoddart & Mosqueda, 2015), five interventions included participants earning endorsements at the secondary level (i.e., Heineke, Smetana, & Sanei, 2019; Lyon, 2013a & 2013b; Lyon, Stoddart, Bunch, Tolbert, Salinas, & Solís, 2018; Roberts, Bianchini, Sook Lee, Hough, & Carpenter, 2016; Siegel, 2014; Tolbert, Knox, & Salinas, 2019), and one intervention spanned both elementary and secondary levels (i.e., Settlage, Gort, & Ceglie, 2014). Half of the interventions (i.e., Bravo et al., 2014; Gibbons, 2008; Hernandez, 2016; Lyon et al., 2018; Roberts et al., 2016; Stoddart et al., 2013; Stoddart & Mosqueda, 2015; Tolbert et al., 2019) focused on preparing PSTs for science instruction for ELs generally, while two interventions (Lyon, 2013a, 2013b; Siegel, 2014) focused on preparing PSTs to equitably *assess* students in linguistically diverse classrooms, one (i.e., Jung & Brown, 2016) focused on supporting PSTs in identifying and designing supports for academic language demands in their science lessons, another (i.e., Arreguín-Anderson & Alanis, 2017) emphasized PSTs' use of paired learning strategies to support language development in science, and a final intervention (i.e., Settlage et al., 2014) focused on PSTs' ideologies about ELs and science instruction for linguistically diverse classrooms.

Each study was reviewed for the elements of our theoretical framework (see Table 1). It is important to note that the frameworks from which our theoretical framework was developed, as well as our theoretical framework itself, were designed as guides for teacher preparation programs as a whole. Many of the interventions identified in this review profile one component of a larger teacher preparation program. As such, our review here is focused on results that were reported within the contexts of these interventions, recognizing that in many cases individual interventions, because of their roles as parts of larger programs, may not address all components of the framework by themselves, even if the larger program does. We describe the results in aggregate below to better understand what the field knows so far about preparing PSTs to teach science in linguistically diverse classrooms.

Structural Components of PST Preparation for Linguistically Diverse Science Classrooms

Duration. The 12 interventions identified for this review varied in duration (see Table 1). Some interventions lasted only a few hours (e.g., Settlage et al., 2014), a few days (e.g., Hernandez, 2016), or a portion of a semester-long methods course (e.g., Gibbons, 2008; Siegel, 2014). Half of the interventions (i.e., Arreguín-Anderson & Alanis, 2017; Bravo et al., 2014; Jung & Brown, 2016; Lyon et al, 2018; Roberts et al., 2016; Stoddart et al., 2013; Stoddart & Mosqueda, 2015; Tolbert et al., 2019) took place over the course of one semester. Only two interventions (i.e., Lyon, 2013a & 2013b; Heineke et al., 2019) lasted a year or more. While all interventions highlighted positive outcomes and areas for growth, researchers from both of the extended interventions highlighted the duration of the interventions, which provided PSTs extended time to engage with and appropriate targeted instructional practices and beliefs, as a key factor to the successful outcomes. Indeed, Heineke et al. (2019), who chronicled one secondary biology PST's conceptual and pedagogical development across their two-year intervention, noted that their participant's expertise as a science teacher of linguistically diverse students "did not happen as a result of one site visit, course, or assignment" (p. 94).

However, a comparison of two studies with similar foci but differing lengths paints a more complicated picture. Lyon (2013a, 2013b) and Siegel (2014) both focused on developing secondary science PSTs' understanding and implementation of equitable assessment for linguistically diverse science classrooms. In the shorter of the two interventions, Siegel (2014) used his researcher-created McCes equitable assessment framework (see Siegel, 2007 for a description) to support development of PSTs' conceptions of and planning for equitable science assessments for ELs as part of a semester-long science teaching methods course focused on inquiry-based instruction, assessment, and instructional planning. In the longer intervention, Lyon (2013a, 2013b) sought to develop PSTs' assessment expertise, which he defined as knowledge of and beliefs about assessment and use of that knowledge for planning, implementing, and reflecting on assessment, by integrating assessment-focused instruction into three consecutive courses (i.e., two science methods/theory courses and one diverse learners course) for the duration of a year-long teacher education program. A key dimension of his intervention was equity in assessment for linguistically diverse populations.

Results from both studies indicated that, while PSTs showed growth in their conceptual understandings of equitable assessment, translation into planning and instruction was challenging. For example, in Siegel's (2014) study, participants showed growth in four conceptual categories related to equitable assessment, yet only two of 23 participants incorporated assessments that were attuned to all five of the McCes principles for equitable assessment, and use of equitable assessment strategies was generally low. Similarly, Lyon (2013a) found that while PSTs demonstrated more awareness about language issues in assessment and more knowledge about how to scaffold language in such assessments, the translation from understanding to action through instructional planning was lacking. Taking closer look through a multiple case study with three of the eleven participants from the first study (Lyon, 2013b), Lyon found that all three PSTs gained knowledge about and increased their attention to the role of language in science assessment and acknowledged the importance of integrating some sort of scientific discourse into their assessment practices. However, in practice PSTs struggled to decide whether equitable assessment meant reducing language demands or scaffolding them, and were unsure if or how to assess language along with conceptual understanding.

Thus, despite differing durations, results for both equitable assessment studies show similar conceptual growth but also challenges with translating understanding into practice through instructional planning. While it is important to note that both studies had a small number of participants and therefore conclusions cannot be generalized, and that the interventions were not mirror images of one another and therefore differences could exist due to other factors of the interventions, these findings might suggest that challenges related to implementation can persist even with extended intervention duration and that, while duration might be important, simply extending the length of the intervention may not guarantee improved results. This could be heartening news for programs, particularly at the elementary level, where dedication of more than one semester-long course to language and literacy integrated science instruction can be challenging. However, given the small number of studies focused on preparing PSTs to teach science in linguistically diverse classrooms, and the diversity in scope and emphasis among the studies, more research is needed before any definitive conclusions can be made.

Integrated coursework. In line with the NGSS (NGSS Lead States, 2013), research indicating that the integration of language, literacy, and science instruction can support students' language and content acquisition (e.g., Stoddart et al., 2002; Lee et al., 2008), and criteria for inclusion in this review, all of the studies reviewed integrated science and ELD methods and content to encourage science and language integration within PST instruction. Through modeling of science and language integrated practices by science methods instructors and at times mentor teachers, and through instructional planning and teaching opportunities, PSTs saw language strategies embedded within science instruction and had the opportunity to apply the concepts to their own instruction. For example, in one study, Bravo and colleagues (2014) integrated the CREDE Five Standards for Effective Pedagogy (CFSEP) model into an elementary science methods course. The CFSEP model includes five research-backed practices (or standards) found to support academic achievement in culturally and linguistically diverse students across all subject areas. These standards include joint productive activity, language and literacy development, contextualization, challenging activities, and instructional conversation (see Bravo et al., 2014, for a description of each practice). In the CFSEP science methods course, Bravo et al. situated each standard within the science context, highlighting how each practice aligned with and was integral to rigorous, age-appropriate science instruction. PSTs read about, engaged in, and participated in meta-pedagogical discussions about science-based activities exemplifying the CFSEP and also participated in a linguistically and culturally diverse K-5 classroom field placement where intervention mentor teachers were trained in how to support and provide feedback to PSTs during instruction using the CFSEP observation rubric. Analyses of field placement instruction indicated that there were statistically significant differences in observation scores on three of the five targeted practices (language and literacy, instructional conversation, and challenging activities) in favor of the PSTs in the intervention group, though PSTs in both groups struggled to translate methods course learning into instruction at a high level.

Studies from the same group of researchers at the elementary (i.e., Stoddart et al., 2013) and secondary levels (i.e., Lyon et al., 2018) followed a similar model of language and science integration, but with researcher-developed instructional frameworks, and found similar positive results. Other interventions integrated language, literacy, and science through a focus on equitable assessment for ELs (i.e., Lyon, 2013a; Lyon, 2013b; Siegel, 2014), while still others did so through attention to specific ELD strategies for language development within science classrooms (e.g., Arreguín-Anderson & Alanis, 2017; Gibbons, 2008; Hernandez, 2016) or a focus on identifying the language demands of science instruction (Jung & Brown, 2016).

Despite the variation in how interventions integrated language and literacy into science instruction, common themes emerged, including attention to ensuring rigor (e.g., Roberts et al., 2016; Siegel, 2014) while providing scaffolds for language development (e.g., Jung & Brown, 2016; Stoddart et al., 2013), attention to and incorporation of students' cultural, linguistic, and academic resources (e.g., Heineke et al., 2019; Roberts et al., 2016), a focus on scientific discourse and disciplinary language use (e.g., Lyon et al., 2018; Roberts et al., 2016), and an emphasis on collaboration (e.g., Arreguín-Anderson & Alanis, 2017; Bravo et al., 2014). These themes reflect research identifying critical components of language and literacy integrated science instruction (e.g., Buxton & Lee, 2014) and might help PSTs overcome the traditional siloed nature of language and science methods instruction (Bravo, 2016; Stoddart, Solís, Tolbert, & Bravo 2010). For most studies, outcomes were positive but limited, particularly with regard to implementation. These results are discussed further in other sections, below.

Field experience and mentoring. All but one intervention (i.e., Settlage et al., 2014) took place in tandem with at least one field experience, which often occurred in a linguistically diverse classroom. However, the role that field experiences played within interventions varied. In most interventions, connections between field experiences and PSTs' university-based preparation learning were made when PSTs engaged in field-based observations (e.g., Hernandez, 2016; Siegel, 2014), completed field-related assignments (e.g., Gibbons, 2008; Heineke et al., 2019; Roberts et al., 2016), or enacted targeted instructional practices in their field placements (e.g., Bravo et al., 2014; Lyon et al., 2018). In most cases, field experiences appeared to be positioned as contexts to consider as PSTs developed their own instructional materials and lessons (e.g., Jung & Brown, 2016; Siegel, 2014), or as a testing grounds for practices learned in methods courses (e.g. Hernandez, 2016; Lyon, 2013b). One notable exception was Heineke and colleague's (2019) Teaching for Change (TFC) program, which positioned field placements at the center of learning. In their program, 80% of teacher training occurred within the context of school and community-based field experiences that served as anchors for PST learning and teaching.

Many studies point to field experiences as a key factor in understanding both positive and negative intervention outcomes. For example, Siegel (2014) highlighted the importance of providing PSTs field experiences in diverse classrooms, suggesting that PSTs' struggle to translate understandings about equitable assessment into their instructional planning in his study may have stemmed in part from the fact that PSTs did not experience any positive examples of effective equitable assessment use during their field experiences, which occurred in classrooms without high percentages of ELs. As a result, there was a disconnect between the strategies the

PSTs were learning and those being exemplified in classrooms with less diverse populations, leaving the PSTs struggling to understand how to implement the targeted assessment strategies in the context of fast-paced and demanding classrooms.

Hernandez (2016) highlighted the positive impact of field experience as part of her three-day professional development intervention, in which 10 elementary PSTs spent the morning in a bilingual third grade classroom observing and participating in science and language integrated science instruction based on a science version of the Guided Language Acquisition Design Project (Project GLAD), a professional development program and instructional model designed to support educators in integrating oral language and literacy into content area units. During the intervention, Hernandez modeled 20 GLAD instructional strategies she deemed most appropriate for elementary science instruction (for a list, see Hernandez, 2016) through a unit that was taught *within* the third-grade bilingual classroom. Hernandez suggested that this modeling and allowing PSTs to plan for and use instructional strategies in a linguistically diverse elementary classroom under the watchful eye of the instructor was key to her results, which indicated that PSTs moved from a theoretical understandings of EL science instruction to more practical understandings of instruction and how to respond to challenges that arise when strategies are put into practice in the science classroom. She also identified the shared field experience and the opportunity to reflect together afterwards as a key improvement over the commonly separate field experiences in which PSTs observe and practice in classrooms that may or may not embody targeted practices.

Heineke et al. (2019) identified field experiences as key to both positive outcomes and areas for continued growth. In their case study of one secondary biology PST, they found that over the course of their two-year intervention, the participant developed an understanding of the interconnectedness of language and science learning, acknowledged the importance of authentic and collaborative instruction to support students' language acquisition, and positioned his ELs positively by acknowledging and incorporating their linguistic resources into his instruction. Analysis of unit plans, lesson plans, and reflections indicated that the participant developed lessons through a language lens, with particular attention to disciplinary-specific language objectives and scaffolds, which was supported by his professed identity as a science teacher who supports language development within his classroom. Heineke and colleagues pointed to the extensive field experiences as a critical contributor of the positive outcomes and suggested that teacher educators "should go beyond adding a stand-alone, university-based course and instead reconceptualize holistic programs with authentic field experiences to apprentice teacher into inclusive teaching of [emergent bilinguals] in science classrooms" (2019; p. 95). However, they also pointed to shortcomings in their program's field placement opportunities. Though their program appeared to be generally successful in supporting their participant's development of professional expertise for teaching biology to ELs (whom they termed emergent bilinguals), Heineke and colleagues still found lingering misconceptions about student labels that they believe were reinforced by the tracking system and related discourses in the participant's field placement school. The researchers highlighted the disconnect between teacher preparation programs and field placements as a challenge and proposed that field experiences be focused on collaboration with in-service teachers who have expertise teaching science to ELs, and that they provide training for mentor teachers to become co-teacher-educators.

This training for mentor teachers was addressed by a series of interventions by Bravo, Lyon, Stoddart, and their colleagues (Bravo et al., 2014; Lyon et al., 2018; Stoddart et al., 2013) that sought to more fully create connections between university coursework and field experiences. In these interventions, researchers tried to create coherence between university-based methods courses and classroom-based field experiences by training mentor teachers (i.e., Bravo et al., 2014; Lyon et al., 2018; Stoddart et al., 2013) and university supervisors (Lyon et al., 2018; Stoddart et al., 2013) in the same targeted instructional strategies as the PSTs. For example, in their Effective Science Teaching for English Language Learners (ESTELL) project (Bravo et al., 2011; Shaw et al., 2014; Stoddart et al., 2013; Stoddart et al., 2010), Stoddart and colleagues trained mentor teachers and teacher supervisors (charged with periodically observing the PSTs during their field experience) in their instructional model. The ESTELL model incorporates six instructional practices that teachers should use to promote science learning for ELs (Shaw et al., 2014), including integrating science, language, and literacy; scaffolding English language development; using scientific discourse; contextualizing science instruction; integrating inquiry-based collaboration; and developing scientific understanding.

Each mentor teacher and teacher supervisor participated in a two-day professional development workshop where they learned about the ESTELL framework through exemplar lessons, an ESTELL-focused observation guide, and articles about effective mentoring of PSTs and science instruction for ELs. As a result, the instructional practices modeled in methods courses were reinforced by modeling and instructional feedback in their field experiences.

Observations of PSTs during their student teaching field experiences indicated that PSTs who participated in the ESTELL intervention scored significantly higher than PSTs who did not on a number of ESTELL practices, though all scores for all participants still fell within the introductory level. While it is impossible to know the extent to which outcomes were attributed solely to mentor teacher training, the cohesion across methods courses and field experiences was highlighted as a critical component of the intervention (Shaw et al., 2014), an assertion supported by authors of related interventions with similar mentor teacher training components and similar results (e.g., Bravo et al., 2014; Lyon, Stoddart, Solís, Tolbert, Bunch, Roth, Salinas, Knox, Couling, & Butler, 2016).

Thus, whether enacted or not, many studies in this review appear to support coherence between university methods courses and field experiences and highlight the importance of providing opportunities for PSTs to practice targeted strategies in linguistically diverse classrooms, assertions that are backed up by teacher preparation research in STEM disciplines (e.g., NASEM, 2018) and generally (e.g., Darling-Hammond et al., 2005).

Tasks for Learning to Teach in Linguistically Diverse Science Classrooms

Analyzing beliefs and forming new visions of science instruction and linguistic diversity. While many studies described how their interventions might provide opportunities for PSTs to examine their beliefs or, more commonly, develop new visions for science instruction and linguistic diversity, only half of the studies (i.e., Bravo et al., 2014; Heineke et al., 2019; Lyon 2013a; Lyon, 2013b; Siegel, 2014; Settlage et al., 2014; Stoddart & Mosqueda, 2013) provided outcomes related to those opportunities, though others (e.g., Lyon et al., 2016) collected data to that end.

Settlage and colleagues' (2014) study focused exclusively on PSTs' beliefs, seeking to determine how participation in a mediated immersion experience, in which PSTs were taught a physics lesson in Spanish, would alter PSTs' beliefs about ELs and encourage a reassessment of PSTs' perceptions of teaching science in diverse settings. Seven elementary education and three secondary science PSTs with varying levels of self-reported Spanish knowledge participated in a two-hour immersion experience that was part of an advanced science methods course elective focused on teaching science in diverse settings. In the lesson, students engaged in science lab activities in groups of three. As the lesson progressed, more language supports were provided, ranging from no language supports and a ban on English in the first lesson segment to the modeling of numerous language scaffolds and sheltered instruction methods (as operationalized by Echevarria, Vogt, & Short, 2016) and encouraged use of English in the final segment.

Using emotional ratings, reflections written throughout the experience and in a later class, and observations of the participants' interactions during the intervention, the researchers found that the immersion experience created disequilibrium in PSTs' understandings of teaching and learning and prompted reflection on their 'knowledge, preconceptions, experiences, biases, and practices' regarding ELs (p. 61). Though a frustrating and challenging experience for many of the participants, empathy for students learning science in another language was evident in most participants' reflections. Many participants also acknowledged the importance of students' home languages as a resource, not a barrier, to language learning, and many suggested strategies they had seen used in the experience as possible ways to support ELs based on their perceived effectiveness in supporting PSTs' own learning in another language. Reflections on how they used their own resources to participate in the experience also helped to shift PSTs' frames of reference regarding ELs' learning in another language from a deficit mindset to an asset mindset.

The researchers suggest that the experience allowed the PSTs to consider how language can mediate learning in a science classroom by putting them in the shoes of their EL students for a significant period of time and providing time for reflection during and after the experience. In these ways, the intervention supported PSTs in not only examining their beliefs, but also forming new visions of what science instruction should look like in linguistically diverse classrooms. Unfortunately, while the reflections suggest that following the intervention PSTs had positive perceptions about teaching and learning for ELs, we do not know if or how these results ultimately affected PSTs instruction beyond the boundaries of the methods classroom.

Other studies (e.g., Bravo et al., 2014; Heineke et al., 2019; Lyon, 2013a) addressed PSTs' beliefs about language and literacy integrated science *instruction*. For example, Bravo and colleagues (2014) investigated PSTs' beliefs about the efficacy of the five CFSEP practices guiding their elementary science methods course. Results did not reveal many differences in beliefs between the experimental and control groups, which could be due to the high pre-test scores for both groups (i.e., prior to the intervention both groups felt that the CFSEP practices were efficacious for instructing ELs in the science classroom). PSTs receiving the intervention did show stronger beliefs about the efficacy of using joint productive activity (i.e., use of purposeful grouping and sharing of authority during investigations) than participants in the control, but gains were modest. Interestingly, despite the treatment group's increased beliefs about the efficacy of joint productive activity, results from their instructional implementation scores found no significant difference between groups on that practice. More work needs to be done to determine in what ways PSTs might investigate and develop their beliefs about ELs and language and literacy integrated science, as well as if or how those beliefs are related to instruction or instructional planning.

Developing scientific knowledge and understanding language demands. All interventions reviewed were situated within science methods courses or science-focused training opportunities and therefore used science as a lens for learning and as the content of instruction. For example, Stoddart and colleagues' (2013) ESTELL instructional framework was modeled within the context of five state standards-based science units that addressed a series of scientific topics. Further, scientific practices were embedded within their framework (e.g., *developing scientific understanding*, which focuses on key practices related to scientific method as students engage in inquiry-driven science investigations), a choice that was reflected in other studies (e.g., Lyon et al., 2018). However, perhaps because of the emphasis on language and literacy integration, the focus on PSTs' enaction of key scientific *practices*, or the integration of science content knowledge development in other aspects of the wider teacher preparation program, none of the studies assessed PSTs' science content knowledge development as a result of participation in the interventions. Instead, most interventions focused on PSTs' understanding of how language is used for doing science and how to support PSTs in developing lessons or instructing in a way that highlights and supports students' use of language in science.

Perhaps the clearest example of this focus on scientific language came from Jung and Brown's (2016) case study of seven elementary PSTs, in which participants used researcher-created Academic Language Planning Organizers (ALPOs) to develop science lessons. In the study, participants were trained to identify the academic language demands, including discourse, syntax, and vocabulary, of each lesson they developed and to integrate language supports to speak to those demands through their use of the ALPO. The ALPO required PSTs to identify for each lesson they created seven features: content objective(s), tasks (including the language functions used therein), discourse, syntax, vocabulary, language objective, and language supports (Jung & Brown, p. 852).

Analysis of PSTs' lesson plans and related ALPOs suggests that most PSTs were able to identify from their science content objectives the language functions (i.e., how language was being used) and vocabulary (including both the content-specific and general academic vocabulary) necessary for their lesson, and were able to identify and integrate language supports into their lessons to reflect those demands. However, PSTs struggled to maintain a focus on the identified language functions throughout their descriptions of the lesson tasks in the ALPOs and were less clear on the particular syntax and discourse features of their lessons. Further, only half of the ALPOs included language supports that were clearly aligned with language objectives and highlighted the linguistic demands of the lesson. This suggests that PSTs might need more support in highlighting, synthesizing, and responding to language demands in their lessons.

Developing PSTs' understanding of scientific language demands and how language is used to do science was integrated into other studies through the instructional frameworks that PSTs learned and approximated. For example, two of the four dimensions for practice outlined in Lyon et al.'s (2018) Secondary Science Teaching with English Language and Literacy Acquisition (SSTELLA) framework directly relate to language use in science classrooms (i.e., *scientific discourse* and *language and disciplinary literacy*), a theme that is also reflected in other interventions' frameworks (i.e., Bravo et al., 2014; Roberts et al., 2016; Stoddart et al. 2013). Interestingly, results from Lyon and colleagues' (2018) study indicate that the practices with the highest level of fidelity of implementation in PSTs' instruction across six sites were those that fell under the language-focused dimensions (i.e., *student interaction* and *student talk*). In particular, researchers found that a majority of participants enacted these practices at the targeted implementing or elaborating levels, which was in contrast to other practices that were consistently performed at a lower level. Each of these practices (in addition to a third language-related practice, developing literacy) also had positive, though small, effect sizes in favor of the treatment group. This suggests growth in PSTs' disciplinary linguistic knowledge (Turkan et al., 2014) as they sought to provide opportunities for discourse and language use and echoes similar findings from other studies (e.g., Bravo et al., 2014; Stoddart et al., 2013). The researchers highlight this improved focus on discourse as a positive step towards more student-centered activity in the classroom and an evolution in thought about EL support from only pictures and graphic organizers to including opportunities for students to use language in a science classroom.

Attention to science and language *learning* was more nuanced among interventions. Many of the interventions (e.g., Lyon et al., 2018; Roberts et al., 2014; Siegel, 2014) followed or ran concurrently with a language methods course where PSTs learned about theories of second language acquisition, so that interventions could build on this knowledge as they integrated it into science instruction. For example, prior to Roberts el al.'s (2016) capstone science methods course that was developed as part of their NSF-funded STEM Teacher for English Language Learners: Excellence and Retention (STELLER) project, PSTs took two science methods courses and two second language acquisition methods courses that taught language and content separately. Similar to the teacher preparation program in which Lyon's (2013a, 2013b) intervention occurred, in both Bravo et al.'s (2014) and Stoddart et al.'s (2013) interventions, the teacher preparation programs themselves were centered around larger themes of preparing PSTs to be responsive to student diversity as they prepared PSTs for credentials in Cross-Cultural, Language & Academic Development (CLAD) or Bilingual Cross-Cultural, Language & Academic Development (BCLAD). As such, topics such as second language acquisition and language and culture issues were taught in courses leading up to the integrated science methods course (Bravo et al., 2014) and may have supported PSTs' understanding and implementation of targeted practices in a science setting. Some interventions (e.g., Bravo et al., 2014; Jung & Brown, 2014; Stoddart et al., 2013) also highlighted inquiry or sociocultural theories of learning as foundational to how science was taught. However, most studies did not provide specifics and more research is needed to understand how these aspects of teacher preparation are integrated into preparation programs.

Forming understandings of diverse learners and science and language learning. Most of the interventions trained PSTs to identify, and in many cases integrate, their students' funds of knowledge into instruction. The SSTELLA (Lyon et al., 2018; Tolbert et al., 2019), STELLER (Roberts et al., 2016), ESTELL (Stoddart et al., 2013), and CFSEP (Bravo et al., 2014) frameworks all included acknowledgement of students' resources and lived experiences (sometimes called contextualization) as a key part of their instructional frameworks. For both equitable assessment interventions (i.e., Lyon, 2013a & 2013b; Siegel, 2014), identifying and considering students' funds of knowledge when developing assessments was a key component of PST training. For example, one component of Siegel's (2014) McCes framework for equitable assessment required PSTs to consider how linguistically diverse students' sociocultural experiences influenced their understanding and completion of assessments. Settlage et al.'s (2014) study also highlighted the resources ELs bring to science classrooms as PSTs reflected on how they used their own linguistic and academic resources to make sense of an immersion physics lesson.

Unfortunately, despite the interventions' attention to identifying and using students' funds of knowledge in instruction, doing so was one of the greatest areas of struggle for many PSTs. That is, while PSTs often recognized the importance of funds of knowledge, in practice identifying and incorporating students' resources into instruction was a challenge (Bravo et al., 2014; Lyon et al., 2016; Roberts et al., 2016). For example, despite a heavy emphasis on *building on and using students' funds of knowledge and resources* as one of three key principles in Roberts and colleagues' (2016) instructional framework, in post-intervention interviews there was no mention from any of the PSTs about integrating students' funds of knowledge into instruction. In other studies, even when PSTs' scores for incorporating funds of knowledge into their instruction were found to be significantly higher than the control group, the overall implementation scores were low (Lyon et al., 2018; Stoddart et al., 2013; Tolbert et al., 2019).

These findings echo research on in-service teachers showing that, even when teachers think integrating funds of knowledge is beneficial and important, they struggle to incorporate students' cultural and linguistic resources into their science instruction (Lee, Luykx, Buxton, & Shaver, 2007) and do not feel well-prepared to do so (Banilower, Smith, Malzahn, Plumley, Gordon, & Hayes, 2018). In a follow up study on two PSTs from Lyon et al.'s (2018) study, Tolbert et al. (2019) raise a series of questions for teacher preparation programs to consider as they seek to make students' funds of knowledge a more central component of PST training.

One study that showed some success with regard to integrating students' funds of knowledge was Heineke and colleagues' (2019) TFC program. As part of the two-year intervention, PSTs participated in a 12-week field experience where they worked with individual EL-identified students, getting to know the students through interviews and daily interactions, and then considering how they could use what they know about their student's linguistic, cultural, and social resources to tailor instruction to him/her. Though only investigating outcomes for one PST, researchers found that by the end of the intervention, their participant consistently positioned ELs positively and identified and incorporated students' linguistic resources into his instruction. These findings are supported by other, non-science-specific studies on the TFC program (Nasir & Heineke, 2014) and suggest that targeted coursework in conjunction with one-on-one interactions in K-12 settings might be particularly supportive for PSTs developing their abilities to garner and use students' funds of knowledge during instruction, though more studies with greater sample sizes are needed.

Growing a beginning repertoire for science instruction and linguistic support. Recent reforms such as the NGSS and Common Core Standards mean that expectations that were extant when PSTs were students may be different from current expectations (Stoddart, 2016). It becomes imperative, then, that PST have the opportunity to engage in, analyze, and approximate rigorous language and literacy integrated science instruction that they may not have experienced during their own education (Lee & Buxton, 2013). In a majority of the studies reviewed for this paper, PSTs actively observed and participated in the targeted instructional strategies through modeling by methods instructors and at times mentor teachers (e.g., Bravo et al., 2014; Hernandez, 2016; Jung & Brown, 2016; Settlage et al., 2014). PSTs were provided opportunities to reflect on and discuss the strategies (Roberts et al., 2016) and make connections between practice and theory (Heineke et al., 2019). This was an important component of many interventions, especially because a trend among many studies' findings (e.g., Jung & Brown, 2016; Lyon, 2013a; Stoddart et al., 2013; Lyon et al., 2018) was that PSTs tended to enact in their own planning or instruction the methods that were modeled most clearly and engaged in most frequently in their methods courses.

In addition to opportunities to experience and observe target practices, in nearly all of the interventions PSTs were asked to apply what they were learning through instructional planning and/or teaching (i.e., Arreguín-Anderson & Alanis, 2017; Bravo et al., 2014; Gibbons, 2008; Hernandez, 2016; Jung & Brown, 2016; Lyon, 2013a; Lyon, 2013b; Lyon et al., 2018; Siegel, 2014; Stoddart et al., 2013). By engaging in this approximation of teacher tasks (Grossman, Compton, Igra, Ronfeldt, Shahan, & Williamson, 2009), PSTs were encouraged to transfer knowledge and beliefs into practice and implement instructional strategies in supportive environments ranging from in-class microteaching assignments to K-12 classroom instruction.

Interestingly, the transfer from knowledge to practice was consistently highlighted as a challenge for PSTs. In many of the interventions, PSTs appeared to understand the targeted practices yet struggled to incorporate them into their planning or instruction. For example, in all three studies on equitable assessment (i.e., Lyon, 2013a; Lyon, 2013b; Siegel, 2014), PSTs showed growth in conceptual understanding but struggled to implement their new learning and beliefs in their instructional planning. In other studies (i.e., Bravo et al., 2014; Lyon et al., 2018; Stoddart et al., 2013;), researchers found that while PSTs in the intervention group scored significantly higher than the control group on implementation of some practices, PSTs still struggled to enact most targeted instructional strategies beyond the introductory level during their field experiences, and in some cases performed worse than PSTs in the control. For example, Lyon et al. (2018) found that, while PSTs participating in their SSTELLA intervention improved their instructional strategies related to some language-focused practices, three science-focused practices (i.e., *engaging students in scientific and engineering practices*, *communicating big ideas*, and *pressing for evidence-based explanations and arguments*) showed limited and in some cases negative growth among PSTs in multiple programs. This was despite the intervention's intention to integrate scientific sense-making "so that attempts to support ELs' language and literacy development do not distract from or subvert the central goal of enhancing their understanding of science" (p. 1294).

Similarly, Arreguín-Anderson and Alanis (2017) found in their study of 11 bilingual elementary PSTs that participants tended to gravitate towards integrating unstructured or semi-structured paired strategies for language use (i.e., turn and talk and sentence stems) rather than more structured strategies (e.g., think-pair-share, summarizing pairs) because they found them easier to implement. While Arreguín-Anderson and Alanis suggest their findings point to the need to expose PSTs to strategies that feel manageable and easy to implement in order for the strategies to be actualized in instruction, these results and those of the other studies indicate that there is still much work to be done to ensure that PSTs are effective in using multiple targeted practices at high levels in their planning and instruction. These findings echo results from other teacher education research studies that address the implementation of university-based instructional methods in K-12 settings (Cochran-Smith et al., 2015) and suggest that, while teacher preparation programs may be effective in developing PSTs' understandings and entry-level enactment of targeted instructional practices, more needs to be done to support the translation of knowledge into practice within the demands of K-12 classrooms.

Identifying tools to study science instruction and its impact on all students' learning. All of the interventions supported PSTs in developing tools to study science instruction and learning in linguistically diverse classrooms through numerous opportunities for PSTs to observe, interpret, and analyze targeted instructional strategies through reflection on observed or self-implemented instruction. Roberts et al. (2016) made this reflection a key component of their capstone science methods course by highlighting "the mis/connections between theoretical constructs and classroom practice as part of learning about and reflecting on teaching" (p. 81) and engaging PSTs in multiple cycles of reflection about instruction for ELs and their own implementation of it. Hernandez (2016) made these tools evident through opportunities for her PSTs to observe her instructional decisions and student responses, and then interpret and analyze what they had seen, in conjunction with student products, as they worked with the instructor to create lessons for the next day of instruction. PSTs in Arreguín-Anderson and Alanis's (2017) intervention completed weekly reflections and participated in class discussions in which they reflected on their field-based instruction and focused on student learning and reaction in response to it. Other interventions modeled this reflective practice by inviting PSTs to reflect on and analyze the targeted instructional strategies that were modeled in their methods classrooms (e.g., Bravo et al., 2014; Jung & Brown, 2016; Lyon et al., 2018) and at times K-12 classrooms through classroom observations (e.g., Heineke et al., 2019) or video footage of PSTs (e.g., Roberts et al., 2016) or other teachers enacting the key practices (e.g., Lyon et al., 2018). While no studies have investigated PST instruction longitudinally to determine in what ways this training may support their continued professional learning, it is clear that PSTs had opportunities to identify and approximate tools for future learning.

Conclusions and Implications

The purpose of this review was to determine in what ways interventions designed to prepare PSTs for linguistically diverse science classrooms addressed the structural and task-related components we identified in our framework as key to developing PSTs' beliefs about and understanding and implementation of language and literacy integrated science instruction. We found significant diversity in how interventions addressed both the structural and task-related components of our framework, and how those decisions affected outcomes. For example, structurally all interventions integrated language and science instruction and most incorporated field experiences, but how interventions did so varied from researcher-created instructional frameworks with mentor teacher training to language-focused interventions in which field placements served as the testing grounds for interventions, all with some but varying degrees of efficacy. The duration of interventions also varied and, coupled with the diverse focus of the studies, made conclusions about the impact of duration on outcomes difficult to draw.

Task-related components were also covered in different ways and to different extents. For example, all or nearly all of the interventions addressed PSTs' understanding of language demands, growing repertoires for science instruction and linguistic support, understandings of diverse learners, and identification of tools for studying teaching and learning. However, results suggested that even in spite of this, PSTs still struggled to identify and use students' funds of knowledge and transfer their knowledge of key practices into instructional action. Further, some tasks, such as developing PSTs' science content knowledge and supporting PSTs in examining their initial beliefs about teaching science in linguistically diverse classrooms, were underrepresented or understudied in the studies reviewed. Thus, while the interventions reviewed in this study provide a strong foundation of how to support PSTs in teaching language and literacy integrated science instruction, there is much that still needs to be done.

Implications for Teacher Preparation

It is clear from these studies that training for science PSTs should include courses that integrate language and science content and instructional models to provide a more comprehensive understanding of effective instruction for linguistically diverse science classrooms. At the same time, it is important that in the focus on integrating language and literacy, key science teaching methods and instruction are not overlooked or minimized (Lyon et al., 2018). Thus, PSTs should be exposed to how language and literacy can be integrated into science instruction in a way that highlights the language-rich practices of science (e.g., argumentation, communicating results) and is used as the context for students' content *and* language acquisition as they engage in the big ideas of science (Windschitl et al., 2018).

Language and literacy integrated science methods courses require that science methods instructors be aware of and able to integrate methods and theories of language and literacy into their science methods instruction. This can be challenging, particularly because many science teacher educators developed their K-12 teaching experience in classrooms with very different demographics than the classrooms of today (NASEM, 2018). Thus, training for teacher educators (O'Hara & Pritchard, 2008; Tanguay, Bhatnagar, Barker, & Many, 2018) and collaboration between science teacher educators and ESL teacher educators (NASEM, 2018) or in-service ESL teachers (Hones & Alderton, 2017) can be critical for effective language and literacy integrated science methods instruction. Indeed, in many of the studies we reviewed, collaboration or methods instructor training were key component of the interventions. Teacher education programs need to consider in what ways they are providing opportunities for collaboration among language and science instructors, as well as in what ways they are building teacher educator's knowledge about language teaching and learning (Faltis & Valdés, 2016).

Cohesion across program components, in which training programs create a common language and teaching philosophy across teacher education and field placement settings, was also highlighted by many studies as a critical step for science teacher preparation. Teacher education programs should seek to build partnerships with K-12 and community institutions and provide opportunities for mentor teaching training to support this coherence between teacher education and K-12 practice (Athanases & de Oliveira, 2011). Indeed, in response to results indicating PSTs' poorer performance on the reform-oriented, science-related practices of their framework, Lyon and colleagues (2018) cautioned that the ability for PSTs to integrate language and literacy into science instruction requires even more collaboration among universities and mentor teachers to overcome traditional notions of science instruction.

Finally, supporting PSTs in gathering and incorporating students' funds of knowledge into instruction in authentic ways is another area that should be stressed in science PST programs. With the exception of the single case study participant in Heineke et al.'s (2019) study, this was challenging for most PSTs (though PSTs in intervention programs did show significantly higher scores on this feature than PSTs in control groups). Future pre-service interventions need to not only provide explicit examples of how to identify and incorporate funds of knowledge into science lessons, but provide PSTs with sustained opportunities to practice using students' sociocultural contexts to frame their lessons and respond to and integrate students' contributions in the classroom (Lyon et al., 2018; Tolbert et al., 2019).

Implications for Future Research

For many of the components of our framework, there is simply not enough research to draw definitive conclusions. Indeed, one of the greatest needs in the field right now is simply more research investigating PST training for teaching in linguistically diverse science classrooms at all levels. In particular, we found that findings related to development of PSTs' content knowledge for science instruction and understanding of language and science learning, as well as opportunities for PSTs to examine their initial beliefs about teaching science in linguistically diverse classrooms, were unreported or underreported in study findings.

Further research is also needed on how to more effectively support science PSTs in translating their knowledge of effective pedagogical strategies into instructional planning and implementation within the challenging contexts of K-12 classrooms. While some studies suggested significantly higher implementation scores of some practices by PSTs in the intervention groups than those in control groups, in most interventions PSTs were incorporating the targeted strategies at a minimal level. This was particularly true of strategies related to identifying and integrating students' funds of knowledge into instruction. While instructional models such as problem-based learning and engineering design integrated science can provide opportune contexts for teachers to integrate students' cultural, linguistic, and academic experiences into science classrooms, more research is needed to determine how to best support PSTs doing so in a more complete manner.

Some researchers (i.e., Heineke et al., 2019; Lyon, 2013a) suggest that extended time learning about and practicing targeted instructional strategies is beneficial for PST development, assertions backed up by studies noting that PSTs tend to enact the strategies they have had most exposure to and receive the most feedback on (e.g., Bravo et al., 2014). However, the limited number of extended interventions and the diversity of intervention foci make it challenging to draw any conclusions about how duration supports PST enactment of instructional strategies. Thus, more research is needed to determine to what extent duration plays a role in PST performance. Further, while some researchers have plans to follow PSTs into their first years of teaching (e.g., Lyon et al., 2018), none have reported results yet, leaving the field uncertain of how effective language and literacy integrated science interventions of all lengths are on PSTs' ultimate beliefs and teacher performance in the field. More research is needed longitudinally to determine what, if any, effect interventions of varying durations have on PST performance when they enter the field as practitioners, and how the development of tools for teaching during PST programs translate into the use of those tools in K-12 classrooms.

As the EL population continues to grow, more science teachers will have the opportunity to teach ELs in their science classrooms. As such, PST training will be critical for ensuring effective science instruction for all students, including ELs. While much work still needs to be done, the studies profiled in this literature review show promise for supporting science teachers in teaching ELs in a way that encourages both science content and language growth, and ultimately opens doors to scientific exploration for students of all language levels.

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Tables

Table 1

List of Studies Reviewed

				Presence of Tasks for Learning to Teach in Linguistically Diverse Classrooms					
Intervention (grade level)	Study (participants)	Data Sources/ Analysis	Intervention Structure	Beliefs & Vision	Science & Lang. Knowledge	Learners & Learning	Beg. Reper -toire	Tools for Studying Teaching	Outcomes
Academic Language Planning Organizer (ALPO) for Teaching Academic Language (Elementary)	Jung & Brown, 2016 (7 elementary PSTs)	Qualitative (single embedded case study) - Competed ALPOs - Accompanying lesson plans	<u>Duration</u> One semester <u>Integrated Coursework</u> Language planning for science instruction <u>Field Experience & Mentoring</u> Field experience and methods course alternate weekly		X		X	X	- PSTs used ALPO to identify language functions and vocabulary terms and develop clear language objectives - Half of PSTs successful in translating appropriate language support into their lesson plans - PSTs struggled to identify discourse and syntax demands
Adapted version of the Guided Language Acquisition Design Project (Project GLAD) (Elementary)	Hernandez, 2016 (10 elementary PSTs)	Qualitative - Pre-intervention interview - Post-intervention questionnaire	<u>Duration</u> 3-day workshop <u>Integrated Coursework</u> GLAD-focused science instruction in 3rd grade classroom <u>Field Experience & Mentoring</u> PSTs prepare for, observe, participate, and reflect on language and science-integrated instruction under mentorship of teacher educator		X		X	X	- PSTs moved from theoretical to practical understanding of EL instruction in elementary classrooms
CREDE Five Standards for Effective Pedagogy (CFSEP) Elementary Teacher	Bravo et al., 2014 (110 K-8 PSTs)	Quantitative (quasi-experimental) - Survey - Classroom	<u>Duration</u> One semester <u>Integrated Coursework</u> CFSEP integrated science methods course	X	X	X	X	X	- Experimental group scored significantly higher than control on three of five CFSEP domains - Experimental group held more positive beliefs than the control

Education Program (K-8)		Observations using scoring rubric	<u>Field Experience & Mentoring</u> Field experience in diverse K-5 classrooms PD for mentor teachers						about effectiveness of joint productive activity
Effective Science Teaching for English Language Learners Project (ESTELL) (Elementary)	Stoddart et al., 2013 (135 K-8 PSTs)	Quantitative (quasi-experimental) - Classroom Observations	<u>Duration</u> One semester <u>Integrated Coursework</u> ESTELL-integrated science methods course <u>Field Experience & Mentoring</u> Field experience in diverse classrooms PD for MTs and university supervisors	X	X	X	X	X	- Bilingual intervention group scored higher than control on all practices (two statistically significant) - Mixed results for intervention group in English-only program
	Stoddart & Mosqueda, 2015 (151 K-8 PSTs)	Quantitative - Pre- and post-intervention Knowledge and Beliefs Survey		X	X	X	X	X	- Treatment group scored significantly higher that control on all ESTELL practices after the intervention. - Treatment group significantly out-performed control on two efficacy measures
ELD Strategy Integration (Elementary)	Gibbons, 2008 (68 elementary PSTs)	Qualitative - PST reflections	<u>Duration</u> One semester <u>Integrated Coursework</u> ELD strategies taught within the context of a science methods course <u>Field Experience & Mentoring</u> Science lesson taught in concurrent field experience				X	X	- PSTs most often used modelled talk, advanced organizers, and levelled questions to support their ELs during science instruction.
Equitable Assessment in Science (Secondary)	Lyon, 2013a (11 secondary science PSTs)	Mixed Methods - Beginning, middle, and end of year open-ended prompts and interviews - PST commentary on lessons planned and taught	<u>Duration</u> 12 months (3 semesters) <u>Integrated Coursework</u> Equitable assessment integrated into three courses including science theory and science methods	X	X	X	X	X	- Positive growth for all dimensions of assessment expertise (only one statistically significant) - Least growth on equity dimension despite more awareness of language issues in assessment and how to scaffold language in assessment

	Lyon, 2013b (3 secondary science PSTs)	Qualitative (Multiple Case Study) - Interviews - Open-ended surveys - Teacher products - Lesson observations	<u>Field Experience & Mentoring</u> Field experiences running concurrently with courses	X	X	X	X	X	- Knowledge gains about and increased attention to role of language in assessment - Difficulty determining if equitable assessment is congruent with reducing or scaffolding language demands - Unsure if or how to assess language along with conceptual understanding
Immersion Experience (Elementary/ Secondary)	Settlage et al., 2014 (7 elementary PSTs and 3 secondary science PSTs)	Qualitative - Student reflections - Self-reported emotions checklist - Observation of interactions during intervention - Audio-recorded debriefing session	<u>Duration</u> Two-hours plus reflection <u>Integrated Coursework</u> Language immersion experience in advanced science methods elective <u>Field Experience & Mentoring</u> N/A	X		X	X	X	PSTs reflections suggested: - Understanding of language as a mediating factor in content learning - Valuing of home languages in instruction - Empathy for EL experience - Identification of strategies for teaching science to ELs - Shift from a deficit mindset to seeing ELs as capable learners
McCes Framework for equitable assessment (EA) (Secondary)	Siegel, 2014 (23 secondary science PSTs)	Qualitative -Teaching philosophies -Reflective journals -PST-created science units	<u>Duration</u> Part of a semester-long course <u>Integrated Coursework</u> Equitable assessment for ELs <u>Field Experience & Mentoring</u> Observations in a diverse high school	X	X	X	X	X	- Growth in four conceptual categories - More sophisticated understanding of EA - Use of EA strategies was low in unit plans
Paired Strategies for Collaborative Learning (Elementary)	Arreguín-Anderson & Alanis, 2017 (12 bilingual elementary PSTs)	Qualitative - 5E lesson plans - Reflections - In-class discussions and field notes	<u>Duration</u> One semester (15 weeks) <u>Integrated Coursework</u> Paired learning strategies for oral language development in science instruction				X	X	- PSTs mostly used paired strategies that were unstructured and semi-structured (i.e., turn-and-talk and sentence stems) in their instruction, identifying them as easy to use.

			<u>Field Experience & Mentoring</u> Lesson plans from methods course taught in concurrent field placement						
Secondary Science Teaching with English Language and Literacy Acquisition Framework (SSTELLA) (Secondary)	Lyon et al., 2018 (130 secondary science PSTs)	Quantitative (Quasi-experimental) - Classroom Observations - Video Footage - Post-instruction interviews	<u>Duration</u> One semester <u>Integrated Coursework</u> SSTELLA-integrated science methods course <u>Field Experience & Mentoring</u> Field experience in secondary classroom PD for MTs and university supervisors	X	X	X	X	X	- In aggregate, treatment PSTs perform significantly better on three of nine SSTELLA sub-practices - Majority of treatment PSTs enact three practices at target level - Limited or negative growth for PSTs in multiple programs on three scientific activity and reasoning practices
	Tolbert et al., 2019 (2 secondary science PSTs)	Qualitative (Case Study) - Video-recorded teaching events - Field notes - Post-instruction interviews		X	X	X	X	X	- PST receiving SSTELLA training created limited but sustained opportunities for students to use own experiences/ interests to understand science content compared to control PSTs' more "peripheral" contextualization
STEM Teachers for English Language Leaners: Excellence and Retention Project (STELLER) (Secondary)	Roberts et al., 2016 (10 secondary science PSTs)	Qualitative - Post-intervention interviews	<u>Duration</u> One semester <u>Integrated Coursework</u> SLA pedagogical theories, principles, and practices in the context of science <u>Field Experience & Mentoring</u> Field experience in secondary classrooms	X	X	X	X	X	- PSTs described targeted principles in a cursory manner with little attention to using students' funds of knowledge - PSTs reported struggling to identify and respond to ELs' needs and assets - PSTs requested more time for instructional planning and teaching using the targeted principles
Teaching for Change (TFC) (Secondary)	Heineke et al., 2019 (1 secondary science PST)	Qualitative (Exploratory case study) - Program artifacts	<u>Duration</u> Two years <u>Integrated Coursework</u> Application of SLA and EL instructional	X	X	X	X	X	- Understanding of the interconnectedness of language and science learning

		- Lesson/unit plans - Post-intervention interview	knowledge to science methods/field experiences <u>Field Experience & Mentoring</u> Numerous field experiences in local schools and the community							- Identifies as science teacher who supports language development - Acknowledges importance of authentic & collaborative instruction - Positions ELs positively; linguistic resources incorporated into instruction - Developed lesson plans through language lens

Note. Though other resources, including book chapters and conference proposal papers, were used to frame the description of these studies in the body of the manuscript, this table includes only the manuscripts or book chapters describing research studies. MT = Mentor Teacher; PST = pre-service teacher; PD = professional development; SLA=Second Language Acquisition; ELD=English Language Development.

Figures

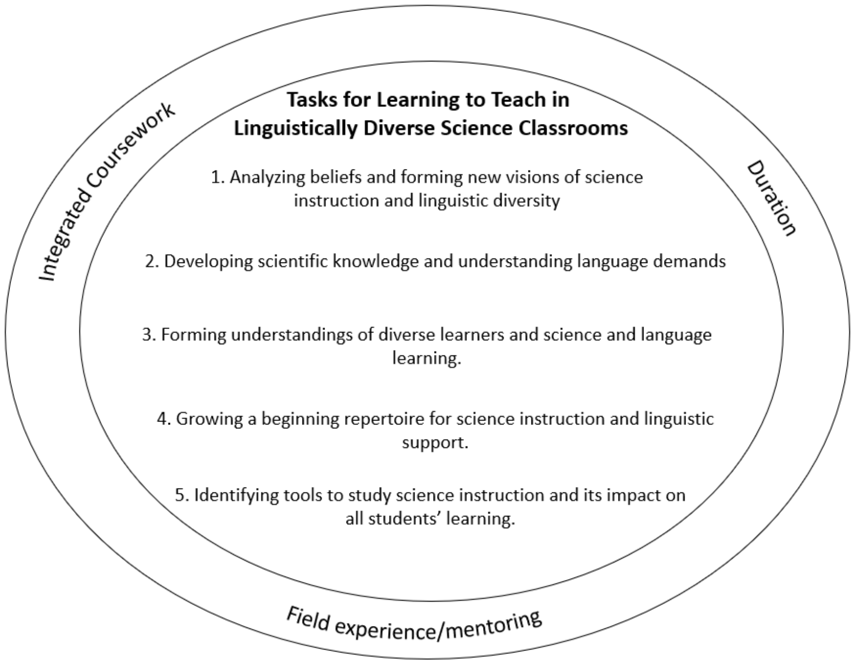

Figure 1. Framework Preparing PSTs to Teach Science in Linguistically Diverse Classrooms

Manuscript 2

Developing Secondary Pre-Service Science Teachers' Instructional Planning Abilities for Language- and Literacy-Integrated Science Instruction in Linguistically Diverse Classrooms

Abstract

As science classrooms become more linguistically diverse, it is becoming increasingly important that pre-service teachers (PSTs) are trained with the skills and knowledge they need to support science learning for all students, especially English Learners. The purpose of this study was to determine how 11 secondary science PSTs' instructional planning for language and literacy-integrated science instruction changed over the course of their participation in two language- and literacy-integrated science methods courses. Data sources included open-ended survey questions, interviews, and participant-created lesson plans, instructional materials, and reflections. Inductive and deductive qualitative analyses were employed to identify themes across participants and data sources. Results suggest that, following participation in the methods courses, more PSTs integrated language- and literacy-integrated science practices into their instructional materials than prior to the intervention. Further, important changes in the nature of integration were observed. Results add to the emerging literature on preparing secondary science PSTs to teach in linguistically diverse classrooms and have implications for science teacher education and student learning.

Introduction

Secondary science classrooms in the United States are becoming increasingly linguistically diverse (i.e., containing students from numerous linguistic backgrounds and with varying levels of proficiency in English, the dominant language of schooling). One segment of this increasing diversity is students classified as English Learners (ELs), defined in this paper as students who are classified by federally-mandated, standardized K-12 language proficiency assessments as learning English as an additional language in schools. ELs currently make up approximately 10 percent of the public school population, and the number is growing (National Center for Education Statistics, 2019).

At the same time that science classrooms are seeing growth in linguistic diversity, recent national science reforms are highlighting language and literacy as key components of science instruction and learning (National Research Council [NRC], 2012). This is evident in the Next Generation Science Standards' (NGSS) science and engineering practices, in which students must use language in numerous ways (e.g., arguing from evidence, communicating findings) to engage in scientific sense-making (NGSS Lead States, 2013; Quinn, Lee, & Valdés, 2012).

This integration of language and literacy into science instruction benefits all students, but particularly ELs. Research indicates that ELs who learn in language- and literacy-integrated science classrooms perform better on both language *and* content measures than ELs who learn language and content separately (e.g., Lara-Alecio, Tong, Irby, Guerrero, Huerta, & Fan, 2012; Shaw, Lyon, Stoddart, Mosqueda, & Menon, 2014; Tong, Irby, Lara-Alecio, & Koch, 2014). Further, by placing ELs in age-appropriate science classrooms, they are given access to the grade-level content necessary to advance to more rigorous science classes, a place where ELs are traditionally underrepresented (Callahan & Shifrer, 2016).

Unfortunately, despite science education reforms calling for the integration of language and literacy into science instruction and research pointing to its benefits for ELs, few pre-service (Durgunoglu & Hughes, 2010) and in-service (Ballantyne, Sanderman, & Levy, 2008) teachers feel prepared to teach ELs. One reason for these feelings might be the lack of preparation teachers receive for teaching ELs during pre-service training (Goodson et al., 2019). Indeed, requirements for science teacher preparation for teaching ELs vary by state, with some states requiring no preparation at all (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). This is despite research indicating greater achievement among Hispanic ELs in states where *all* teachers receive some EL training (López, Scanlan, & Gundrum, 2013).

It is clear, then, that changes are needed in teacher preparation regarding how pre-service teachers (PSTs) are prepared to teach in linguistically diverse science classrooms. Specifically, PSTs need training in how to integrate language and literacy into their science instruction to support the language development of all of their students. This is especially true at the secondary level, where many science teachers identify as content, not language, teachers (Lyon et al., 2018) and might see language solely as a vehicle to express content understanding rather than as a mediator of learning (Bunch, 2013).

Unfortunately, very little research has addressed PST preparation for linguistically diverse classrooms, particularly at the secondary level (for a review, see Rutt, Mumba, & Kibler, in press). This is important to note, because in a recent report on the state of ELs in STEM, determining how science teacher preparation programs can increase PSTs' knowledge about and use of STEM language and discourse and culturally sustaining pedagogies was identified as one of the top research agendas for science teacher educators (NASEM, 2018). Thus, in response to this need, this study investigated how secondary science PSTs' instructional planning for linguistically diverse science classrooms changed following their participation in two language- and literacy-integrated science methods courses. Specifically, the research questions addressed in this study are:

1. To what extent, if at all, did PSTs' instructional planning for language- and literacy-integrated science change following their participation in two semester-long language- and literacy-integrated science teaching methods courses?
2. In what ways, if at all, did the nature of PSTs' instructional planning for language- and literacy-integrated science change following their participation in two semester-long language- and literacy-integrated science teaching methods courses?

Review of Literature

The linguistic diversity of science classrooms and the increased emphasis on language and literacy in science instruction require that all secondary science PSTs gain the skills and knowledge necessary to teach language- and literacy-integrated science (Lyon et al., 2016). However, what that training looks like is still up for debate (Bunch, 2010; Buxton & Lee, 2014). In the sections that follow, diverse opinions on teacher preparation for linguistically diverse classrooms are described, followed by a review of the extant literature addressing how these ideas are being applied to secondary science teacher preparation programs.

Language- and Content-Integrated Teacher Preparation

Opinions on how to best prepare PSTs to teach in linguistically diverse content-area classrooms vary. Some researchers stress the importance of adding additional courses on language development theory and practice to preparation programs, while others suggest integrating English language development (ELD) strategies into methods courses addressing other diverse learners (for a review, see Bunch, 2010). However, while courses on language acquisition theory and practice are important for providing PSTs with knowledge to understand ELs' language development (Wong-Fillmore & Snow, 2018), the traditional manner of teaching these topics in language methods courses separate from science methods courses means that science PSTs are saddled with the responsibility of determining how to integrate language theories and practices with science instructional methods (Bravo, Solís, & Mosqueda, 2011). Similarly, integrating language methods into courses geared towards instructional methods for diverse learners generally does not provide adequate attention to the unique language knowledge and practices necessary for teaching ELs in science classrooms (Lucas, Villegas, & Freedson-Gonzalez, 2008). In both cases, it can be challenging for PSTs to connect theoretical knowledge of language and literacy with the day-to-day practices of science teachers (Bunch, 2010).

An alternative and increasingly popular approach emerging in science education research is to position issues of language and literacy within the context of content methods courses, thereby creating a natural connection between language theory and practice and, in the case of this study, science teacher practice (Valdés, Bunch, Snow, & Lee, 2005). In doing so, language is positioned as a central component of what it means to do science (Valdés, Capitelli, & Quinn, 2018), rather than as an extra component that must be taught separately. Positioning language instruction in this way is important for pre-service science teacher preparation for many reasons. First, it highlights the ways in which language is being used to *do* science, something that secondary science PSTs, who tend not to see themselves as language teachers (Lyon et al., 2018) often overlook (Dellicarpini & Alonso, 2014). Second, because most secondary teachers have greatest interest in their particular content areas (Bunch, 2010), positioning language as an integral part of science instruction might help to move teachers' perceptions of language from the margins of instruction to a position of necessity for all students (Valdés et al., 2005). Finally, integrating language, literacy, and science instruction can remove the burden on PSTs to reconcile differing or at times competing advice that they might receive if language and science methods are taught separately (Weinburgh, Silva, Smith, Groulx, & Nettles, 2014).

Given these benefits and the emphasis on language and literacy in the NGSS, more researchers are beginning to look at the role of language- and content-integration in science teacher preparation. While many of these studies have occurred at the elementary level (e.g., Bravo, Mosqueda, Solís, & Stoddart, 2014; Stoddart, Bravo, Mosqueda, & Solís, 2013), studies have also emerged in secondary science teacher education. We review these studies next.

Research on Preparing Secondary Science PSTs for Language and Literacy Integration

Though still few in number, interventions focused on preparing secondary science PSTs to teach in linguistically diverse classrooms tend to fall into one of two categories: studies focused on preparing PSTs for equitable assessment (i.e., Lyon, 2013a; Lyon, 2013b; Siegel, 2014), and studies focused on preparing PSTs for general language- and literacy-integrated science instruction (i.e., Heineke, Smetana, & Sanei, 2019; Lyon et al., 2016; Lyon et al., 2018; Roberts, Bianchini, Sook Lee, Hough, & Carpenter, 2016; Tolbert, Knox, & Salinas, 2019). Because of this study's focus on preparing PSTs for language- and literacy-integrated science instruction generally, it is on the latter group of studies that this review is focused.

In the first of three interventions addressing PST preparation for language- and literacy-integrated science instruction, Heineke and colleagues (2019) used an exploratory case study to investigate in what ways their two-year Teach for Change (TFC) teacher preparation program helped foster professional expertise for teaching ELs, whom they termed emergent bilingual students, in one secondary science PST. In addition to the program's focus on preparing PSTs to teach emergent bilinguals through coursework, a hallmark of TFC was the significant amount of time PSTs spent in the field, with over 80 percent of the program occurring in diverse school- and community-based field placements.

Using their participant's program assignments, lesson and unit plans, and an interview, Heineke and colleagues (2019) found that over the course of the intervention, the participant was able to develop an understanding of language and science learning as interconnected, a sentiment that was echoed in his lesson plans through the integration of opportunities for authentic and collaborative learning and a focus on science-specific language objectives and scaffolds. The PST also positioned his emergent bilingual students positively through the integration of their linguistic resources into his instruction, though he still struggled with institutional discourses that positioned emergent bilingual students in contrast to "regular kids" (Heineke et al., 2019, p. 93). While the one-person sample size makes it challenging to know the success of the intervention across multiple participants, the overall positive results for developing one PST's professional expertise for teaching science to emergent bilinguals are heartening. Heineke and colleagues pointed to the multiple field experiences, duration of the program, and mentorship the PST received from an expert in multilingual instruction as key factors to the PST's success.

Other studies' results were more mixed. For example, in their nationally funded study using their Secondary Science Teaching with English Language and Literacy Acquisition (SSTELLA) instructional framework, Lyon and colleagues (2018) analyzed the instructional practices of 130 secondary science PSTs from six different teacher preparation programs during their linguistically diverse student teaching field experiences. They found that, though overall scores for all groups were low, particularly for practices falling under the *contextualized science activity* dimension, PSTs receiving the SSTELLA training significantly outperformed control participants on three of the nine SSTELLA practices (i.e., *student interaction, science talk*, and *adapting and applying contextualization*). Further, a majority of PSTs were able to achieve the targeted implementing or elaborating levels of enactment on three of the practices (i.e., *student interaction*, *student talk*, and *literacy*). Interestingly, while PSTs seemed to implement at higher levels strategies focused on students' language use, researchers found limited or negative growth for practices related to scientific reasoning. They suggest that, despite their efforts to train PSTs' mentor teachers, PSTs' poor performance on these practices might have been related to the type of instruction modeled in PSTs' student teaching placements, which might have included more teacher-directed scientific activities. In addition to tighter collaboration between universities and field placement mentor teachers, Lyon and colleagues suggest that teacher preparation programs should place a strong emphasis on how language can be integrated into the central practices of science. Further, because PSTs were more likely to use practices that they saw modeled most often in their methods courses, Lyon and colleagues also highlight the need for targeted instructional practices to be repeatedly modeled in science methods courses.

PSTs' struggles with contextualizing learning and language-rich science practices were also reflected in the results from Roberts and colleagues' (2016) study on their STEM Teachers for English Language Learners: Excellence and Retention (STELLER) project. In their study, 10 secondary science PSTs participated in a capstone science methods course focused on applying second language acquisition theory to science instruction. Researchers used post-intervention interviews to assess understanding of the three targeted instructional principles that framed the intervention (i.e., *providing students with cognitively demanding science work*, *providing opportunities for rich language and literacy exposure and practice*, and *building on and using students' funds of knowledge*). They found that following the intervention PSTs had a basic understanding of the three principles but struggled to describe how to implement them at a high level. This was especially true for using students' funds of knowledge to guide instruction. Though PSTs recognized the importance of gathering such knowledge, they were unable to describe how to access and integrate these resources into their instruction. Further, though PSTs felt most comfortable with language and literacy exposure for ELs, their descriptions of this principle and the cognitively demanding science work principle failed to integrate language-rich tasks common in science, such as arguing from evidence. Roberts and colleagues (2016) suggested that the disappointing results indicate a need for more explicit instruction on the principles, with more opportunities for PSTs to plan for and implement focal strategies.

The studies described above are a critical start to determining how to best prepare secondary science PSTs to teach in linguistically diverse classrooms, highlighting both successes and areas for growth. In all studies, PSTs showed growth in their understandings of or abilities to apply key instructional strategies designed to support ELs in science classrooms, and in the only study with a control group, intervention PSTs outperformed control PSTs on some practices (Lyon et al., 2018). However, both conceptual (e.g., Roberts et al., 2016) and practical (e.g., Lyon et al., 2018) growth was limited, even when there were statistically significant differences between intervention and control groups. This was particularly true of PSTs' ability to contextualize learning and use students' funds of knowledge to guide instruction (Lyon et al., 2018; Roberts et al., 2016; Tolbert et al., 2019), findings that are supported by research on PSTs at the elementary level (e.g., Bravo et al., 2014) and with in-service teachers (e.g., Lee, Luykx, Buxton, & Shaver, 2007). While Heineke et al.'s (2019) study showed some success with this practice, their PST's attention to his ELs' funds of knowledge was focused mostly on students' linguistic abilities. It is unclear to what extent instruction was otherwise contextualized.

Lyon and colleagues (2018) also found that PSTs struggled to implement practices related to scientific reasoning at a high level, and Roberts and colleagues (2016) noted that, when considering cognitively demanding work, PSTs rarely included language-rich scientific tasks. Both groups of researchers emphasized the need for explicit and repeated modeling of key practices during methods courses. Further, these findings suggest that more research is needed to determine how to best support language and literacy integration in the service of students' engagement in language-rich science and engineering practices.

Finally, Heineke et al. (2019) and Lyon et al. (2018) both noted the role that PSTs' participation in student teaching classrooms may have played in how they talked about their students and the ways in which they taught. They suggested that more work be done to create conceptual bridges between university coursework and in-service teacher training to ensure more cohesion across contexts.

Though these studies provide a good starting place for understanding secondary science PST preparation for teaching in linguistically diverse classrooms, the nascency of the field means that there is still much to be done (for a review, see Rutt et al., in press). Given the urgency placed on more research in this field (NASEM, 2018), the significance of this study comes in a large part from its contribution to a field where research is urgently needed yet still largely undeveloped (Rutt et al., in press). However, this study also offers a unique perspective on secondary science PST preparation. In particular, this study focuses on not only the extent to which PSTs take up (or do not take up) through instructional planning the targeted language- and literacy-integrated science practices taught in the intervention, but also *how* they do so, looking for similarities and differences across participants both before and after the intervention. As a result, these findings will provide additional, nuanced understandings of how PSTs do or do not integrate language and literacy into their science instruction through instructional planning following participation in language- and literacy-integrated science teaching methods courses. The conceptual framework that guided this study, as well as descriptions of the intervention, are described next.

Conceptual Framework

The intervention and analysis of this study were guided by the researcher-developed Teaching English Learners Language- and Literacy-Integrated Science (TELLIS) framework. The TELLIS framework draws on sociocultural perspectives of learning (Duff, 2007; Duff & Talmy, 2011; Vygotsky, 1978) suggesting that language learning is a social process that occurs through learners' use of language to participate in particular communities of practice (Lave & Wenger, 1991). It is through meaningful, science-focused interactions with peers and the teacher in these communities that students develop their abilities to speak and write English (Valdés et al., 2018) as they simultaneously learn and engage with science content and exercise their roles as members of the science classroom's community of practice (Duff, 2007). In doing so, they are provided with meaningful, contextualized opportunities for language use (Zuengler & Miller, 2006) while receiving exposure to the grade-level content need to advance their trajectory to more challenging science classrooms (Callahan, 2018).

With these theories in mind, a primary goal of this framework is to ensure that language is not being taught in isolation, but through engagement in the science and engineering practices outlined in the NGSS. Toward this larger goal, the TELLIS framework includes five instructional strategies critical for language- and literacy-integrated science instruction, all of which are situated within students' engagement in rigorous, age-appropriate science and engineering practices for learning and doing science. These strategies include providing opportunities for students to experience and use discourse inherent to science, creating opportunities for literacy development, implementing strategies for language understanding and use, using students' multilingualism as an instructional support, and contextualizing science learning (see Figure 1). It is important to note that each strategy in the framework necessarily overlaps to some extent with the other strategies. For example, multilingualism as an instructional support can be considered a strategy for language understanding and use, and small group work can drive opportunities for discourse inherent to science and support language understanding and use. However, these strategies are presented separately to ensure sufficient attention to each, so that none of the key strategies get lost or subsumed under other strategies. Thus, each strategy is addressed in turn, below.

---Insert Figure 1 here---

Discourse Inherent to Science

Science is fundamentally collaborative and communicative (NRC, 2012). All of the NGSS science and engineering practices require the use of language (Quinn et al., 2012) and therefore provide rich affordances for language learning (Valdés et al., 2018) and substantive conversation (Gibbons, 2018). By engaging students in approximating the discourses of science, such as arguing from evidence or representing and explaining models, teachers can provide rich and meaningful contexts for students to practice new language. Through these science-focused uses of language, teachers can guide students in noticing the ways in which language is being used in scientific discourse (Valdés et al., 2018), and provide them with opportunities to practice those discourses in ways that are necessary for engaging in scientific investigation, not as a task for the sake of practice alone (Lyon & Solis, 2016). In this way, language is positioned a tool for doing science, not an additional concept to be learned.

Opportunities for literacy development. Because ELs are acquiring English proficiency at the same time that they are acquiring content knowledge, it is critical for teachers to intentionally plan for the content *and* linguistic development of their students (Harper & de Jong, 2004). In the same way that language development is fostered through engagement in scientific discourse, teachers must also consider in what ways reading and writing are being used in the act of doing science and create explicit goals to further develop these skills within the context of scientific inquiry. In focusing on literacy in the science classroom, students come to understand the role of literacy in the scientific enterprise, from disseminating information to building background knowledge. In the science classroom, literacy might take the form of traditional reading and writing skills, such as being able understand how to read and write scientific explanations and arguments. However, it can also include the ability to read and develop charts, graphs, and models, or design and read experimental procedures (Lee & Buxton, 2013a). Like with scientific discourse, it is important that teachers identify the ways literacy is being used in their classrooms and ensure that students have opportunities to observe and practice these literacies through teacher modeling and students' own interactions with the targeted literacy practices (Gibbons, 2015; Valdés et al., 2018). In this way, literacy plays a key role in science learning and doing while also supporting ELs' language development.

Strategies for language understanding and use. While scientific discourses and literacies might be new to all students, ELs are learning these discourses and literacies in a language that they are still developing (Goldenberg, 2013; Lyon et al., 2018). Thus, ELs might need additional language supports that are unique from those needed by students for whom the language of schooling is more familiar (Lucas & Villegas, 2013). As noted above, primary among these language support strategies are multiple opportunities for students to gain exposure to, engage with, and pay attention to how language is being used to make and communicate scientific meaning (Quinn et al., 2012). All students, but especially ELs, should have multiple opportunities to participate in scientific meaning-making through engagement in language-oriented science and engineering practices, so that language is being used in authentic contexts.

In addition to opportunities for language use, teachers should also be aware of general ESOL language support strategies that can bolster ELs' learning while maintaining the rigor of the science content and practices. These strategies include using textual supports such as graphic organizers, providing multimedia representations of content, providing additional time for practice and discussion, and incorporating hands-on learning activities (Goldenberg, 2013). The SIOP model (Echevarria, Vogt, & Short, 2016) is a popular model in schools that highlights numerous language scaffolds and sheltered instruction methods that can support EL learning.

As teachers incorporate more opportunities for students to engage with reading and writing in science contexts, they can also support ELs with before, during, and after reading strategies (Gibbons, 2015) and through modeling and providing multiple examples of science writing genres, accompanied with guided "noticing" of structures common to these genres (Quinn et al., 2012). While the diversity of students who fall under the EL label means that there are no one-size-fits-all strategies for supporting ELs in language use and learning, being aware of a large array of supportive practices can provide PSTs with a tool kit to draw upon as they learn more about their students' unique language abilities and build on the language and literacy strategies students bring to the classroom.

Contextualized learning. Science instruction fosters more interest and feelings of applicability when it is connected to students' life experiences and interests (NRC, 2012). When teachers contextualize instruction, they "facilitate authentic connections between classroom learning and issues, contexts, problems, and/or experiences that extend beyond the science classroom" (Tolbert, 2016, p. 63). To this end, instructional strategies such as problem- and project-based learning and engineering design integrated science instruction, which are meant to situate science learning in real-world, student-related problems or tasks, have become increasingly popular. However, it is also important for teachers to recognize that linguistically diverse students might come to the classroom with unique linguistic and cultural experiences and resources that might not align perfectly with Western scientific practices or classroom norms (Buxton & Lee; 2014; Lee & Fradd, 1998). Teachers need to attend to these unique affordances and intentionally incorporate them into science instruction. Indeed, culturally responsive pedagogy suggests that diverse learners learn best when teaching and learning "occur in a culturally supported, learner-centered context, whereby the strengths students bring to school are identified, nurtured, and utilized to promote student engagement" (Richards, Brown, & Forde, 2007). Gonzalez, Moll, and Amanti (2005) use the term "funds of knowledge" to describe the cultural, intellectual, and linguistic resources students bring to the classroom that are grounded in their familial, cultural, and community experiences. Such funds of knowledge could range from family and community knowledge to popular culture to students' own activities and interests (Moje, Ciechanowski, Kramer, Ellis, Carrillo, & Collazo, 2004). When teachers use funds of knowledge to contextualize science learning, they not only encourage more active engagement, but provide multiple entry points to content through connections to ELs' lives (Tolbert, 2016).

Multilingualism as an instructional support. One of the many funds of knowledge that ELs bring to the classroom is experience with languages other than English. This knowledge of other languages is at the heart of local bilingual and global instructional programs such as content and language integrated learning (CLIL), both of which use students' home languages as a medium for instruction. Research suggests that the use of students' home languages is an important resource for student learning. For example, students who are literate in their home language have been found to use those literacy skills to accelerate their English learning (Genesee, Lindholm-Leary, Saunders, & Christian, 2005), and science's Latin roots mean that speakers of Latin-based languages, such as Spanish, share many cognates with common scientific terms (Bravo, Hiebert, & Pearson, 2007), which might serve as a bridge to science vocabulary understanding (Quinn et al., 2012). Further, encouraging the use of home languages during small group activities can serve as a support for understanding content and as a confidence-booster for ELs, which in turn can lead to more participation and engagement, especially with regard to students' participation in complex scientific processes such as arguing from evidence (González-Howard & McNeill, 2016; Swanson, Bianchini, & Lee, 2014). In sum, ELs benefit when they are able to draw on their full linguistic repertoires (García, 2009), including informal and formal registers of English and home or other languages with which they are familiar (NASEM, 2018). Thus, it is important for science teachers to learn how hybrid language practices can be leveraged within the context of science instruction and activity to improve student learning.

The TELLIS framework is designed for PSTs as a way to understand how they can meet the needs of their ELs while maintaining the rigor of the secondary science classroom. However, while the framework is meant to specifically meet the needs of ELs, the practices of the TELLIS framework can be beneficial to *all* students, regardless of language status. For example, facilitating students' engagement in discourse inherent to science and contextualizing learning are high-leverage practices that can foster deeper understanding and engagement in science content (Windschitl, Thompson, Braaten, & Stroupe, 2012). As such, while the framework highlights strategies that are especially necessary for ELs, all of these instructional strategies can be beneficial to all students in the science classroom.

Methods

Context and Participants

This study took place at a large research university in the mid-Atlantic during the fall and spring of the 2018-2019 academic year. Participants were 11 secondary science PSTs (four males, seven females) ranging in age from early twenties to early thirties who were enrolled in a one-year teacher certification program and had undergraduate degrees in biology, earth science, chemistry, or engineering (see Table 1). Five participants had prior formal or informal teaching experience. Four participants considered themselves bilingual in Spanish and English and one participant considered himself receptive bilingual in Ilocano.

The one-year secondary science teacher certification program allowed students with a baccalaureate degree in science or engineering to earn a teaching license with endorsement in secondary science education (6-12) in a chosen area of emphasis (i.e., biology, chemistry, earth science, or physics). During the summer semester prior to the intervention, participants took general education courses that included a multilingual methods course focused on language and literacy development for English Learners. The course was taught by the first author and ran in conjunction with a six-week practicum experience in which PSTs worked with ELs in an academic summer camp. During the fall semester, which was the first semester of this intervention, PSTs were also enrolled in a languages and literacies course focused on reading and writing in the content areas (though this course was not focused specifically on EL populations).

---Insert Table 1 here---

Acknowledging research suggesting that training is most effective when it is sustained and when teachers have the opportunity to practice targeted instructional activities in K-12 classroom settings (Lee & Buxton, 2013b; Rutt et al., in press), our study took place during two consecutive science methods courses (fall and spring) that occurred in conjunction with field experiences in local secondary science classrooms. The weekly, three credit-hour methods courses were built on a foundation of active science learning and research-based science teaching strategies focused on engaging students in the NGSS science and engineering practices (NGSS Lead States, 2013). The first methods course addressed research-based science teaching methods, the nature of science, constructivist teaching and learning, and technology integration. The course was designed to provide PSTs with opportunities to enhance their understandings of secondary science education theory and practice. For example, PSTs received instruction on theories such as constructivism and conceptual change and learned about and applied through instructional planning a variety of instructional models for science teaching (i.e., predict-observe-explain [POE], the 5E model, problem based learning, engineering design integrated science, partial and full inquiry, guided instruction, stations-based learning, and demonstrations). The second methods course was designed to further enhance PSTs' knowledge for science teaching through exposure to and application of additional instructional models and strategies (i.e., project-based learning, case-based learning, target labs, discrepant events, technology integration, and argumentation) and through instruction on science lab development and student assessment. Both 2.5-hour long methods courses occurred in the evening once a week and included all secondary science PSTs in the 2018-2019 teacher certification program.

Intervention

To ensure that science and language methods were presented in an integrated manner, the TELLIS instructional framework was situated within the structure of both science methods courses. In this way, language was presented as part of science activity, not an "extra" to be taught in addition to science (Valdés et al., 2005). Following an initial introduction to the TELLIS framework early in the first semester, the five TELLIS framework practices were integrated into all science instructional methods (listed above) that PSTs learned through modeled lessons using both the targeted science instructional methods (e.g., the POE model) and the TELLIS instructional practices. Most weeks focused on the integration of one of the TELLIS instructional practices (e.g., scientific discourse for the POE instructional strategy). However, because research suggests that PSTs tend to enact practices they see modeled most often in their methods courses (Lyon et al., 2016; Stoddart et al., 2013), TELLIS strategies were consistently integrated throughout all instruction, so that even when one practice was emphasized, the others were incorporated, highlighted, and discussed. Thus, while integrating scientific discourse was a primary focus of the POE lesson, all other practices (i.e., strategies for language understanding and use, use of students' multilingualism, opportunities of literacy integration, and contextualization) were highlighted as well.

During each modeled lesson, PSTs were invited to engage in meta-pedagogical discussions about the lesson, discussing the science and language strategies they saw, the benefits and challenges that arose, and how they might enact such strategies in their own classrooms. Because of the student-centered nature of the instructional strategies, these instructional methods served as rich grounds for language learning and use. Thus, in line with our focus on language for *doing* science (Valdés et al., 2018), PSTs also reviewed the science instructional methods for how language was being used (or should be used) in order for students to learn scientific content and engage in scientific processes.

Finally, PSTs designed a lesson or activity on a science topic of their choice that embodied the science method they learned (e.g., POE) and that incorporated the instructional strategies of the TELLIS model. They were also asked to describe how their lessons were meeting the needs of ELs (either those in their classrooms or generally). During the second methods course, two of these lessons were taught during PSTs' student teaching placements and required a more detailed reflection.

Data Collection

To answer the research questions and support validity and trustworthiness through triangulation of data sources and methods (Denzin, 1978), pre-intervention surveys, post-intervention semi-structured interviews, and PSTs' lesson plans, instructional materials, and reflections were analyzed (see Table 2). Each data source is described next.

---Insert Table 2 here---

Pre-intervention survey. PSTs' integration of language- and literacy-integrated science instruction into their instructional planning prior to the intervention was assessed using an open-ended question on a pre-intervention survey. PSTs were asked to write a narrative describing a science lesson they would teach on a topic of their choice in a linguistically diverse middle or high school science classroom. Their narrative was expected to include the objectives of the lesson, a description of the lesson, and a description of how PSTs would adapt the lesson to meet the needs of all of their students (ELs and non-ELs). They were also free to add any other aspects of instruction. PSTs completed the survey on the first day of class, prior to participation in the science methods courses.

Lesson plans, instructional materials, and reflections. To understand the extent to which PSTs incorporated language- and literacy-integrated science instruction into their instructional planning after the intervention, two lesson plans (with accompanying instructional materials) designed for and taught in PSTs' student teaching classrooms were analyzed. For each lesson plan, PSTs were required to write a reflection on how they developed their lesson plan specifically to meet the needs of the ELs in their classrooms or, if they had no ELs in their student teaching classrooms, how they would change their lesson to support the needs of a hypothetical EL (see Appendix A). Because the lesson plans were designed toward the end of the teacher preparation program, after a majority of the intervention had occurred, it is believed that these lesson plans best reflect PSTs' understanding of how to develop language- and literacy-integrated science lesson plans.

Semi-structured interviews. Lesson plans were triangulated with 45-60 minute, semi-structured interviews that were conducted at the conclusion of the intervention. The interview protocol was reviewed by experts in science, English Language Development (ELD), and qualitative methods prior to implementation, and was piloted on two other PSTs in the science methods course who were part of a different preparation program and therefore not included in the analysis. Based on feedback from the experts and the two PSTs, the interview questions were revised for substance, clarity, and meaning. In the interview, PSTs were asked to describe each component of the TELLIS framework and consider which they found easiest and most challenging to integrate into instruction. Their responses were useful in understanding and interpreting the presence of the TELLIS practices in PSTs' lesson plans.

Data Analysis

Deductive and inductive qualitative data analysis methods were employed to answer the research questions (Miles, Huberman, & Saldaña, 2014). To determine the extent to which PSTs integrated the TELLIS framework practices into their instructional planning before and after the intervention, PSTs' open-ended survey responses and lesson plans, related instructional resources, and reflections were analyzed using cycle coding (Miles et al., 2014). During the first cycle, a codebook was created using the five practices of the TELLIS framework as *a priori* codes (Saldaña, 2013). To strengthen the codebook's reliability, two researchers coded approximately 30% of the data using the initial codebook, meeting to reconcile differences and further refine the codebook as necessary. The resulting codebook was then used by the first author to code the remaining data.

Once this first cycle of coding was complete, frequency counts were calculated for each code, and excerpts were inductively analyzed using descriptive and *in vivo* coding (Saldaña, 2013). The resulting child codes were defined and added to the codebook. Frequency counts were conducted for each child code and excerpts were reviewed to better understand the nature of each TELLIS practice's integration. The results from the pre-intervention survey analyses were compared with the analyses of the post-intervention lesson plans and reflections to better understand how PSTs' planning for language- and literacy-integrated science instruction changed following their participation in the language- and literacy-integrated science methods courses.

These findings were supported by post-intervention interviews, which were coded using the same coding scheme as above. The results from these analyses are detailed, below.

Results

In total, 33 lesson plans were reviewed to determine to what extent and in what ways PSTs integrated language- and literacy-integrated science instructional practices into their lesson plans before and after participation in the language- and literacy-integrated science methods courses. Overall, results indicated positive changes in PSTs' implementation of the TELLIS practices in their instructional planning after participation in the science methods courses. These changes were reflected in the increased number of PSTs including each component in their lesson plans, as well as in the quality of each component's inclusion. Results are described by research question, next.

Extent to Which PSTs Incorporated Language and Literacy Integrated Science Practices

The first research question sought to determine the extent to which PSTs' integration of language- and literacy-integrated science instruction changed in their lesson plans following their participation in the language- and literacy-integrated science methods courses. Results indicated that more PSTs integrated a greater number of the TELLIS instructional strategies following science methods course participation (see Table 3). While prior to the intervention, all or nearly all PSTs included *discourse inherent to science* and *strategies for language understanding and use* in their lesson plans (see Table 3), the remaining TELLIS instructional practices appeared less frequently in PSTs' pre-intervention lesson plans. Specifically, just over half of the PSTs integrated opportunities for some form of literacy (i.e., reading or writing, but not both) in their lesson plans, only four discussed how they would contextualize students' learning, and only one PST (Erin) explicitly addressed the use of students' multilingualism in her lesson plan.

---Insert Table 3 here---

In contrast, following their participation in the revised methods courses, all PSTs integrated *contextualized learning*, *discourse inherent to science, opportunities for literacy development*, and *strategies for language understanding and use* in at least one, though often both, of their lessons. While use of *students' multilingualism as an instructional support* still only occurred in 6 of the 11 PSTs' lesson plans, the growth from only one PST prior to the intervention is notable. Overall, these results show positive growth in the presence of the TELLIS practices in PSTs' lesson plans, suggesting that by the end of the methods courses PSTs were considering each of the practices as they developed their lesson plans.

Nature of PST Incorporation of Language and Literacy Integrated Science Practices

The second research question considered in what ways the nature of PSTs' integration of each TELLIS component changed following their participation in the two language- and literacy-integrated science methods courses. Results indicated that following participation in the revised methods courses, PSTs integrated more small group and partner discourse, more opportunities for students to use language for authentic scientific purposes, and a greater variety of strategies to support language understanding and use. While more PSTs also contextualized learning and integrated students' multilingualism as a resource in the classroom, these areas showed opportunities for growth. The nature of integration for each TELLIS practice is reviewed next.

Discourse inherent to science. Though the number of PSTs integrating discourse opportunities in their lessons was high prior to the intervention, one notable area of change in PSTs' instructional planning from pre- to post-intervention was the types of discourse PSTs used in their lesson plans. In the pre-intervention survey lesson plans, discourse occurred mostly in whole-group settings (see Table 3), often in the form of teacher-guided discussions or instruction and, in only two instances, through student-centered whole group discussion via small group sharing. Further, only five PSTs provided opportunities for small group discourse and no PSTs integrated partner discourse into their survey lesson plans.

In contrast, following participation in the language- and literacy-integrated science methods courses, all PSTs used small group or partner discourse in at least one of their lesson plans, though whole group discourse still remained popular (see Table 3). While a majority of PSTs used small group or partner discourse opportunities to have students answer content-related questions or engage in other school-typical activities (e.g., creating presentations), 8 of 11 PSTs (as compared to four prior to the intervention) also provided opportunities for students to use partner or small group discourse to engage in scientific practices such as developing models, explaining scientific phenomenon, and sharing and discussing scientific observations, data, and research findings, a trend that was echoed in the whole group discourse opportunities. For example, in their lesson plans, Christian, Erin, and Rachel had their students argue from evidence as part of whole-class Socratic seminars, philosophical chairs, or debate activities. Prior to the whole class debate, students worked in groups to develop their claims and identify evidence to support them. In reflecting on the philosophical chairs activity that occurred in her linguistically diverse sixth grade science class, Erin wrote,

> Most students started to see both sides of the argument. I saw this both through students restating each other's arguments . . . and then directly rebutting them. There were [*sic*] a lot of "I understand what John means with ______, but I think ________ is also important." These are not the statements I hear from typical 6th graders, and the maturity many students were able to demonstrate was remarkable. I also saw students changing sides of the discussion when they were given the option to.

Here, Erin highlighted the benefits that emerged from providing her students with opportunities to engage in discourse for authentic purposes, noting that through these opportunities students were able to engage in ways they had not in the past. In sum, the findings related to PSTs' use of discourse in their lesson plans suggests that after the intervention, PSTs attended to opportunities for intentional, student-centered, and scientifically authentic language use, even as more traditional, teacher-led discourse remained prominent in lesson plans as well.

Opportunities for literacy development. Another change from PSTs' pre- to post-intervention lesson plans was PSTs' integration of opportunities for literacy development. Prior to the intervention, just over half of the PSTs included either reading *or* writing in their lesson plans. Following the intervention, all but one PST (Greg) included both reading *and* writing in at least one of their lesson plans, but often in both (see Table 3). For most PSTs, the primary purpose of integrating reading into both pre- and post-intervention lesson plans was to supply students with information or real-life contexts for the content they were learning. Informational articles were common both before and after the intervention, whereas after the intervention information was also supplied through case studies, news articles, and for over half of the PSTs, through internet searches.

More interesting was how PSTs integrated writing into their lesson plans. While a majority of excerpts coded for writing in the post-intervention lesson plans included instances of students taking notes or answering open-ended questions to demonstrate their understanding of concepts, all PSTs but one (Peter) also used writing to engage students in NGSS science and engineering practices (SEPs) in at least one of their lesson plans, with six participants doing so in both lessons. The most common SEP addressed in lessons was engaging in argument from evidence. For example, in a high school biology class Ana asked students to use evidence they learned in class to make a claim about the theory of evolution. In Ashley's middle school life science class, students had to construct persuasive essays arguing for or against cloning using evidence from classroom readings and learning. Other opportunities to engage in the NGSS SEPs through writing included students (1) crafting and answering research questions; (2) forming explanations of scientific phenomena observed in the classroom; (3) completing data collection and analysis (4) using mathematical reasoning; (5) designing solutions to engineering problems; (6) developing models; (7) and making observations and predictions.

It is important to note that similar findings were evident among the three lesson plans developed prior to the intervention that integrated writing, where students were asked to develop and record experimental procedures, make predictions, and write chemical equations. However, the increased inclusion of meaningful writing practices by nearly all PSTs after participation in the science methods courses suggests that PSTs were able to identify how writing can be used in the act of doing science and indicates a focus on literacy integration for authentic scientific purposes that was not present for most PSTs prior to the intervention.

Strategies for language understanding and use. Closely tied to PSTs' use of discourse and literacy in the classroom was their integration of strategies for language understanding and use. All PSTs integrated these strategies into their lesson plans before and after the intervention. The notable difference from pre- to post-intervention was found in the diversity of supports provided. From pre- to post-intervention, PSTs more than doubled in number the types of supports included in their lesson plans, suggesting a greater knowledge of diverse options for supporting ELs based on students' needs and the assigned task.

PSTs made clear connections between students' opportunities for language use and their integration of language supports. That is, both before and after the intervention, PSTs provided scaffolds meant to specifically support ELs' needs. Prior to the intervention, this took the form of vocabulary instruction, group work, modeling, visuals, and adapted readings or writing outlines. After the intervention, structured group work and graphic organizers were popular supports for both reading and writing, and sentence stems and guided notes were identified by multiple PSTs to support students' writing. All of these supports had been modeled during the science methods courses. Similarly, the adapted readings (either by reading level or by language) and the integration of visuals, bolding, or underlining provided by multiple PSTs as a support for reading reflected strategies either modeled or discussed during class. Peter's lesson plan on non-Mendelian inherited traits provides a good example of many of the reading supports included in PSTs' lessons plans. In his reflection, Peter described how he assessed students' readiness by considering their current grade in the unit, their WIDA levels (i.e., English language proficiency levels as measured by an annual standardized language assessment) for reading, and informal observations, and then divided students into tiered groups. In describing the differences among the readings for each group, he wrote,

> The tier 1 "Skin Color Article" reading contains numerous visuals, underlined key words, and embedded questions to help students check their understanding. My tier 4 article, on the other hand, contains none of the aforementioned scaffolds, has more text, and relies more heavily on the student's background knowledge of chromosome structure. Not surprisingly then, ELs who have been identified as having a low WIDA reading score may be placed in the lower tiers while ELs with more developed reading abilities might be placed in higher tier groups. Grouping may also be done so as to intentionally group ELs with friends of theirs who can help them share their ideas. An EL with a high reading ability but low speaking ability might still be placed in tier 3 or 4 but grouped with a friend who could assist them in sharing their ideas to the wider group and class.

The intentional grouping evident in Peter's description was a common strategy employed by a majority of PSTs after the intervention but by none prior to the intervention, and was a strategy that was discussed often in the science methods course. In the lesson plans, this occurred often by pairing ELs with students who speak the same home language for linguistic support, or by pairing ELs with students who would stretch the ELs' use of English. For example, Martin wrote of the hypothetical case study EL in his reflection,

> Since she often asks for translation help in order to completely communicate her thoughts, I would group her with one peer who is able to translate, and one peer who is only fluent in English. This combination would provide Guadalupe with a peer who can stretch her speaking and listening skills, and one to provide support in her home language should she need it. She would have the option to speak in Spanish should she choose, and the chance to practice her English speaking with a native speaker.

In this excerpt, Martin describes how he intentionally paired his EL student not only to support her language use, but to further develop it as well. This intentionality, coupled with the variety supports PSTs integrated into their lessons by the end of the intervention, suggests that PSTs were considering in what ways ELs might need additional support to engage in and grow through rigorous science instruction.

Contextualized Learning. While there were positive changes in the number of PSTs contextualizing learning from pre- to post-intervention, a closer look at the nature of contextualization in PSTs' lesson plans both before and after the intervention suggests little change in the nature of contextualization between the two time points. Both before and after the intervention, contextualized learning was manifested in lesson plans as a mix of generic connections to science in the natural world (e.g., conservation of energy in rollercoasters; cell processes in supporting basic human functions) and in global issues (i.e., climate change and genetically modified organisms), as well as through more student-group-specific but still generic connections to students' lives (i.e., conservation of energy in teenage driving; examples of chemical reactions in students' lives outside of school).

In only a few cases did PSTs focus on students' individual and culturally-influenced lived experiences, interests, and assets, and this was often in relation to students' linguistic repertoires. For example, in both of his lesson plans at the end of the intervention, Martin considered how to incorporate the hypothetical EL's linguistic strengths into his assessments by providing assessments that aligned more closely with her strengths in writing. Similarly, Ashley and Nicole consistently provided opportunities for the hypothetical EL to use her literacy in Spanish to read translated versions of informational articles or write her thoughts in Spanish first, though always with the ultimate goal of translating the work into English.

However, these examples of individualized attention to ELs' funds of knowledge were rare and, with the exception of one pre-intervention lesson that suggested using examples from students' home countries, were entirely language-focused. This struggle for most PSTs to identify and integrate individual students' funds of knowledge, especially for their culturally and linguistically diverse ELs, is noteworthy because in post-intervention interviews, 7 out of 11 PSTs identified contextualization as the easiest TELLIS practice to implement in their instruction. This might suggest a disconnect between PSTs' understanding of contextualization and framework expectations. Indeed, in their post-intervention interviews, PSTs often described contextualized learning as making content relevant to students' lives through providing real-world examples or contexts for learning. Oftentimes, this included connections to students' prior learning and lived experiences as a group. For example, Nicole described contextualization as "bringing what you're learning into a real-life scenario, giving it context around it. So why are we learning this? How can we relate it to you?"

In contrast, only two PSTs (i.e., Greg and Christian) highlighted the unique cultural and linguistic differences and background knowledge that ELs bring to the classroom. For example, in his interview Christian noted of his own instruction,

> The next step . . . that I don't necessarily take, is contextualizing [learning] to EL students specifically, whereas their background might be dissimilar to the background of the majority of the students I'm teaching. So, the examples that I use sometimes I don't think about, oh maybe I can use an example that's non-Western. A non-Western, non-American concept. Like when I talk about proteins I don't just talk about hamburgers or things like that. So that's the next step that I don't necessarily feel that I've gotten into a habit of taking yet. But I know it would contextualize it for EL students better.

Here Christian shows a recognition of the next step to be taken in personalizing learning for his EL students, but acknowledges that he is still working towards that goal. While Christian's remarks show a deeper understanding of the role cultural diversity plays in contextualization, most PSTs' descriptions of contextualization mirrored their integration of contextualization in their lesson plans: general and majority-group specific. This type of incorporation might have reflected the way in which contextualization was taught during the methods courses, in which ELs were not individually identified but rather described in generalizations, and where modeling focused on these generalizations, with attention to student-specific attributes occurring only in post-lesson discussions.

Multilingualism as an instructional support. Because only one PST integrated multilingualism as an instructional support in her lesson prior to the intervention, it is challenging to make comparisons between the nature of PSTs' integration of students' multilingualism in their pre- to post-intervention lesson plans. However, some interesting trends did emerge within the quality of multilingualism integration following the intervention. First, multilingualism was often used in conjunction with small group or partner work (i.e., students were encouraged to use their multilingual repertoires in these settings) or when students were reading or writing (e.g., through the use of translated articles from online sources). Unlike in the only pre-intervention lesson plan integrating multilingualism, where the PST used a Spanish cognate to explain the meaning of a scientific prefix, in lesson plans after participation in the science methods courses, multilingualism was never used as part of the teacher's instruction or during whole class sharing, even when PSTs were able to speak the same language as some of their students. Diverse languages were also rarely used in final products (i.e., a turned in piece of work or whole class share out), with most PSTs maintaining an expectation that students would translate their work to English prior to sharing with the class or turning in an assignment.

This focus on multilingualism as being integrated solely during group activities was reflected in PSTs' interviews. A majority of PSTs highlighted this TELLIS practice as the most difficult to integrate, describing their inability to find resources or translated materials in non-English languages and struggles to find peers who spoke the same languages as the primary reasons for this component being so challenging. For example, when considering how she might use students' multilingual abilities in her future classroom, Nicole explained,

> Say I only have one student who speaks French and I have three students that speak Spanish. Those three students . . . can all just speak with each other, use their home language. The student that speaks French, I don't have anyone to communicate with them . . . So they would have no one to communicate with.

This suggests that Nicole understood students' multilingual abilities to be useful largely for peer-to-peer interactions, a sentiment that was reflected in most PSTs' integration of students' multilingualism in their lesson plans. Thus, while this is an important area of growth, it also suggests that PSTs might have been less comfortable with how to integrate home languages beyond student-to-student discourse.

Discussion

The purpose of this study was to determine to what extent and in what ways PSTs' instructional planning for language- and literacy-integrated science changed following their participation in two semester-long, language- and literacy-integrated science courses. Results suggest that, following the intervention, PSTs integrated more TELLIS practices into their lesson plans than prior to the intervention. Indeed, prior to the intervention, only *strategies for language understanding and use* was present in all PSTs' lesson plans. This finding might reflect PSTs' participation in a non-content specific ELD methods course that occurred immediately prior to the intervention, where strategies for language understanding and use were often highlighted.

In comparison, after the intervention, all PSTs included all TELLIS practices, with the exception of *using students' multilingualism as an instruction support*, in at least one of their lessons, though often in both. This change suggests that, while general ELD methods courses are useful in developing PSTs' understanding of second language development and building a repertoire of strategies for supporting ELs' language understanding and use, language- and literacy-integrated science courses might be necessary to ensure that PSTs are providing opportunities for language use and development within the context of engagement in authentic science and engineering practices.

Indeed, another finding of note in this study was that following the intervention, nearly all PSTs integrated language and literacy into their classroom through student engagement in language-rich science and engineering practices. This is important to note for two reasons. First, other studies investigating PSTs' integration of language and literacy into science instruction (e.g., Lyon et al., 2018; Roberts et al., 2016) found that PSTs struggled to integrate rigorous and language-rich science practices into their instruction, despite a focus on these scientific practices during their methods courses. Second, research suggests that secondary science PSTs can struggle to see the relevance of literacy integration in science classrooms (Salerno, Brown, Rutt, & Heny, under review). While the small number of participants in this study precludes any generalizations of the findings, the increase in the number of PSTs integrating language and literacy with science and engineering practices after the intervention, particularly language-rich ones like argumentation, might speak to the benefits of integrating language and literacy into science instructional methods in the way it was done in this study. That is, it is possible that the integrated manner in which the methods courses were taught, where TELLIS practices were layered within science teaching instructional strategies focused on NGSS science and engineering practices, might have led to this positive outcome.

In addition to how discourse was used for scientific purposes, the increased opportunities for small group and partner discourse evident in the post-intervention lesson plans also indicated growth in PSTs' thinking about language- and literacy-integrated instructional planning. Because much of students' meaning-making occurs as they use language to do science (Valdes et al., 2018), these additional opportunities for students to engage in smaller settings are critical for supporting their language and content knowledge development. Improved opportunities for scientific discourse was also found in other studies (e.g., Lyon et al., 2018) to be an easily improved area of teacher instruction and might suggest a feasible entry point for PSTs into language- and literacy-integrated science instruction.

One area of struggle for many pre-service (e.g., Bravo et al., 2014; Lyon et al., 2018) and in-service (e.g., Lee et al., 2007) teachers is contextualizing learning. It is notable that following the intervention, all PSTs made attempts to contextualize learning, as compared to only four PSTs prior to the intervention. However, while PSTs' attempts were at times grounded in local and global issues and experiences (Tolbert, 2016), PSTs rarely considered how cultural differences could affect students' uptake of these attempts to contextualize learning. Indeed, while PSTs were able to highlight how science concepts were related to common observations in the natural world, global issues, and events prevalent in adolescents' lives, most PSTs failed to identify and integrate ELs' unique cultural and linguistic needs and affordances into their instruction. We suggest that the way contextualization was taught could be to blame. While discussions of how students' individual funds of knowledge could drive instruction occurred throughout the course, no lessons explicitly modeled how to consider particular ELs' funds of knowledge and instead modeled the broader, more general connection to students' lives. This oversight is important because ELs' cultural experiences and understandings might not align perfectly with Western scientific practices or classroom norms (Lee & Fradd, 1998), and students learn best when their funds of knowledge are integrated into and nurtured through instruction (Richards et al., 2007). Thus, while recognizing that it is not feasible for PSTs to integrate the unique funds of knowledge of every student into every lesson, showing students how to identify these funds of knowledge and highlighting areas of cultural disconnect, much like Christian noted in his interview, as well as modeling what contextualization looks like that considers students' individual funds of knowledge, are critical next steps for fully contextualizing science and language learning.

Finally, of note was that after the intervention, just over half of PSTs used students' multilingualism as an instructional support in their lesson plans, as compared to all PSTs integrating the other four TELLIS practices. For many PSTs, this component of the framework was the most challenging, with many PSTs citing lack of translated resources for instruction or few other students who speak the same language as reasons for its difficulty. More research is needed to determine how teacher preparation programs can best support PSTs in identifying resources and additional strategies for integrating students' multilingual abilities into instruction.

Implications

The findings from this study indicate that PSTs were able to develop skills for integrating language and literacy integrated science into their instructional planning following their participation in two language- and literacy-integrated methods courses. These results have implications for both science teacher educators and science education researchers. First, this study suggests that targeted language- and literacy-integrated science interventions can support PSTs in integrating of language and literacy into their instructional plans. Indeed, courses in ELD alone might not be adequate to prepare PSTs for linguistically diverse classrooms. In particular, teacher educators should consider how they can provide access to integrated science methods courses in which instructional practices for language- and literacy-integrated science are embedded in common science instructional methods to support PSTs in providing more opportunities in their own instructional planning for language and literacy development through participation in authentic scientific practices. Because of the limited context in which this study was conducted, future research should consider in what ways this type of intervention can be implemented across various contexts and PST populations.

This study also suggests that science teacher educators need to model how to integrate ELs' *individual* funds of knowledge, including their multilingual repertoires, into science instruction, rather than simply talking about what this might look like. Indeed, previous research has emphasized the importance of instructor modeling for PST uptake of targeted practices (e.g., Stoddart et al., 2013; Lyon et al., 2018). At the same time, PSTs need opportunities to identify and integrate individual ELs' funds of knowledge into their own instruction. While some studies have shown success in this through one-on-one work with ELs (e.g., Heineke et al., 2019; Nasir & Heineke, 2014), more research is needed to determine how learning from these activities is reflected in PSTs' instructional planning and implementation, and how student-specific contextualized learning can be modeled in science teaching methods classrooms.

Finally, more research is needed to determine how, if at all, PSTs carry teacher preparation learning into their first years of teaching, and how teacher educators might support PSTs' continued integration of language and literacy into science instruction even beyond the limits of preservice preparation programs.

As science classrooms become increasingly linguistically diverse, it is becoming critical that all teachers have access to training to support rigorous, language- and literacy-integrated science instruction in their classrooms. This study suggests one possible way to meet this need, so that ultimately all students can have access to the rigorous science instruction that is claimed to be for all students (NGSS Lead States, 2013).

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Tables

Table 1

Study Participants

Participant	Race/ Ethnicity	Gender	Age	Content Area	Prior Teaching Experience	Bilingual
Ana	Hispanic	Female	24	Biology	Yes	English-Spanish
Ashley	White	Female	25	Biology	Yes	English-Spanish
Christian	Asian	Male	25	Biology	No	English-Ilocano
Erin	Undisclosed	Female	27	Earth Science	Yes	No
Greg	White	Male	27	Earth Science	No	No
Kelly	White	Female	22	Engineering	No	No
Martin	White	Male	22	Chemistry	No	No
Nicole	White	Female	24	Biology	No	No
Peter	White	Male	25	Biology	Yes	English-Spanish
Rachel	White	Female	22	Biology	No	English-Spanish
Tracy	White	Female	33	Biology	Yes	No

Table 2
Data Sources by Research Question

Research Question	Data Sources
To what extent did PSTs' instructional planning for language and literacy integrated science change following their participation in two semester-long language and literacy integrated science teaching methods courses?	Pre-intervention open-ended survey question Two post-intervention lesson plans with instructional materials and reflections
In what ways, if at all, did the nature of PSTs' instructional planning for language and literacy integrated science change following their participation in two semester-long language and literacy integrated science teaching methods courses?	Pre-intervention open-ended survey question Two post-intervention lesson plans with instructional materials and reflections Semi-structured post-intervention interview

Table 3

Integration of TELLIS Components in Instructional Design by Participant Pre- and Post-Intervention

Participant	Contextualized Learning		Science Discourse w = whole class g = small group p = partner t = teacher/student		Multi-Lingualism as Support		Goals for Literacy w=writing r=reading		Strategies for Language Use/ Understanding	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Ana		X	X (w)	X (w,g)		X	X (r)	X (r,w)	X	X
Ashley		X	X (w,g)	X (g,t)		X		X (r,w)	X	X
Christian		X	X (w)	X (w,g,p)		X	X (w)	X (r,w)	X	X
Erin	X	X	X (w)	X (all)	X			X (r,w)	X	X
Greg	X	X		X (w,g)				X (w)	X	X
Kelly		X	X (w,g)	X (w,g,p)			X (w)	X (r,w)	X	X
Martin	X	X	X (w)	X (w,g)		X	X (w)	X (r,w)	X	X
Nicole		X		X (all)		X		X (r,w)	X	X
Peter	X	X	X (w,g)	X (w,g,p)			X (r)	X (r,w)	X	X
Rachel		X	X (w,g)	X (w,g,t)			X (w)	X (r,w)	X	X
Tracy		X	X (g)	X (all)		X	X (r)	X (r,w)	X	X
Total (out of 11)	4	11	9	11	1	6	7	11	11	11

Note. Because of the numerous columns and close-set text, borders were intentionally retained and color-coding was used for the presentation of this table.

Figures

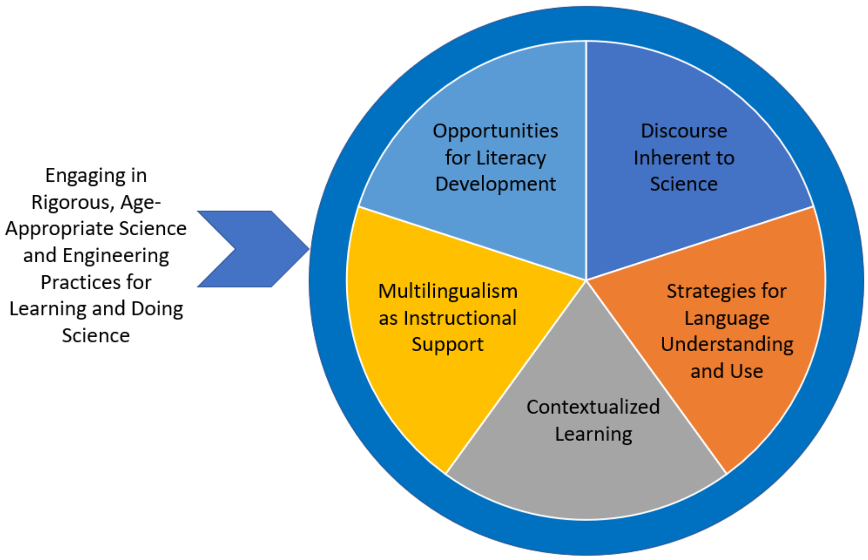

Figure 1. Teaching English Learners Language- and Literacy-Integrated Science (TELLIS) Instructional Framework.

Appendix A

Hypothetical EL Profile for consideration by PSTs without ELs in their Student-Teaching Classrooms

Guadalupe moved to your school at the beginning of last year from Mexico. In Mexico she was living with her grandparents and attending the local school. Her entrance exam suggests that she is fully literate in her home language of Spanish, and her school records from Mexico show that she has taken science courses prior to arriving. Her Newcomer teacher informs you that Guadalupe loves to write in Spanish and will often be found writing poetry during her free time. Following a year in the Newcomer Program, her English ability is still developing, and according to WIDA she is at Level 2 for speaking, listening, reading, and writing. She is a hard worker and wants to show what she knows, so she will often ask her Spanish-speaking peers to help her translate her thoughts into English.

Manuscript 3

Examining Secondary Science Pre-Service Teachers' Implementation of Language- and Literacy-Integrated Science Instruction through a Cultural Historical Activity Theory Lens

Abstract

The increasing attention to language in recent educational reforms coupled with the growing linguistic diversity of United States classrooms means that teacher educators and researchers need to consider how to best prepare secondary science pre-service teachers (PSTs) to teach language- and literacy-integrated science in the context of linguistically diverse classrooms. Unfortunately, research in this field is in its nascency, with few studies addressing how PST preparation in language- and literacy-integrated science translates into instruction in science classrooms, and no studies considering the unique contextual factors that affects PSTs' uptake of these reform-oriented instructional practices. The purpose of this multiple case study was to determine the extent to which three secondary science PSTs were able to integrate language- and literacy-integrated science instruction into their linguistically diverse student teaching classrooms, and to consider the unique contextual factors that supported and constrained their uptake of the targeted practices through an activity theory lens. Results indicated that PSTs were able to implement language- and literacy-integrated science instructional practices at the targeted level for most practices. However, contextual factors of their student teaching activity systems, including PSTs' division of labor with mentor teachers, understandings of classroom and school norms, and expectations of their classroom communities, acted as supports and constraints in their abilities to implement some practices. Results add to the slowly growing body of research on preparing secondary science PSTs to teach in linguistically diverse classrooms and have implications for both science teacher educators and researchers.

Introduction

Recent national reforms, including the Common Core Standards (Council of Chief State School Officers, 2010) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), emphasize the integration of language and literacy into all content areas at the K-12 level (Bunch, 2013). In science, this integration takes the form of eight science and engineering practices (SEPs) that are meant to exemplify "what scientists do as they engage in scientific inquiry and . . . [in part] what students must do both to learn science and to understand the nature of science" (Lee, Quinn, & Valdés, 2013). The SEPs are language-rich practices, requiring students to use language as they ask questions, explain models, engage in argumentation, and communicate their findings, among other tasks (Quinn, Lee, & Valdés, 2012). This increased attention to language and literacy in science is advantageous for all students, but it is particularly beneficial for students classified as English Learners (ELs)[1]. Research suggests that ELs show more growth in both science achievement and language and literacy development when language and literacy are integrated into science instruction than when science and language are taught separately (e.g., Lara-Alecio, Tong, Irby, Guerrero, Huerta, & Fan, 2012; Lee, Maerten-Rivera, Penfield, Leroy, & Secada, 2008; Tong, Irby, Lara-Alecio, & Koch, 2014). This might be particularly true when language- and literacy-integrated science is taught within the context of

[1] Numerous labels are used in research and in state and federal documents to describe students who are learning an additional language in school, including English Learners (ELs), English Language Learners (ELLs), Limited English Proficient (LEP), and Culturally and Linguistically Diverse (CLD). Additionally, recent research has begun to adopt labels that more clearly acknowledge students' linguistic resources, such as emergent bilingual (García & Kleifgen, 2018) or multilingual. Regardless of the term used, there is a danger in trying to apply one label to such a diverse group of learners in that such blanket terminology fails to acknowledge the many differences that exist among students with regard to language readiness, home language literacy, and years of English instruction, among other factors. While recognizing the shortcomings of these terms, for the purposes of this review students who are classified by federally-mandated, standardized K-12 language proficiency assessments as learning English as an additional language in schools will be referred to as English Learners (ELs). This term was chosen because of its ubiquity in EL research and policy. However, authors' original terminology will be retained when describing other research studies.

scientific inquiry (Amaral, Garrison, & Klentschy, 2002; Stoddart, Pinal, Latzke, & Canaday, 2002).

However, a renewed focus on language and literacy in science can also be challenging for ELs, especially for those who are entering the United States' education system for the first time in middle school or high school and who are faced with learning English through complex course content in a shorter amount of time (O'Hara, Pritchard, & Zwiers, 2016). In order to excel in these settings, ELs need content teachers who are well-trained in research-based strategies for teaching science to ELs (Lucas & Villegas, 2013). Unfortunately, requirements for content teacher preparation for teaching ELs vary by state, with some states requiring no preparation at all (National Academy of Sciences, Engineering, and Medicine [NASEM], 2018). As a result, many teacher education programs are not adequately preparing pre-service teachers (PSTs) to teach in science classrooms inclusive of ELs (de Jong & Harper, 2005; Tolbert, Stoddart, Lyon, & Solis, 2014), leaving much of the emerging science teacher work force unprepared for the linguistically diverse science classrooms (i.e., classrooms containing both students classified and not classified as ELs) of the 21st century, especially at the secondary level (NASEM, 2018).

Fortunately, teacher educators and researchers are beginning to take note of this gap in science PSTs' training. In the past decade, research has started to emerge that investigates programs designed to prepare PSTs to teach language- and literacy-integrated science to students in linguistically diverse classrooms (see Rutt, Mumba, & Kibler, in press). These initial studies are providing some insight into how science teacher preparation programs can prepare science PSTs for classrooms inclusive of ELs. However, the small number of studies at the secondary level means more needs to be done to understand the complexities of how PSTs learn to integrate language and literacy into their instruction. In particular, few studies (e.g., Lyon, Stoddart, Bunch, Tolbert, Salinas, & Solís, 2018) have investigated how secondary science PST training for language- and literacy-integrated science translates into PSTs' instruction in the classroom, and none have closely investigated how the activity systems (Engeström, 1987) in which PSTs participate, such as their field experience activity systems, relate to the enactment of targeted instructional strategies. This is an important area of research because the extent to which PSTs take up practices supported by teaching methods courses offered in teacher preparation programs can vary by PST (Thompson, Windschitl, & Braaten, 2013), and field experiences have been found to impact PSTs' beliefs and practices (Clarke, Triggs, & Nielsen, 2014). By investigating how PSTs' participation in their field experiences is associated with their implementation of instructional practices learned in their teacher education programs (i.e., language- and literacy-integrated science instruction), researchers can begin to shed light on how PSTs' participation in various activity systems affects their instructional decisions and can consider how teacher educators can respond to these decisions. Thus, the purpose of this study is to determine in what ways PSTs' participation in their student teaching placements is related to their enactment of language- and literacy-integrated science instruction in those settings. In particular, this study seeks to answer the following research questions:

1. To what extent do secondary science PSTs enact language- and literacy-integrated science instruction during their student teaching experiences?
2. How is PSTs' participation in different student teaching activity systems associated with their enactment of language- and literacy-integrated science instruction during their student teaching experiences?

3. In what ways do the mediating elements (i.e., tools, division of labor, rules, and community) of the student teaching activity systems operate within the system to support or constrain implementation of language- and literacy-integrated science instruction?

Review of Literature

As noted above, research on preparing PSTs to teach in linguistically diverse classrooms is growing. While much of this research has occurred at the elementary level (e.g., Bravo, Mosqueda, Solís, & Stoddart, 2014; Jung & Brown, 2016; Stoddart, Bravo, Mosqueda, & Solís 2013), recent research on secondary-level interventions has emerged. These studies vary in focus, ranging from studies addressing PST preparation for equitable assessment in linguistically diverse classrooms (i.e., Lyon, 2013a; Lyon, 2013b; Siegel, 2014) to interventions focused on language- and literacy-integrated science instruction more generally (i.e., Heineke, Smetana, & Sanei, 2019; Lyon et al., 2018; Roberts, Bianchini, Sook Lee, Hough, & Carpenter, 2016; Tolbert, Knox, & Salinas, 2019). Because of the focus of this paper on PSTs' implementation of language- and literacy-integrated science instruction generally, this review addresses the latter group of studies.

The studies that address preparing secondary science PSTs for language- and literacy-integrated science instruction vary in scope, from a single case study (i.e., Heineke et al., 2019) to a quasi-experimental, multisite study (Lyon et al., 2018). Interventions in these studies ranged in duration from 10 weeks (i.e., Roberts et al., 2016) to two years (i.e., Heineke et al., 2019). All three interventions ran in conjunction with field placements.

In Roberts et al.'s (2016) STEM Teachers for English Language Learners: Excellence and Retention (STELLER) program, PSTs participated in a 10-week capstone science methods course that applied theories of second language acquisition to science instruction. The capstone course was structured around three key principles (i.e., *building on and using students' funds of knowledge and resources*, *providing students with cognitively demanding work*, and *providing students opportunities for rich language and literacy exposure and practice* [pp. 83-84]) designed to support PSTs in developing "adaptive dispositions" to guide their planning and instruction for ELs (p. 82). During the course, PSTs read about, discussed, implemented, and reflected on each principle.

Roberts and colleagues used semi-structured interviews to investigate 10 PSTs' understanding of the three principles at the conclusion of the capstone course. They found that, while PSTs demonstrated a basic understanding of each principle, they struggled to understand how to implement them at a high level. For example, in their descriptions of the *language and literacy* and *cognitively demanding science work* principles, PSTs made no reference to language-rich science practices such as arguing from evidence or explaining models, instead focusing on vocabulary and cognitively demanding science tasks that did not require rich opportunities for language use, such as asking students to build an electromagnet as an introduction to electromagnetism (Roberts et al., 2016). *Building on and using students' funds of knowledge* (i.e., the cultural, linguistic, and intellectual resources students bring to the classroom [González, Moll, & Amanti, 2005]), was especially challenging for PSTs, despite their acknowledgement of its importance. In particular, PSTs seemed unsure of how to identify and integrate students' funds of knowledge into their instruction. Roberts and colleagues highlight more opportunities for PSTs to engage in instructional planning and implementation of the focal strategies as a possible remedy to their disappointing results.

One intervention that showed more success with contextualizing learning was Heineke et al.'s (2019) Teach for Change (TFC) undergraduate and graduate education program. The TFC program was unique in its heavy emphasis on field experiences, through which PSTs spent a majority of the program in school or community-based field placements working with emergent bilinguals. PSTs began by first learning foundational principles of second language acquisition and instruction for emergent bilinguals (the authors' chosen term for ELs) before applying their learning to science-specific instruction. Throughout the program, PSTs moved through eight sequences with different foci and experiences related to preparation for teaching emergent bilinguals. During Sequence 3, PSTs worked one-on-one with emergent bilinguals to discern their funds of knowledge and assess their current linguistic abilities, and to then suggest appropriate instructional methods based on identified strengths and areas for growth. In their exploratory case study of one secondary science PST, Heineke and colleagues found that by the conclusion of the program, their participant professed a more asset-oriented mindset when considering ELs and took steps in his instructional planning to identify and integrate his students' linguistic resources. They also found that the PST consistently developed lessons through a language lens, identifying himself as both a science and language teacher and acknowledging the value of authentic and collaborative instruction for supporting language development. Despite these findings, the participant still struggled to identify the limitations of using labels such as "regular kids" to compare emergent bilinguals to other students, which the researchers suggest might be attributed to the "institutional practices and discourses" that were extant in the PST's school-based field experiences (p. 93). They highlight the possible disconnect between teacher preparation programs and K-12 school field experiences as an area for growth.

The final study (i.e., Lyon et al., 2018) was both the largest study, and the only one that observed PSTs' instructional implementation in secondary classrooms. Lyon and colleagues sought to determine the extent to which secondary science PSTs from six teacher preparation programs across three different states implemented targeted instructional practices during their field placements. Researchers trained participants using their researcher-created Secondary Science Teaching with English Language and Literacy Acquisition (SSTELLA) framework, which includes four dimensions (i.e., *scientific sense-making*, *scientific discourse, language and discipline literacy*, and *contextualized science activity*) that are further divided into nine instructional practices. Through courses that ranged from 10 to 15 weeks long, PSTs experienced, analyzed, discussed, and rehearsed the targeted practices.

PSTs' instruction, which occurred during their field placements in classrooms with SSTELLA-trained mentor teachers (MTs), was observed using a researcher-created observation rubric. Results indicated that, in aggregate, PSTs receiving SSTELLA training performed significantly better on three practices, *student interaction*, *science talk*, and *adapting and applying contextualization* than PSTs in the control group who did not receive the SSTELLA training, though overall scores for both groups were low, particularly for *contextualization*.

Looking at results by program, researchers found that a majority of participants enacted three of the practices, *student interaction*, *student talk*, and *literacy*, at the targeted *implementing* or *elaborating* levels of enactment. However, they also found that in multiple programs PSTs who received the SSTELLA training showed limited or negative growth on three practices related to scientific activity and reasoning: *engaging students in scientific and engineering practices*, *communicating big ideas*, and *pressing for evidence-based explanations and arguments*. Like Heineke et al. (2019), Lyon and colleagues suggest this disconnect could be attributed in part to expectations in field placement classrooms, in which activities encouraged by MTs may reflect more teacher-directed, “cookbook” investigations that do not align with the practices of scientific inquiry.

Though very few in number, the studies reviewed above provide some insights into PST preparation for language- and literacy-integrated science instruction. In all three studies, PSTs showed conceptual or practical growth following interventions focused on language- and literacy-integrated science instruction. However, results from all of the studies also indicated that, though there was growth, it was often uneven or limited, so that even when PSTs were enacting targeted instructional practices at a higher level than PSTs who did not receive training in language- and literacy-integrated science instruction (i.e., Lyon et al., 2018), the level of implementation for some practices failed to reach targeted levels of implementation. This was particularly true for PSTs’ use of contextualized learning, findings that are supported by research on in-service teacher professional development studies as well (e.g., Lee, Luykx, Buxton, & Shaver, 2007). Perhaps the study that showed greatest growth for PST outcomes was Heineke et al.’s (2019) study investigating the instructional planning and self-reported implementation of one secondary science PST. However, the small number of participants (i.e., one) makes it hard to know the extent to which results might be reflected in other secondary science PSTs. Further, Heineke et al. did not observe implementation in the classroom. As such, growth was only evident through instructional planning documents and the PST’s self-reports.

Indeed, only one study (i.e., Lyon et al., 2018) specifically investigated PST implementation of targeted practices in K-12 settings, and no studies addressed how student teaching contexts may have related to PSTs’ implementation of targeted practices, despite researchers’ conjectures that these contexts likely influenced results (e.g., Heineke et al., 2019; Lyon et al., 2018). This is important to note because it is not enough for PSTs to understand language- and literacy-integrated science instruction if they cannot implement it in the contexts for which it is designed, that is, in secondary science classrooms (Hammerness, Darling-Hammond, Bransford, Berliner, Cochran-Smith, McDonald, & Zeichner, 2005). Further, research suggests that even when PSTs receive the same training in targeted instructional practices, PSTs' uptake of those practices can vary (Thompson et al., 2013), and field placements and interactions with MTs might play a large role in PSTs' development as instructors (Clarke et al., 2014). Indeed, field experiences have been highlighted by PSTs as the most helpful component of teacher preparation programs for feeling prepared and efficacious when teaching ELs (Harper, Platt, Naranjo, & Boynton, 2007).

Thus, it is important for science teacher educators and researchers to understand not only the extent to which PSTs are implementing language- and literacy-integrated science instruction in secondary classrooms, but also in what ways the contexts of those field experiences are supporting or hindering PSTs' implementation of targeted instructional practices. To investigate these themes in the current study, cultural-historical activity theory (CHAT), described next, was used.

Theoretical Framework

This study is guided by Cultural Historical Activity Theory (CHAT). Popularized by Engeström (1987), CHAT is an expanded version of activity theory, which originated from the work of Russian psychologists Lev Vygotsky (1978) and Alexei Leont'ev (1978), and is built on the concept of mediation, or the idea that human thought and action is mediated by the sociocultural and sociohistorical contexts in which they are operating (Nussbaumer, 2012).

Activity systems are comprised of six socially mediated elements, visually represented in an activity triangle (see Figure 1; Engeström, 1987). At the center of the activity system is the subject. In this study, the subjects were three secondary science PSTs who completed their student teaching experiences in linguistically diverse secondary science classrooms. Subjects work towards a particular goal or product, termed the object, as they engage in the activity of the system. In this study, the object of focus was language- and literacy-integrated science instruction as operationalized by the researcher-created Teaching English Learners Language- and literacy-integrated Science (TELLIS) instructional framework (see below for a description).

---Insert Figure 1 here---

Subjects' attainment of the object is mediated by a series of factors, including tools, community, rules, and division of labor. Tools, also termed instruments, are both conceptual and practical resources that subjects can use to achieve the object. In this study, the conceptual tools to which PSTs had access included but were not limited to their beliefs about the importance of language and literacy integration in science instruction, and their understandings of second language development and its impact on science learning, and their perspectives on effective science instruction. Examples of the practical tools to which PSTs had access included the TELLIS instructional framework strategies, classroom resources (including technology), observed strategies from the MT, and their own multilingual repertoires, among others.

The community of an activity system consists of other people in the system working towards the same object. In the present study, these community members included the mentor teacher, the students, and the teaching aids, among more peripheral members (i.e., school administrators, families). In an activity system, the subject's interactions with the community are mediated by the division of labor, or the roles that each member takes up toward achievement of the object, and the rules or norms of the activity system, which are defined not only by the community members within the activity system, but by the broader sociocultural and sociohistorical contexts within which the activity system operates (Foot, 2014). In the present study, the rules or norms included the mentor teacher's expectations, the socially constructed norms of the classroom, and more distally, social historical norms and expectations of the school and school system and United States secondary education generally. The division of labor included the roles the mentor teacher, PSTs, students, and teacher aids, among others, took toward achievement of the object, language- and literacy-integrated science instruction. It is important to note that the division of labor in an activity system "is typically mediated by sociohistorical power structures and patterns of relations both within the community and between a community and the larger culture/society of which it is part" (Foot, 2014, p. 6). Thus, in classroom contexts like those described in this study, power differentials can exist between PST and MT, teacher and student, and teacher and aid, among others, and can influence the actions members take towards attainment of the goal.

The strength of CHAT as a framework is its ability to highlight the socially and historically created contexts in which PSTs are teaching, and to investigate how the mediating elements of those contexts can support or contradict movement toward the desired outcome (Engeström, 1987). While ultimately PSTs will choose the type of instruction they will use, CHAT highlights that such decisions are mediated by factors within the PSTs' student teaching activity systems and, of note for this paper, the contradictions between them. Indeed, research suggests that science PSTs' uptake of targeted instructional practices provided in their university coursework can be mediated by the various elements of their student teaching activity systems such as division or labor, norms, tools, and community, and that the resulting dissonance can affect PSTs in different ways (Thompson et al., 2013). For example, if dissonance is minimal it can become fodder for identity development that ultimately supports learning. However, if the dissonance is too great, PSTs might simply adopt the instruction present in the field placement classroom, therefore missing out on opportunities to enact the targeted instructional practices (Horn, Nolen, Ward, & Campbell, 2008). Thus, teacher educators and researchers need to understand the contexts within which PSTs' language- and literacy-integrated science instruction occurs to better understand reasons for the variation in PSTs' uptake of targeted instructional strategies. In particular, CHAT can support teacher educators and researchers in identifying the mediating elements that create contradictions between desired outcomes and PST action, and use this information to consider in what ways they can support PSTs as they work through such contradictions. As Engeström (2001) argues, it is through such contradictions that change in activity can occur. Thus, having a pulse on contradictions within student teaching activity systems and the role that teacher education training has in those systems can be critical for ensuring change in the desired direction.

Significance of This Study

The significance of this study comes in a large part from its contribution to a field of science teacher education research that is urgently needed yet is still largely underdeveloped (Rutt et al., in press). Indeed, determining how science teacher preparation programs can increase PSTs' knowledge about and use of STEM language and discourse and culturally sustaining pedagogies to support ELs' learning in the science classroom is considered one of the top research agendas for science teacher educators (NASEM, 2018). Despite this, few researchers have heeded this call, especially at the secondary level (Rutt et al., in press). Further, among the studies that have focused specifically on preparing secondary science PSTs for teaching in linguistically diverse classrooms, only one (i.e., Lyon et al., 2018) observed how PSTs transferred their knowledge into action through implementation of targeted instructional practices in secondary science classrooms. Thus, this study provides needed additional research to this slowly growing field.

In addition, this study also looks more closely at the contexts in which PSTs are enacting language- and literacy-integrated instruction during their teacher training, that is, PSTs' student teaching field placements. This is important for two reasons. First, research suggests that PSTs' field experiences and interactions with MTs can have a large impact on PSTs' beliefs and instructional practices (Clarke et al., 2014), and that even when PSTs receive the same university-based training, their implementation of targeted practices can vary (Thompson et al., 2013). By better understanding the contexts within which PSTs are implementing targeted instruction for the first time, teacher educators can address areas of conflict through university coursework and partnerships with local secondary science teachers.

Second, research suggests that PSTs often struggle to transfer understanding of targeted instructional practices into action within the demanding contexts of K-12 classrooms (i.e., Lyon et al., 2018; Stoddart et al., 2013; Siegel, 2014). A better understanding of PSTs' experiences in their student teaching placements can support teacher educators in contextualizing their own instruction to highlight common challenges in secondary science classrooms and guide PSTs in identifying strategies to overcome them. Thus, this study provides insight into both teacher educators and teacher researchers about how student-teaching contexts can support or hinder PSTs' implementation of language- and literacy-integrated science instruction.

Methods

Research Design

To answer the research questions, a mixed methods multiple case study design was used. This design was selected because of its utility in examining phenomena within the context in which it occurs (Yin, 2006). The integrated nature of activity systems necessitates a research method that allows for deep investigation of action in context, particularly "when the boundaries between phenomenon and context may not be clearly evident" (Yin, 2014, p. 16), as is the case with PST instruction in student teaching activity systems. Indeed, the mediation of action (i.e., teaching) by the many elements of the activity system (i.e., divisions of labor, tools, etc.) blurs the lines between activity and context. Thus, to better understand action within an activity system, a case study methodology can be useful.

A multiple case study was chosen because multiple cases provide several representations of a phenomenon within different contexts and open up opportunities for cross-case analyses (Borman, Clarke, Cotner, & Lee, 2006). In doing so, similarities and differences can be identified in how the mediating factors of the student teaching activity systems are related to PSTs' implementation of language- and literacy-integrated science (Stake, 2013). Further, individual mediating elements can be investigated within the larger system to determine how they support or constrain TELLIS implementation, providing insight into how PSTs navigate these opportunities and tensions when making instructional decisions. As a result, this multiple case study can help the field to better understand a larger phenomenon (i.e., PSTs' instructional choices in linguistically diverse classrooms) through close examination of a few cases (Rossman & Rallis, 2017).

The TELLIS Instructional Framework

The training PSTs received in this study was guided by the researcher-created Teaching English Learners Language- and Literacy-Integrated Science (TELLIS) instructional framework. The TELLIS framework was designed to support PSTs in meeting the needs and highlighting the assets of their ELs within the context of rigorous, age-appropriate secondary science instruction.

Though developed with ELs in mind, the TELLIS framework includes instructional strategies that are beneficial to all students and are mirrored in high-leverage practices identified for science teacher preparation generally (e.g., Windschitl, Thompson, Braaten, & Stroupe, 2012).

Grounded in sociocultural perspectives of learning (Duff, 2007; Duff & Talmy, 2011; Vygotsky, 1987) and informed by research on strategies for language and science integration (e.g., Lee & Buxton, 2013) and similar instructional frameworks (e.g., Lyon et al., 2018; Stoddart et al., 2013), the TELLIS framework includes five instructional strategies meant to support language- and literacy-integrated science instruction (see Figure 2). The TELLIS strategies include *integrating opportunities for experiencing and using discourse inherent to science*, *creating opportunities for literacy development*, *implementing strategies for language understanding and use*, *using students' multilingual repertoires as instructional supports*, and *contextualizing science learning*. To ensure that language development occurs in the act of *doing* science (Valdés, Capitelli, & Quinn, 2018) rather than in isolation, all five strategies are situated within an overarching expectation that students are engaging in rigorous, age-appropriate science and engineering practices for learning and doing science. These TELLIS strategies are described, below.

---Insert Figure 2 here---

Discourse inherent to science. The communicative and collaborative nature of science (National Research Council [NRC], 2012), as exemplified in the NGSS science and engineering practices (e.g., arguing from evidence, communicating findings), provides significant opportunities for language development (Valdés et al., 2018) through substantive conversations (Gibbons, 2015) that are situated within science activity. That is, as students engage in common scientific practices, teachers are afforded opportunities to draw students' attention to how language is being used for doing science (Valdés et al., 2018) and to provide further opportunities for students to practice the discourses that are necessary for engaging in scientific investigation. Language is positioned as a tool necessary for scientific activity, rather than as a task to be practiced in isolation (Lyon & Solís, 2016). In this way, students are provided with contextualized and meaningful opportunities to develop both their linguistic and scientific understandings.

Opportunities for literacy development. Language development is fostered not only through discourse, but also through opportunities for students to develop their literacy skills, defined here as reading and writing. Like discourse, opportunities for literacy development should be embedded within the context of scientific inquiry. In the science classroom, literacy includes both opportunities to read and write in the traditional sense (e.g., reading scientific research or writing scientific explanations) as well as the ability to decipher and develop charts, graphs, and models, or read and write experimental procedures (Lee & Buxton, 2013). Teachers should identify in what ways reading and writing are used to engage in scientific practices and meaning making in the science classroom, and to then use teacher modeling and intentional planning to ensure that students have opportunities to observe and engage with the targeted literacy practices (Gibbons, 2015; Valdés et al., 2018). In doing so, students can better understand the role of literacy in the scientific enterprise and approximate practices exemplifying literacy use in science.

Strategies for language understanding and use. At the secondary level, students will face scientific discourses and literacies that might be new to them. While this unique form of speaking, reading, and writing can be challenging for all students, ELs face an additional challenge in that they are still developing the language through which they are learning these new discourses and literacies (Goldenberg, 2013; Lyon et al., 2018). It becomes imperative, then, that teachers are providing appropriate supports to ensure that ELs can engage in language-heavy scientific practices even as they are learning the language to do so. One important way to do this is to ensure that all students, but particularly ELs, have multiple opportunities to observe, engage with, and pay attention to language as it is used to make and communicate scientific meaning (Quinn et al., 2012). In particular, students should have multiple opportunities to collaborate with one another as they engage in scientific activities that center around language-rich science and engineering practices. In this way, language is used to learn scientific content and practices through engagement in authentic contexts.

However, it is not enough to simply create opportunities for language use if ELs are not provided the support they need to engage in those language-rich opportunities. Given the diversity of students who are labeled ELs, teachers need to be familiar with a variety of language support strategies, commonly called English to Speakers of Other Languages (ESOL) strategies, so that they have a large toolkit of strategies to provide the support necessary for individual students. Strategies such as using graphic organizers, modeling, providing extended wait time, and including opportunities for hands-on learning (Echevarria, Vogt, & Short, 2016; Goldenberg, 2013) can support ELs as they engage in rigorous, age-appropriate science instruction. Literacy strategies, such as incorporating before, during, and after reading activities (Gibbons, 2015) or providing thorough modeling of how to write in various scientific genres, can support students in "noticing" and ultimately producing the structures common to scientific reading and writing (Quinn et al., 2012). In sum, it is critical that teachers are familiar with a variety of ESOL and literacy strategies that can build on the language and literacy strategies ELs bring to the classroom and can act as a means to support EL engagement in the language-rich practices common to the science classrooms.

Contextualized learning. In order for science instruction to be meaningful, it should be connected to students' life experiences and interests (NRC, 2012). Science teachers contextualize learning when they create authentic and recurring connections between the scientific content and practices learned in the classroom and students' experiences, interests, and sociocultural contexts outside of the classroom (Tolbert, 2016). Given that science as a discipline is centered around human explanation of the natural world, connections between real-world occurrences and problems relevant to students' lives are an important way to contextualize learning. However, while this type of contextualization can be effective, it is also important that teachers recognize the unique cultural, intellectual, and linguistic experiences and resources, or funds of knowledge (Gonzalez et al., 2005), that ELs bring to the classroom, and to consider in what ways these experiences and resources might not align with Western science classroom practices or norms (Buxton & Lee, 2014; Lee & Fradd, 1998). This is particularly true because research on culturally responsive pedagogy suggests that students learn best when their funds of knowledge are identified and utilized to promote student engagement (Richards, Brown, & Forde, 2007). By doing so, teachers can create connection between content and students' lives that encourage active engagement and provide different avenues for students to access science content (Tolbert, 2016).

Multilingualism as an instructional support. One unqiue resource for learning that many ELs bring to the science classroom is faculty with languages other than English. In addition to the many cognitive benefits, such as improved problem-solving skills, attributed to multilingualism (see Adescope, Lavin, Thompson, & Ungerleider, 2010), research also suggests that multlingual children may have better metaglinguistuic awareness than monolingual peers (Bialystok, 2001), which can support students' learning of additional languages. Further, students who are literate in other languages might be able to transfer their literacy skills to support language development in English (Genesee, Lindholm-Leary, Saunders, & Christian, 2005), particularly when students' home languages are spoken in the classroom (NASEM, 2017).

While it is important to recognize that not all students who share a home language speak that language outside of the classroom (Braden, Wassell, Scantlebury, & Grover, 2016), teachers can tap into ELs' linguistic resources by drawing connections between scientific terminology and students' other languages (Quinn et al., 2012), providing and actively integrating multilingual resources into classroom instruction, and encouraging the use of preferred languages to make meaning during small group activities. In doing so, students' multilingualism may not only support improved content understanding but might also encourage more active participation, particularly as students engage in complex and linguistuicially-demanding science practices such as arguing from evidence (González-Howard & McNeill, 2016; Swanson, Bianchini, & Lee, 2014).

Study Context

The context for this study is two language- and literacy-integrated secondary science teaching methods courses and a student teaching field experience that occurred as part of a one-year secondary science teacher education program at a large, mid-Atlantic university. As part of the program, the language- and literacy-integrated secondary science courses were taught consecutively in the second and third semesters of the three-semester program and ran concurrently with field experiences in local middle and high schools. Each course met once weekly for two and a half hours. The courses introduced PSTs to the nature of science, foundational learning theories (e.g., constructivism), research-based, and active-learning instructional methods (e.g., inquiry, the Predict-Observe-Explain [POE] model, etc.) and engineering design integrated science instruction designed to engage students in science and engineering practices (NGSS Lead States, 2013). To emphasize the integrated nature of language, literacy, and science learning, the TELLIS framework was integrated into instruction and assignments in both science teaching methods courses. PSTs were introduced to the TELLIS framework at the beginning of the first methods course. During the introductory lesson, PSTs worked in small groups to describe their understandings of each TELLIS instructional practice. These initial understandings were then used as a catalyst for an instructor-led, whole class discussion about what each practice meant, the research to support it, and examples of what each might look like in a secondary science classroom. After this initial introduction, the TELLIS strategies were integrated weekly into modeled lessons and assignments targeting particular science instructional methods (e.g., POE). Oftentimes, one practice from the TELLIS framework would be highlighted for a particular method, but because PSTs tend to integrate into their own instruction the practices they see modeled most often (Lyon, Stoddart, Solís, Tolbert, Bunch, Roth, Salinas, Knox, Couling, & Butler, 2016; Stoddart et al., 2013), care was taken to address all five practices during each lesson (see Appendix A for a description of an example lesson).

Following the first author's modeling of a language- and literacy-integrated science lesson, PSTs engaged in small-group and whole-class meta-pedagogical discussions about the science instructional method and the TELLIS strategies used, addressing how the lesson as a whole provided opportunities for science and language development, and highlighting and responding to the challenges that might arise when using the methods and practices in secondary science classrooms. The student-centered nature of the science instructional methods provided rich grounds for discussions about how language was being used to *do* science (Valdés et al., 2018). As a result, the integrated nature of language, literacy, and science was consistently reinforced.

After experiencing and discussing each modeled lesson, PSTs were required to develop their own language- and literacy-integrated lesson plans, activities, or units that exemplified the targeted science instructional method. During the second methods course, two of these lesson plans were enacted in PSTs' student teaching classrooms.

In addition to the field placements running concurrently with the methods courses, PSTs also participated in a languages and literacies course in the fall semester focused on integrating literacy into secondary classrooms (but not with a focus on EL-classified students). In the summer semester prior to the first science methods course, PSTs also took a multilingual methods course in which they learned about theories of second language acquisition and strategies for supporting ELs' language and literacy development in secondary classrooms. This course was inclusive of all content areas (i.e., English language arts, social studies, science, and math) and was also taught by the first author of this paper.

Participants

Three participants were purposefully selected from a larger sample of all 11 PSTs enrolled in the one-year secondary science teacher preparation program during the 2018-2019 academic school year. PSTs were chosen due to their placements in linguistically diverse secondary science classrooms for their student teaching experiences. All PSTs had previously earned baccalaureate degrees in a science discipline or engineering. Successful completion of the teacher education program resulted in a teaching license with endorsement in secondary science education (grades 6-12) in a chosen discipline (biology, chemistry, earth science, or physics).

All three participants (see Table 1) participated in the same science teaching methods courses, in which they learned about the TELLIS framework. Each participant is described in more detail, below.

---Insert Table 1 here---

Ana. Ana is a 24-year-old, Hispanic female who was seeking a biology teaching license. Prior to enrolling in the teacher education program, she worked as an aid in a classroom for autistic students in a local high school. Ana described herself as fluent in English and Spanish, the latter to which she credited to being raised in-part by her Spanish-speaking grandmother and other Spanish-speaking family members, as well as to the Spanish classes she took in high school. Her student teaching placement was at Ridgeview High School, a large, diverse high school where she taught three tracked sections of biology (i.e., two above standard and one Advanced Placement) and one tracked anatomy and physiology class. One of Ana's above standard biology classes was the focus of this study and included linguistically, socioeconomically, and racially diverse learners (see Table 1) in grades 9 to 11. Ana described the classrooms as representative of the diverse nature of the school. Ana's MT was Ms. Johnson. At the time of data collection, Ms. Johnson was in her 22^{nd} year of instruction as a biology and/or anatomy and physiology teacher (the latter course which she created), and for 21 of her 22 years, she taught ELs. She did not recall any professional development related to supporting ELs in the classroom in the past few years, though she had previously taken a Spanish for educators course. Ms. Johnson is not endorsed in English as a Second Language (ESL) instruction.

Erin. Erin is a 27-year-old, White female who was seeking an Earth science teaching license. Prior to enrollment in the teacher education program she worked in environmental education settings largely focused on experiential and field-based learning for K-12 students and adults. Erin described herself as fluent in English with novice abilities in French and German. She attributed her French and German abilities to classes in middle school and high school, as well as an immersion experience in Austria during high school, and post-graduate scientific work in the South Pacific with largely French-speaking guests. Her student teaching placement was at Stone Manor Middle School, which was an Advancement Via Individual Determination (AVID) demonstration school. AVID is a college preparatory program that focuses on preparing first-generation college students for higher education. Erin taught three 82-minute, sixth-grade general science classes at Stone Manor each day. Her classes were heterogeneous, including EL-classified students, students receiving special education services, and students in the gifted program. Erin's MT was Ms. Smith. Ms. Smith was in her 12th year of teaching and had ELs in her classroom each year. During the 12 years, she primarily taught sixth grade science, but she also taught one year of seventh grade science and a few semesters of sixth grade social studies. During the semester that Erin was in her classroom, Ms. Smith was the sixth-grade team leader. A few years prior to her participation in the study, Ms. Smith participated in a school-wide, two-year professional development opportunity centered around Zaretta Hammond's (2015) book, *Culturally Responsive Teaching and the Brain: Promoting Authentic Engagement and Rigor among Culturally and Linguistically Diverse Students*. While Ms. Smith notes that the experience helped her and her fellow teachers rethink students' use of their multilingual repertoires in the classroom, it is unclear the extent to which the training focused specifically on language development and training teachers to support ELs linguistically. Ms. Smith is not ESL endorsed.

Rachel. Rachel is a 22-year-old, White female who was seeking a biology teaching license. She enrolled in the teacher education program directly following her undergraduate work at another university. Rachel described herself as bilingual in English and Spanish, attributing her Spanish abilities to being raised by a Bolivian nanny, taking six years of Spanish in high school, participating in an immersion Spanish experience in Mexico during high school, and growing up with a Spanish-speaking best friend. In addition to English and Spanish, Rachel also took some American Sign Language classes. Her student teaching placement was also at Stone Manor Middle School, where she taught three 82-minute, seventh-grade life science classes. Like Erin's classes, Rachel's classes were heterogenous, with a mix of students receiving special education, English as a Second Language (ESL), and gifted services. Rachel's MT was Ms. Raymond. Ms. Raymond was in her 25th year of teaching and had ELs in her classroom for 13 years. During the 25 years, she taught language arts, biology and life science, special education, and AVID at the middle school and high school levels. In addition to being certified in secondary science instruction, Ms. Raymond is also certified in K-12 special education. Ms. Raymond identified several professional development sessions over the years that addressed working with ELs in the classroom, and noted that their weekly meetings often included ideas for EL students, though this did not occur every week. Ms. Raymond is not ESL endorsed.

Positionality Statement

The nature of qualitative research positions the researcher as a key instrument in the study (Creswell, 2014). In this study, the lead author's role as a co-instructor of both methods courses, as well as of a seminar course in which PSTs reflected on their student teaching experiences, provided opportunities for observations and conversations with PSTs that supported interpretation of PSTs' understanding of their activity systems and their understanding and implementation of language- and literacy-integrated science instruction. Through the researcher's participation in training the PSTs in language- and literacy-integrated science instruction, she assumed the role of participant observer (DeWalt & DeWalt, 2011) and was afforded significant insight into the contradictions and congruencies evident between the targeted instructional practices espoused in the university and the practices described by PSTs and MTs and observed in the student teaching classrooms. This allowed for a deeper analysis of how elements of the PSTs' student teaching activity systems may have challenged and supported PSTs' attainment of the activity system's object.

The lead author kept a methodological journal and recorded analytic memos throughout data collection and analysis that not only allowed for reflection on the additional insights gained through her position as instructor, but also helped create an audit trail for research decisions along the way (Guba & Lincoln, 1981). Further, following the compilation of initial findings, data was revisited to look for disconfirming evidence (Creswell & Miller, 2000) that was integrated into the authors' understandings and descriptions of study outcomes.

Data Collection

In an effort to provide credibility to the study through triangulation (Denzin, 1978; Rossman & Rallis, 2017), multiple data sources were used to answer each research question (see Table 2). To determine to what extent the PSTs enacted language- and literacy-integrated science instruction during their student teaching experiences (research question one), participants' program-required, summative teaching performance assessments (TPAs) were analyzed. For the education program's TPA, PSTs were required to develop and teach in their student teaching classrooms an instructional mini-unit of approximately 3-5 lessons in length. Units were required to include clear learning targets aligned with state and national standards, high quality lesson plans and instructional materials, and plans and instruments for formative and summative student assessment. PSTs video-recorded the implementation of their units and used the video to reflect on their teaching efficacy. As such, TPA data sources included PSTs' instructional units (including lesson plans and related instructional materials), video footage of each day's lesson implementation, and the reflection and analysis work PSTs completed after their instruction. TPAs were chosen to analyze participants' instructional abilities for two reasons. First, because the TPAs were summative and passing was required to graduate, it was assumed that the TPAs were exemplars of participants' "best work" with their students. The lesson plans, instructional materials, assessments, implementation, and reflection highlighted PSTs' syntheses of what they had learned, applied in the context of authentic teaching situations. Second, because the TPAs required PSTs to design and implement a unit, lesson planning and instruction occurred over multiple days, providing multiple representations of PSTs' work.

PSTs' TPAs were triangulated (Denzin, 1978) by two semi-structured interviews (Brenner, 2006) with the PSTs that occurred approximately one week apart at the conclusion of their student teaching experiences. The first interview focused on PSTs' understanding of the TELLIS framework and their ideas about language- and literacy-integrated science planning and instruction (see Appendix B). The second interview focused more specifically on the PSTs' student teaching activity systems (see Appendix C). Semi-structured interviews were also conducted with each PST's MT at the beginning of the following school year and focused on elements of the student teaching activity system and PSTs' implementation of the TELLIS strategies (see Appendix D). The interviews as a whole served to provide a broader picture of the PSTs' implementation of the TELLIS framework across their student teaching experiences, beyond the TPA unit. All interview protocols were reviewed by experts in science and English Language Development (ELD).

---Insert Table 2 here---

The semi-structured interviews with PSTs were also used to understand participants' perceptions of their student teaching activity systems (Engeström, 1987) and to investigate how their participation in their student teaching activity systems was associated with (research question two) and supported or constrained by (research question three) the elements of those activity systems. As such, during the interviews, PSTs were asked about various aspects of their student teaching experiences that spoke to the different elements of the activity system. These interview questions allowed PSTs to speak to each element of their student teaching activity systems to provide a window into understanding how these elements mediated their enactment of the TELLIS framework.

PST interview responses were triangulated (Denzin, 1978) by TPA video footage and written documents and by the semi-structured MT interviews that also addressed the various elements of the activity system. The interviews provided a fuller understanding of the MTs' own experiences with and beliefs about teaching ELs, as well as the MTs' expectations regarding instruction in the classroom and the MT/student-teacher relationship. This triangulation of perspectives (Creswell, 2014) provided a deeper and more complete understanding of the community, tools, rules, and division of labor aspects of the PSTs' student teaching classroom activity systems, particularly given the MTs' roles as the primary decision-makers in the classroom. In this way, contradictions and congruencies could also be highlighted to better understand that activity system as a whole.

Finally, interviews were supported by PSTs' student teaching seminar reflections that occurred weekly during the student teaching experience. In the reflections, PSTs were asked to reflect on a particular aspect of their student teaching experience, including behavior management, differentiation, and assessment. The reflections provided insight into PSTs' perspectives of their student teaching activity systems throughout the semester to provide a more holistic view of how they understood and operated within their systems.

Data Analysis

Qualitative and quantitative methods were used to analyze the data. Steps of analysis for each research question are reported, below.

Analysis for research question one. To analyze PSTs' TPAs for evidence of TELLIS implementation, video footage from all lessons[2] in each PST's unit was reviewed. While viewing each video-recorded lesson, field notes were recorded and were then coded for the TELLIS framework strategies. The resulting chunks of data for each TELLIS component were then re-reviewed and assessed using the researcher-created TELLIS Instructional Integration scoring rubric to produce an overall score for each component of the TELLIS framework (see Table 3).

Informed by rubrics from similar studies designed to assess PSTs' implementation of science instruction for ELs (e.g., Lyon et al., 2018; Stoddart et al., 2013), the TELLIS Instructional Integration scoring rubric was developed by the researcher with input from experts in science and ELD to capture the extent to which PSTs integrated each component of the TELLIS framework into their instruction. Like the scoring rubrics from which the TELLIS Instructional Integration scoring rubric was adapted, the scoring scale included four enactment levels, ranging from 0: Not present, in which there is no evidence the TELLIS component in the PST's instruction, to 3: Extending, in which the PST moves beyond targeted implementation of a practice to engage at a level that is above and beyond the targeted expectations. Criteria for each level of enactment were developed based on the goals of each component of TELLIS as described in the framework, and examples were identified for each level of enactment for each

[2] Due to recording problems (i.e., dying battery and camera malfunction), half of Erin's Day 2 lesson and most of Ana's Day 1 lesson were missing.

TELLIS component. The target level of implementation for PSTs was a Level 2 or 3 for each component. To ensure that the rubric criteria were observable with clear distinctions among enactments levels, the primary researcher used the rubric to score video footage of a lesson that was not part of the study data to ensure that the rubric criteria were observable with clear distinctions among enactments levels. Results from this initial trial run led to minor changes for clarity and helped further refine examples for each enactment level for each TELLIS component.

---Insert Table 3 here---

To support validity and reliability of the scoring rubric, one video-recorded lesson for each participant was coded by both the primary researcher and a secondary researcher. The researchers independently analyzed the videos as described above, using time stamps in their field notes for easy reference. After this initial analysis, the researchers compared and discussed their results to come to a consensus and further refine the scoring rubric for clarity and discernibility. The revised rubric was reapplied to each of the three lessons to ensure that all lessons were analyzed using the most current rubric.

The primary researcher then followed the same cycle of analysis for each of the PSTs' remaining lessons using the updated rubric. Because instruction naturally fluctuates based on learning objectives and activities, and in line with similar scoring rubrics (e.g., Lyon et al., 2018), the highest score for each component was retained to indicate a clearer picture of what the PSTs could do overall. Thus, if for one lesson contextualization was scored at a 1, but in another lesson it was scored at a 2, the higher score was retained. The results of this analysis were overall scores for each TELLIS component that were inclusive of all of the participant's lessons in their units. These scores were paired with average scores that suggested sustained implementation of each TELLIS component across the entirety of the unit.

Analysis for research questions two and three. To better understand the activity systems in which PSTs taught their TPA lessons, and the supports and constraints that they provided, PST and MT interviews were transcribed and, along with PSTs' student teaching reflections, coded using the mediating elements of the activity system (i.e., rules, tool, community, and division of labor) as *a priori* codes (Saldaña, 2013). This analysis resulted in data chunks for each mediating element of the PST's activity system (Miles, Huberman, & Saldaña, 2014), from which thorough qualitative descriptions were created for each element and, along with qualitative observations from the TPA video footage and written documents, were compiled into narrative summaries (Way, 1998) for each participant. These narratives served to summarize each case before compiling data into data matrices (Miles et al., 2014) for cross-case comparison (Stake, 2013).

During the cross-case analysis, similarities and differences among PSTs' activity systems for each activity system element were reviewed with particular attention to how the elements supported or constrained PSTs' implementation of TELLIS-centered instruction. To support trustworthiness (Rossman & Rallis, 2017), the matrices were reviewed again after initial conclusions were made to identify any disconfirming evidence (Creswell & Miller, 2000) for each conclusion. The results of these analyses are described, below.

Results

Analysis of instructional video, TPA documents, interviews, and reflections suggests that PSTs were able to enact most TELLIS strategies at the targeted Implementing level (or close to it) at least once during their TPA units, though scores varied across lessons. Further, PSTs' activity systems appeared to play a large role in which strategies PSTs employed most fully. Results are described in detail by research question, below.

Research Question One: Extent of TELLIS Instruction Enactment

Overall, all participants were able to reach or nearly reach the *Implementing* domain of TELLIS enactment for most of the TELLIS strategies at some point during their units (see Table 4). The average enactment score for each TELLIS strategy by PST fell mostly at the *Beginning* level of enactment, but nearing *Implementing*, and in no single lesson did any PST reach *Implementing* for all TELLIS instructional strategies. However, given that particular lesson structures lend themselves to some TELLIS strategies more than others, this was not surprising nor necessarily discouraging. Indeed, in line with similar studies (i.e., Lyon et al., 2018), the highest possible scores for each strategy were considered most indicative of what PSTs were able to do through their instruction.

One marked difference in TELLIS strategy implementation among participants was their use of students' multilingual repertoires to support learning. This strategy was Ana's strongest area of TELLIS instruction, both overall and on average, and was the only instructional practice that any PST enacted at an *Implementing* level on average. Throughout all of Ana's lessons she worked closely with her Spanish-speaking students, moving in and out of Spanish to help make meaning of what students were seeing in their small group work, to clarify directions, to manage behavior, or to just converse socially. Though she only once used Spanish as part of whole class instruction (i.e., when giving directions for an activity in Lesson 2), she welcomed, encouraged, and participated in students' Spanish use often during small group work or individual check-ins, which constituted a significant portion of her class. This was in contrast to Erin and Rachel, who made no observable moves to integrate students' multilingual resources over the course of their units, even despite Rachel sharing a language with all of the ELs in her TPA classroom. Possible reasons for differences in the use of multilingual repertoires, and other instructional decisions, are further explored in the results for research questions two and three.

---Insert Table 4 here---

Beyond levels of implementation, themes of *how* PSTs implemented the TELLIS strategies emerged. For example, while all PSTs integrated opportunities for literacy development at the *Implementing* level at least once (and for Ana, during most of her lessons), these literacy opportunities were almost always in the form of student writing. Reading in all three PSTs' units was often relegated to reading instructions or brief pieces of information to help complete the task, and not completed for scientifically authentic reasons. In contrast, the writing that students did often required them to draw conclusions, defend claims, and make comparisons, showing a greater use of literacy for authentic purposes in science.

For all PSTs, strategies to support language understanding and use were mostly focused on supporting language understanding. All three PSTs were proficient at integrating numerous instructional strategies, most often centered around message abundancy, or providing information in many different modalities (Gibbons, 2015), to support their students' understanding of what they were hearing or reading. In contrast, other than the occasional use of sentence frames or allowing students to use visuals in their output, very few supports for output were included. This may have particularly accounted for the lack of EL participation during whole group discussions that was observed in video footage of Erin and Ana's TPA lessons. Indeed, no ELs were ever observed orally participating in whole-class discussions during any of their TPA lessons, and though ELs did consistently participate in Rachel's whole-class discussions, Ms. Raymond, Rachel's MT, pointed out that ELs were much less-willing to participate when scientific language was expected, though these type of language expectations were never observed during the TPA lessons. While there could be many explanations for ELs' decisions to participate, strategies for supporting students' language use, particularly during discussions, could have been beneficial.

Finally, it is important to note the level to which PSTs sought to contextualize students' learning, particularly given how challenging this strategy often is for teachers (Bravo et al., 2014; Lee et al., 2007; Lyon et al., 2018). In at least one lesson per unit, each participant framed her instruction in real-life phenomenon to help students better understand the context in which they were operating. Erin's entire unit was framed within students' task of designing a house that would withstand hurricane-force winds. Rachel, pulling on her training in Ambitious Science Teaching (Windschitl, Thompson, & Braaten, 2018) during her undergraduate work, developed essential questions to frame each lesson that were grounded in real-life phenomena. Finally, while Ana most often used isolated examples to help connect content to students' lives (i.e., relating biotechnology to crime shows students might have seen), she also grounded her instruction on antibiotic resistance around students' interaction with the flu and antibiotics, something that might have been prescient in students' minds given the recent flu season. Thus, these results indicate that PSTs were able to not only identify ways to contextualize learning to support their ELs' understanding of key scientific topics, but to frame their entire lessons with these authentic events.

Research Questions 2 and 3: Associations with and Affordances and Constraints of the Activity System

Research questions two and three addressed what, if any, associations were evident between PSTs' participation in their student teaching activity systems and their enactment of TELLIS instructional strategies, with particular attention to the affordances and constraints the various mediating elements provided. Results suggest that PSTs' activity systems played a large role in constraining enactment of some TELLIS strategies and providing affordances for the enactment of others. Of the mediating elements of the PSTs' activity systems, community, division of labor, and norms, and the interactions between them, provided the greatest affordances and created the greatest constraints for PSTs to integrate the TELLIS strategies into their instruction. This is not to say that tools played no role in PSTs' instructional implementation, but rather that they were often found to play a supporting role within the context of the other activity system elements and by themselves did not largely impact PST implementation. Each mediating element and its association with TELLIS implementation are reviewed next.

Division of labor. The division of labor evident in each PST's activity system was one of greatest areas of difference among the activity systems, and one that had the greatest impact on PSTs' ability to instruct in a TELLIS-oriented manner. From day one, Ana felt supported to engage in any type of instruction she saw fit and took advantage of this freedom. Ms. Johnson noted in her interview that she sought to make Ana's student teaching experience as close as possible to what first-year teaching might be like, acting as a facilitator of planning and reflection and a supporter of content and behavior management, but following Ana's lead in every way. As Ana described in her interview, "I think she was very chill with whatever I did, and she was always an after-reflection, never a before-reflection. . . . She just let me try and see what happened." For Ana, the student teaching classroom was an experiential learning opportunity where she could play the role of primary instructor and decision-maker, but with the support of an experienced teacher to reflect with and by whom she could run decisions. As a result, she was more willing to take risks and try things out that were not common in that classroom setting, including increased amounts of group work, opportunities for literacy development, and a direct focus on how language is used in science, all of which align with TELLIS instructional practices and can support EL (and all students') learning opportunities. More than any other PST, Ana worked to revise how teaching and learning was done in the context of a more traditional schooling system, and credited Ms. Johnson's openness and direct support of Ana trying anything new to her ability to do so.

In contrast, both Erin and Rachel seemed to align their instruction more closely with what their MT was already doing. This was evident in the ways they talked about their own instruction during their interviews, describing what "we" did as often as they described what "I" did when asked how they personally implemented instruction in the classroom. For example, when asked how she integrated the TELLIS practice *discourse inherent to science* into her instruction, Erin explained, "We would do a fair amount of, 'Talk to your neighbor. Talk to your table. Have a table answer.'"

For Rachel, this close alignment worked well because she and Ms. Raymond had similar perspectives on good instruction and used what they both described as a co-teaching model. As a result, Rachel felt like an equal contributor to classroom decision-making and instruction and was comfortable trying new things such as providing experiential learning before applying vocabulary, providing more visuals and guided-notetaking, and developing graphic organizers to support students' meaning-making, all of which were evident in the video footage of her TPA lessons. These additions were beneficial not only for her ELs, but for many of her students, and Rachel felt confident in her ability to reach her ELs, something that was reiterated by Ms. Raymond, describing Rachel as "well-suited" to meet the needs of her ELs.

With the exception of her TPA, where Rachel took the full lead on developing and implementing her own lessons, Rachel reporting aligning her instruction closely with Ms. Raymond's instruction, often adapting what Ms. Raymond had done before to "make it my own," but keeping similar structures. This may have been in part a product of having taught with Ms. Raymond during the prior semester. For example, in anticipation of taking over as lead teacher, Rachel wrote in her reflection:

> I've been looking over all of Ms. Raymond's materials and figuring out how I will modify them to make them my own. However, many of the lesson plans that I submitted last semester were just modified versions of Ms. Raymond's lesson plans, so I think I'm already in great shape!

In many cases Rachel's adoption of Ms. Raymond's materials and instructional strategies was positive, with Ms. Raymond already including significant amounts of contextualization, differentiation, and group work to support more individualized but collaborative learning, all strategies that align tightly with TELLIS instruction. However, there were also some areas of instruction, such as a heavy reliance on whole group discussion, minimal opportunities for literacy development, and an acceptance of a monolingual narrative of instruction, that Rachel seemed to adopt despite their incongruence with TELLIS strategies. While these instructional decisions were likely made easier by their alignment with Ms. Raymond's instructional style, in some cases they appear to be influenced more by Rachel's own perspectives of good science instruction and her observations of her students rather than her feeling the need to teach lockstep with Ms. Raymond. For example, when considering integrating opportunities for literacy development, Rachel explained in her interview:

> I have trouble doing [that] just because I have content that I had to teach and at the end of the day, it's kind of hard to also then slam down the literacy development. . . . so many of them have literacy issues and at what point do I stop teaching the content and try to teach them things that they're also learning in their English language arts classes or hopefully they are. I guess I don't know.

Here, Rachel seemed to conflate integrating literacy in the science classroom with teaching English language arts rather than highlighting the ways literacy is used to engage in scientific practices and meaning-making. While this might have been informed in part by a school-wide initiative to integrate literacy twice a semester through annotating scientific news articles using an ELA-specific strategy, it was also a perspective Rachel expressed many times during her university coursework.

Similarly, Rachel's heavy use of whole-class discussion might have resulted from the high level of participation she observed in her classroom. Observations of her video-recorded TPA lessons indicated that approximately half of the students would participate voluntarily during whole-class discussion (including two of her ELs), and Ms. Raymond noted that Rachel was very cognizant of calling on and attending to those who didn't often have their hands in the air, something that was also affirmed by TPA video. Students' willingness to participate in whole-class settings might have been the result of the positive classroom climate that both Ms. Raymond and Rachel strived to set, and may have led Rachel to be more welcoming of this form of discourse, despite Ms. Raymond's note that ELs often didn't feel comfortable participating in these settings when more science-specific vocabulary was required.

Like Rachel, Erin's instruction aligned closely with her MT's, but out of a feeling of obligation, not by choice. Erin was very cognizant of the fact that she was operating in "someone else's classroom," and from very early on recognized how that might limit her ability to instruct in a way she wanted, writing in an early reflection:

> I think I have a broader idea of what can be done within a classroom environment and what learning can look like, but I also realize that this is her classroom. Realistically, I think by the end of the semester this could be a major struggle for me.

Even though there were components of Ms. Smith's instruction that Erin didn't agree with, she felt uncomfortable "rocking the boat" or "stepping on toes." As a result, she felt she only had the power to make small changes in her instruction, including the supports she provided for her ELs. For example, in discussing the changes that she made to the formatting of worksheets to support her ELs(i.e., chunking information, adding visuals, and bulleting responses), Erin noted in an interview, "it's what felt like the lowest time, biggest benefit thing that I could do in the context of where I was." Erin was hesitant to integrate any big changes, such as revising how students were assessed to be more EL-friendly, even if she knew it would be beneficial to her ELs, because she did not want to push too far or create friction between her and Ms. Smith. Her hesitations highlight how power differentials can play a role in PSTs' uptake of strategies, in that Erin was perhaps overly cautious in challenging expectations she perceived from her MT.

Erin's alignment with Ms. Smith's instructional style was at times advantageous to her students. As a teacher in an AVID demonstration school, Ms. Smith had adopted the program's WICOR (Writing, Inquiry, Collaboration, Organization, and Reading) strategies, many of which aligned with the TELLIS framework. In particular, Ms. Smith focused a great deal on structures and supports for student-to-student discourse, vocabulary development (as a part of a whole-school initiative), occasional integration of literacy (i.e., through the twice-a-semester reading and annotation of scientific articles initiative), and contextualization (i.e., through Socratic seminars or debates on hot-button, content-related science issues). However, Ms. Smith also firmly held the belief that "good teaching is good teaching," a notion that has been challenged in research regarding instruction for ELs (de Jong & Harper, 2005), and while she attempted to differentiate her instruction for her students generally, she reported in her interview that she never implemented any instructional strategies that were particularly designed for her ELs unless they were suggested by the ESL teacher who met with them once a week as part of what the school called a professional learning community (PLC). Erin felt that this more general focus on differentiation restricted her own ability to implement more strategies, or at least significant ones, explaining:

> My MT's expectations were that you're having all of this, what a lot of others would think is differentiation, just every single day but . . . because that was the expectation, I didn't feel comfortable pushing it a lot further but also didn't feel like it was doing them a disservice as it was.

As a result, Erin only implemented small changes that she felt Ms. Smith overlooked. It's not surprising, then, that when she was asked to what extent Erin met the needs of her ELs, Ms. Smith noted:

> I don't know that there was necessarily like a specific thing that I was like, 'Oh you can tell that she's being mindful of that' . . . [or] if there was anything that she specifically was bringing from [her university courses] being like, 'Oh this I need to like focus on.'

Perhaps what was most interesting about this relationship was that Erin reported that Ms. Smith never said anything to her when she tried something new or pushed beyond "normal," and Ms. Smith never explicitly suggested that Erin's instruction needed to align closely with her own, noting instead that she was trying to give Erin as much of the experience of being a first year teacher as possible. The disconnect, then, appeared to come from Erin's struggles to read Ms. Smith, and the feelings she got that Ms. Smith was not pleased when her instruction moved too far away from the classroom norm. This disconnect was evident in both Erin and Ms. Smith's description of a TELLIS-aligned strategy Erin commonly employed in the classroom: having students act out scientific processes. Erin highlighted this as a great way to get kids up and moving and to see concepts in new ways, but emphatically noted that Ms. Smith did not like to do this sort of thing. She said Ms. Smith never said anything, but highlighted one instance where she felt some "not-great things" coming from Ms. Smith about what she was doing and therefore stopped. Interestingly, in her interview Ms. Smith highlighted Erin's tendency to have students act things out as something she did well to keep things relevant. This suggests a disconnect between Ms. Smith and Erin's perspectives about Erin's instructional decisions and seemed to be at the heart of their different understandings of what was allowed and encouraged.

One additional component of Erin's activity system that may have explained in part the disconnect between Erin and Ms. Smith's reports about the division of labor was their participation in a PLC. Each week, Erin and Ms. Smith met with the other sixth grade teacher and the ESOL teacher to review what they would be teaching for the week. Typically, Ms. Smith and the other teacher would plan together, and Ms. Smith reported that they stayed mostly on-track with each other even when Erin was the lead teacher, explaining, "We still did a lot of planning together just because, you know, like I said, [teacher] and I tend to do. We were a really cohesive group."

It is possible that Ms. Smith perceived the co-planning that occurred in the PLC as a support for Erin, while Erin perceived it as a limiting factor in her ability to truly take the lead in instruction. Interestingly, Rachel noted that it was in part the *lack* of her and Ms. Raymond's participation in a PLC that allowed her to have so much freedom in instruction, explaining in a reflection, "Ms. Raymond is going to give me a lot of autonomy in changing things and trying new things, especially since we don't have to account for anyone else in the PLC and their opinions." This begs a question about the role PLCs can play when PSTs' ideas of instruction are different from what is considered the norm, particularly if MTs feel they need to ensure their PSTs' instruction is aligned with PLC instruction.

Norms of the classroom, school, and broader education communities. While the relationship between MT and PST is well documented as having a substantial impact on PSTs' instruction (i.e., Clarke et al., 2014), results of this study indicate that the norms of the classroom and broader school and education communities do as well. One of the norms that affected all PSTs was the expectation that state standards be taught in their entirety, but only to the level dictated in the standards. For all three PSTs, the pace of instruction that was required led to less than ideal instruction. In a reflection on her student teaching experience generally, Erin noted that she felt like most days information was just "crammed down [the students'] throats," and in reflecting on her TPA unit, Rachel noted that the pressure of getting through all of her TPA content in the amount of time allotted made it challenging to "give the students more of a chance to interact, practice, and review." Ana felt that the pace she needed to maintain to prepare her students for the end-of-year standardized test kept her moving forward at the expense of really checking in with her students, and she felt she was probably planning at a level lower than what advance courses should receive due to the time pressure. In reflecting on one lesson in particular, she noted, "a lot of time it was just like, 'Are we okay? Do we get it? Can I help you explain this? Is this making sense? and not really having the time to dig deeper with them." In each of these cases, PSTs felt that they were unable to teach in a way that was best for their students or aligned with TELLIS strategies because of the pressure of getting through the content, and at times would completely avoid certain TELLIS strategies (i.e., literacy in Rachel's case) because there simply wasn't time for something additional.

All of the PSTs also had major disagreements with how students were taught in the context of traditional schooling systems. For Erin, the discontent stemmed from the misalignment between the traditional instructional practices and school set up of her student teaching placement and those she had come to find most effective in her experience as an environmental educator. In considering her frustration with the way school was done, she explained, “Kids didn't go outside. We had woods, we had fields, and we didn't use them.” Erin struggled with how science was taught in a way that focused more on facts and practices than authentic learning, and felt they missed numerous opportunities to contextualize their students’ learning within the context of their own school grounds.

For Ana, it was the didactic nature of instruction at the high school level that was inconsistent with her own understanding of good science instruction. She was a firm supporter of sociocultural and student-directed learning and found the expectation of mostly receptive learning to prepare students for a test at odds with her focus on student interaction, literacy integration, and engaging in the big ideas of science. Interestingly, where Erin felt crippled by these broader norms and felt that she was unable to instruct in a way she felt was best in the context of these more traditional structures, Ana pushed through the contradiction, trying out new instructional strategies despite pushback from students and misalignment with how things were traditionally done. However, Ana only did this to an extent: she recognized when the norms of schooling might create too much pushback from both her students and other teachers, such as if she were to forgo formal lecture and notes entirely for project-based learning focused on students making meaning together, and therefore retained some hallmarks of traditional instruction in addition to her more reform-oriented practices. This was evident in the video footage of her TPA lessons in daily lecture and note-taking sessions in addition to group work and active learning.

For Rachel, challenges came from the heterogeneity of the classroom. She was committed to meeting her diverse students’ needs but struggled to do so, feeling that to do so was an insurmountable task and in trying, she was being unfair to everyone, including herself. She felt like she was being pulled in many directions and as a result, could not adequately meet the needs of her ELs, differentiating in general rather than focusing specifically on differentiation for language (though this was included). She was so frustrated by her inability to meet all of her students' needs that she became largely turned off from the idea of heterogeneous classrooms, writing in one of her final reflections, "I think that I am going to look for a school that levels their science classes; I am just not finding a lot of success with the heterogeneous model – though I know it has its benefits."

Norms also seemed to play a role in PSTs' implementation of one TELLIS practice in particular, integrating students' multilingualism into instruction. While Ana used Spanish with her Spanish-speaking students as an additional language of instruction, Erin rarely reported using students' home languages, and Rachel reportedly did so only for behavior control (though this was not evident in her TPA video). In addition to their own multilingual repertoires (i.e., Ana and Rachel were both fluent in Spanish, the home language of a majority of their students, and Erin had a beginning level of German and French proficiency), their decisions to use students' home languages might have been a product in part of how other languages were received in their student teaching activity systems. When asked about the use of students' home languages in the classroom, all three mentor teachers acknowledged that until just recently the expectation had been English only in the classroom, but now, as Ms. Smith put it, "the pendulum [was] swinging back" toward more inclusive practices.

The extent to which MTs picked up on this trend shift varied. While Ms. Smith (Erin's MT) did not seem opposed to the trend of integrating students' home language in the classroom, she also did not appear to see a big a role for languages other than English in instruction and cited her own monolingualism as a restriction to her ability to use students' home languages in the classroom. Erin seemed to pick up on this: when asked about using students' home languages in the classroom, Erin replied, "We had to use English," though she also noted that she never reprimanded her students for using other languages with one another.

Ms. Johnson and Ms. Raymond reported taking more actionable steps to integrate students' home languages into the classroom. For example, when Ms. Raymond (Rachel's MT) was asked how she supports her ELs specifically, she described language-related supports like translating documents and tests if students were literate in their home languages, pairing up students who speak a similar home language, and providing translation dictionaries. Ms. Johnson, Ana's MT, also welcomed the use of students' home languages, reporting that she tried to provide supports for her students' home language use through supplying bilingual dictionaries and taking a course in Spanish for Educators. She also noted that she was planning to provide more opportunities for students to do projects in their home languages. Both Ms. Raymond and Ms. Johnson highlighted Ana and Rachel's multilingualism as a key tool for instruction and suggested that doing so was, as Ms. Raymond described it, "good for the kids," suggesting that they were open to the use of Spanish in the classroom.

Interestingly, despite both Ms. Raymond's and Ms. Johnson's support of multilingualism in the classroom, there were vast differences in Ana and Rachel's use of their own multilingual repertoires to support students' learning, largely stemming from their response to their students' resistance of using Spanish in the classroom. Both Ana and Rachel received pushback from their students when they asked if their Spanish-speaking students wanted to use their home language in the classroom. According to Ana,

My Spanish-speaking students talk to each other and [are] like, 'Don't talk in Spanish.

> Practice in English. You have to use English.’ I'm like, ‘No, no, guys, you can talk in Spanish. It doesn't bother me.’ They're like, ‘Well ...’ I guess some other teacher is telling them that they only should speak in English.

Similarly, when Rachel asked her students if they wanted her to explain content in Spanish, something she had done with students the previous semester, they said no. Unlike Ana, Rachel took this refusal at face-value, noting “obviously I'm not going to push them if they say no.”

It is impossible to draw definitive conclusions about students’ motives for rejecting the use of Spanish without directly asking them, and research cautions us against assuming that the presence of a home language other than English indicates bilingualism (or a desire for bilingualism) in the household (Braden et al., 2016). Still, it is possible that Ana and Rachel’s students’ hesitancy to use their home languages may have stemmed from the broader institutional discourse about home languages being inappropriate in the classroom that, until recent years, had dominated the school system. That is, these more global linguistic norms may have affected students’ reception of PSTs’ attempts to integrate their home languages into instruction. Interestingly, Rachel and Ana’s responses to their students’ pushback may also have been influenced by the monolingual norms of United States schools (Palmer & Martinez, 2016). While Rachel might have understood students’ multilingual repertoires as a tool to support learning, her acquiescence of students’ unwillingness to use Spanish might have stemmed from her deep-rooted understanding of English as the primary language of schooling. Even Ana, who pushed back on her students’ resistance and came to a compromise where they would use both English and Spanish, rarely situated students’ home language as an equally valuable linguistic tool, with video observations of her TPA indicating that she placed Spanish mostly in a supportive role to clarify English instructions or support meaning-making in small groups or individually (though she did this to a great extent). However, she did report offering her students the opportunity to write final assignments in Spanish. Unfortunately, her students never capitalized on the opportunity.

The PSTs also struggled to use students' multilingual resources in their instruction if they themselves were not well-versed in the students' home languages, even despite instruction during the intervention highlighting ways to do so. For example, in considering multilingualism as a resource, Rachel explained, "I speak the language that 85% of my ELs spoke, so if I'm in that situation again, . . .I think that comes pretty easy to me. But, if I can't speak Urdu or Pashto or whatever, I can't use that." Similarly, though Ana used a significant amount of Spanish with her Spanish-speaking ELs, she was less clear on how to support her non-Spanish speaking ELs in using their home languages. This was evident in the observations of her instruction, where she supported and used multilingualism with her Spanish speakers often, but made no similar attempts with her EL who spoke Arabic, though she did report applauding (but not suggesting) the student's self-initiated use of Google translate to understand research she was reading as part of their final project. Thus, while both Rachel and Ana felt comfortable integrating students' multilingual repertoires into instruction when they were familiar with the language, they struggled to support students' multilingualism when the language was unknown to them.

Community. Finally, PSTs' understanding of their activity systems' communities, in particular their students, impacted their instructional decisions. For Rachel, this was a mismatch in her somewhat deficit-oriented perception of students' levels of content understanding and her ability to dive more deeply into content. In particular, she wrote in a reflection:

> I am also kind of longing for higher level material. These kids ask great questions, but with the level we go into they can't really understand the complex answers. I still give them the answers to see how much they can grasp, but obviously it goes over most of their heads.

For Erin and Ana, it seemed to be students' indoctrination into a particular type of schooling that created the greatest friction. The result of this indoctrination appeared to be a preference for didactic, teacher-centered forms of instruction that made students resistant to engage in more reform-oriented instruction. Indeed, both Ana and Erin pointed to students' lack of readiness for their hesitancy to integrate TELLIS-oriented, student-centered instructional strategies such as opportunities for student discourse, rigorous and authentic learning activities, and literacy into their instruction. For example, Ana noted:

> I definitely wish I had more norms with projects and with group work and higher expectations of what those look like, but I was downplaying what I would actually do because I wasn't sure how prepared they were going to be for it, so it was like, I'll just make it a little less than what they probably could do because I don't know if they are ready for that level of work.

Similarly, Erin wrote in one of her reflections:

> While I'd really like to try moving towards more open-ended inquiry and PBL-type learning, I think this group of 6th graders first needs to focus on how to use the resources that they have and how to apply prior knowledge. . . . I rarely see students consult their notebooks for questions. Instead they muddle in the midst of 'I don't know, and if I sit here long enough not knowing, someone will tell me the answer'. . . . How do you nip that and reprogram it?. . . . How realistic is it to push 11 and 12 year-olds to take that kind of ownership when they may only be pushed to do so in one class?

It appeared to Erin and Ana that their students' willingness and ability to share more of the division of labor by being agents of their own learning was tempered by the way they had "done school" their whole lives. As a result, Erin and Ana altered their instruction to meet their students' current needs at the cost of providing more authentic, age-appropriate, and rigorous instruction as outlined in the TELLIS framework.

For example, in addition avoiding more inquiry and problem-based learning types of instruction, Erin also noted struggling to integrate effective literacy opportunities given her perception that her students could not write. In reflecting on her attempts to integrate meaningful writing into her TPA assessments, Erin wrote,

> One of the struggles I was not anticipating with sixth grade is the number of students for whom the physical act of writing is a challenge. This may be one of the areas that I struggle most with as a teacher, as it makes differentiating even more challenging.

Similarly, when she tried to integrate more movement in the classroom to support student learning, her students struggled to follow behavioral expectations, making it more challenging than expected.

While Ana was unwilling to give up on reform-oriented practices, she noted that student pushback made the innovative instruction more challenging to implement, which made learning less productive. This was particularly the case relating to Ana's attempts to integrate augmented, or technology-enhanced, reading into her lessons. In one of her reflections, she wrote, "while [augmented reading] seemed like a great strategy, my kids did not like it and it ended up hurting my goals a lot and I think led to lower outcomes on that content." Ana also noted in her interview that sometimes her students simply would not do the reading at all. These setbacks can be concerning because they might turn PSTs off of key instructional practices that they might otherwise take up. Given the importance of literacy in language development and science learning, it is important that teachers find ways to integrate reading in a positive manner.

It is interesting to note that Rachel did not voice student resistance to different types of instruction as a barrier to her instruction, which might speak to the parallels that were extant between her chosen instructional implementation and that of Ms. Raymond. Because she was able to implement instruction that she felt aligned with her understanding of effective science teaching, and because that paralleled what students were already doing, the friction that was evident for Ana and Erin might have been diminished for Rachel.

Another student-related factor that impacted all three PSTs' instruction was student motivation and behavior. Ana and Rachel bemoaned a general air of apathy among their students, and all PSTs noted that some of their students opted to not do work either in or out of the classroom, which they found frustrating.

PSTs also struggled to manage their students' behavior, most often evidenced in students talking while another student or the teacher was talking and in off-task behavior, whether looking at phones in Ana's class or engaging in non-classroom activities in Erin and Rachel's classrooms. Ana was uncomfortable with discipline, seeing it as a power move and institutionally unfair, and Rachel often did not agree with her MT that students' infractions were worthy of being sent out of the room, nor did she think sending students out was a good way to address behavior. In TPA lesson video observations, both PSTs made threats of repercussions for behavior, but they did not follow through and as a result they acknowledged that student behavior impacted their ability to teach in a manner most beneficial for their ELs. For Ana, student behavior made it more challenging for her to check in consistently with her students and impacted students' abilities to engage in TELLIS practices like scientific discourse, particularly because they seemed to view group work as a time for off-task socialization. Behavior issues during her TPA also led Ana to rearrange and ultimately cut out portions of her instruction, writing in her TPA reflection:

> If students took too long on one aspect of the lesson I had not expected, it would inevitable (*sic*) affect my next lesson which would require me to rework my original plan to supplement for the lost time. The classroom climate mostly contributed to this challenge because my students are particularly chatty, unmotivated and have many interpersonal issues amongst the social groups present in my class. The social components of my students' lives often surfaced during class for a variety of reasons which interrupted the learning environment of my class.

For Rachel, off-task behavior made it challenging for her to ensure she was integrating all of her planned supports to meet her students' varying needs and led her to question her ability to allow students to engage in key TELLIS practices like engaging in scientific discourse with one another, even for short periods of time. For example, she told her TPA class right before a turn and talk during one of her TPA lessons, "I really hope taking 45 second to talk isn't going to derail this." In both cases, PSTs' reaction to their students' behavior led to less exposure for their students to key TELLIS instructional strategies.

Erin took a more active approach to reprimanding inappropriate behavior by stopping her instruction numerous times to ensure quiet. While a quiet classroom is helpful for language learners, the start-and-stop nature of her instruction was hard to follow and lacked the flow that would occur with continued conversation. Further, sometimes Erin cut off on-task student-to-student discourse, which for some ELs may have been the way they were most comfortable conversing (Gibbons, 2018).

Behavior management is often a problem for PSTs, so it is not surprising that these PSTs also struggled to keep their students focused and on-task. However, the impact that this had on their ability to effectively teach their ELs is notable, as all of them ranked student behavior as a top mitigating factor to ensuring they were meeting the needs of their ELs in their interviews.

Discussion

The results from this study suggest that instructional models like TELLIS can support PSTs' integration of language- and literacy-integrated science into linguistically diverse student teaching classrooms. In particular, results indicated that all PSTs were able to implement most of the instructional strategies at the targeted *Implementing* level during at least one of their four unit lessons, with average implementation hovering at the mid- to high-*Beginning* level for most practices. These findings reflect those of similar studies (i.e., Lyon et al., 2018) and suggest that PSTs can adopt targeted levels of reform-based, language- and literacy-integrated science instructional practices—even when working in contexts where these practices are not reinforced—when exposed to “a set of core practices, supported by tools and routines over time” (Thompson et al., 2013, p. 609). Given the lack of preparation most PSTs receive for teaching science in linguistically diverse classrooms (NASEM, 2018), these findings join others as a call for teacher preparation programs to consider language- and literacy-integrated science instructional models like TELLIS to train secondary science PSTs for classrooms inclusive of ELs.

Of particular notice in these findings was PSTs’ integration of contextualized learning into their instruction. Unlike in previous studies where contextualization seemed to be more peripheral (Lyon et al., 2018; Tolbert et al., 2019), all three PSTs in at least one of their TPA lessons (and for Erin and Rachel, in many) framed their lessons with a relevant contextualizing event. For Erin and Rachel, attention to this TELLIS practice might have been reinforced by their MTs’ own efforts to contextualize learning. However, all three participants also identified contextualizing learning as a key component to science instruction, in some cases pointing to their own prior experiences (i.e., Rachel’s work with the Ambitious Science Teaching framework [Windschitl et al., 2018] and Erin’s work in experiential learning) as factors that encouraged those mindsets. Framing lessons in real-life events can support students’ engagement and understanding of key scientific principles by making connections to authentic events that they experience in their own lives (Tolbert, 2016). Thus, PSTs’ ability to frame their lessons in broader contextualized themes was an important finding, particularly given that even in-service teachers’ struggle with contextualization (Lee et al., 2007).

In contrast, PSTs struggled to implement strategies that responded to the full linguistic demands of their lessons. That is, while all three PSTs excelled at integrating strategies to support students' language understanding (i.e., input), there were fewer supports for students' language use (i.e., output), which may have impacted ELs' willingness to participate, especially in whole-class discussions. These findings point to the shortcomings of simply providing a "toolkit" of strategies if PSTs are unaware of or unable to implement the strategies in a congruent and cohesive way that supports language use across domains (i.e., listening, speaking, reading, and writing; de Jong & Harper, 2005). Future interventions and research should consider how to support PSTs in identifying and integrating output-specific strategies so that all students can engage in discourse and literacy in their classrooms.

Also related to input was the lack of opportunities for literary input in each PST's observed lessons. While Ana acknowledged a commitment to literacy and made attempts to integrate readings in her instruction generally, both Rachel and Erin portrayed literacy integration as an English Language Arts activity that took away from the time they needed to teach science or tackle more pressing instructional issues. Other studies (e.g., Rutt & Mumba, under review; Salerno, Brown, Rutt, & Heny, under review) have echoed these findings, highlighting the need for more research on how to support PSTs in valuing reading as a key component of scientific activity and therefore a worthy addition to science instruction.

While PSTs' were able to implement most of the TELLIS instructional practices in their student teaching placements, this study also found that the extent to which PSTs took up each instructional strategy was largely affected by elements of their activity systems, including their working relationships with their MTs (division of labor), their perceptions of their students' abilities and willingness to participate (community), and their own willingness to challenge traditional instructional norms (norms and rules). These findings echo other researchers' assumptions that field placements and interactions with MTs play a role in PSTs' instruction (i.e., Heineke et al., 2019; Lyon et al., 2018) and highlight the critical role that activity theory can play in helping to identify the contextualizing factors that might inform PSTs' instructional decisions, and how teacher educators and researchers can take actionable steps to mitigate constraints and amplify supports in such cases.

For example, for all PSTs, it was the relationship with their MTs that provided the most affordances (Ana and Rachel) and constraints (Erin) to their instruction. For Ana and Rachel, the freedom provided to them by their MTs was liberating, allowing particularly Ana to experiment with numerous TELLIS-aligned instructional strategies. Conversely, the restrictions Erin perceived on her ability to "think outside the box" with regards to instruction not only limited her ability to implement larger scale, TELLIS-oriented changes in her instruction, but also left her feeling empty and robotic as an instructor, unsure of who she was as a teacher. Further, it is important to note that, though Erin was able to reach the *Implementing* level for many of the TELLIS strategies over the course of her unit, she described her TPA unit as very atypical of the type of instruction that occurred throughout the rest of the semester (including when she was lead teacher). Indeed, it could have been the university-required implementation of an engineering design integrated science lesson that gave Erin the leverage to move beyond the small-scale moves she typically used, though even then she reported feeling that at times she was pushing too far. Future research should consider the role instructional models like engineering design integrated science can play in supporting PSTs to integrate student-centered, TELLIS-aligned instruction, particularly within the context of more traditional instructional settings.

Beyond liberties to enact instruction as PSTs pleased, MT modeling also played a significant role in two PSTs' uptake of TELLIS strategies. Indeed, in a trend that is backed up by other research (i.e., Lyon et al., 2018; Stoddart et al., 2013), both Erin and Rachel picked up and employed most fervently the TELLIS strategies that were modeled most often in their MT's teaching (i.e., discourse for Erin and contextualization for Rachel). This shows the importance of mentor teacher modeling and support in encouraging PSTs to engage in reform-focused instructional practices, and supports other researchers' calls for more training for MTs in language- and literacy-integrated science instruction (e.g., Heineke et al., 2019; Lyon et al., 2018). However, MT training alone does not seem to be sufficient in ensuring MTs' implementation of language- and literacy-integrated science instruction (Lyon et al., 2018), and as such it is equally important that teacher preparation programs prepare PSTs to navigate the disconnect that can occur between reform-oriented teacher preparation programs and contextual discourses that may be espoused in traditional classroom. Indeed, Erin appeared to be almost paralyzed by her relationship with Ms. Smith, struggling to get a read on how far she could push and as a result opting to not push far. While this certainly could have been attributed to matters of personality, with Erin seeking to avoid conflict and Ms. Smith preferring to keep things consistent, they also suggest heightened awareness of the power differentials that exist in MT-PST relationships and how in particular settings, those differentials can lead to PSTs' compliance with instructional decisions that do not align with their own understandings of good instruction (Yoon & Larkin, 2018). Thus, working with PSTs on how to navigate power-imbalanced relationships and open lines of communication with MTs could foster greater transparency that might in turn support PSTs' confidence to engage in more reform-oriented instructional practices. This could be especially true in contexts where the MT and PST are working as part of a PLC and may feel beholden to additional opinions.

Training that is inclusive of both PSTs and MTs, in which they work together to plan for and implement language- and literacy-integrated science instruction, is another avenue that warrants future research, particularly because other studies have shown that collaborative learning environments can support positive perceptions and implementation of instructional strategies for supporting ELs in science classrooms (Dellicarpini & Alonso, 2014). Such a design moves beyond the often-brief training MTs get in the targeted instructional strategies and provides opportunities for PSTs and MTs to work together to be agents of change in their schools.

In addition to the division of labor between MTs and PSTs, larger classroom, school, and institutional norms also affected PSTs' abilities and willingness to implement some TELLIS strategies. This was especially evident in Ana and Rachel's willingness to integrate their multilingual resources into instruction to support the Spanish-speaking ELs in their classrooms, and in their students' resistance to their attempts to do so. These findings reflect those from other studies (e.g., Vomvoridi-Ivanović, 2012) and highlight the role that larger institutional norms might play within the student teaching activity system. That is, English's general dominance as the language of schooling in the United States (Palmer & Martinez, 2016), and past perceptions espoused in the schools that other languages are at best a language for home and at worst a roadblock to learning English, dictate what is considered "normal" for instruction and may have led both students and teachers to, if not outright reject the use of home languages in the classroom, at least not think of it as a critical resource for learning (Vomvoridi-Ivanović, 2012). This was evident in Rachel's reluctance to push the use of Spanish when her students opted out, and also in Erin's stark statement about the use of other languages in instruction: "We use English." Only Ana fought back against the hegemonic tendencies of monolingual instruction by encouraging the use of and often using Spanish to make meaning with some of her students. However, even in Ana's case, sharing findings with peers was always required to be in English, again reflecting the norm of English as the dominant language of schooling.

While it is important to recognize that students' choices to not speak their home languages are not always influenced by perceived pressures related to institutional norms (Braden et al., 2016), and that teachers' decisions to use students' home languages are often products of numerous mediating factors (Kibler & Roman, 2013), it is critical that teacher training programs highlight for PSTs the existence of monolingual norms and the roles they play in both teachers' and students' resistance to using other languages in the classroom, particularly those languages that PSTs do not speak themselves. More work also needs to be done to support PSTs in challenging conventional understandings of school settings as monolingual contexts. It is not enough to present students' home languages as a resource. Rather, PSTs need to grapple with the idea of hybrid language practices (Palmer & Martinez, 2014) as an important norm for educating multilingual students and need more exposure on how to foster students' use of their multilingual repertoires within the context of the science classroom, even when the PST is unfamiliar with students' home languages.

PSTs also found that the community of their activity systems, particularly their students, largely impacted the extent to which they integrated some TELLIS instructional strategies. This was highlighted through PSTs' discussions of student behavior and student readiness and linked directly back to the larger educative norms present in the classrooms and schools in which they taught. In particular, all three PSTs noted that their students were not "ready" for the type of instruction they wanted to use, much of which connected to key strategies highlighted in the TELLIS framework that would support their ELs' language and science learning, including numerous opportunities for discourse and literacy development (Ana), authentic, contextualized learning (Erin and Rachel), and deep dives into the big ideas of science (all PSTs). As a result of this perceived lack of readiness, PSTs altered or at times completely avoided the reform-oriented instruction they were hoping to implement.

These findings suggest that teacher preparation programs need to be more attuned to the disconnect between not only the practices and discourses of traditional schooling systems and the reform-oriented practices commonly taught in teacher preparation programs, but also to students' reactions to such reforms. Indeed, while Ana recognized that school norms prescribed a particular type of instruction, it was her students' resistance to the reform-oriented instruction that she felt made her instruction so challenging (and led to her watering down her expectations). Thus, it is important that PSTs are not only trained in language- and literacy-integrated science instruction, but that they are also taught how to implement that type of instruction with students who may be comfortable with business-as-usual and might not be willing to take up a greater division of labor in the classroom. In particular, PSTs need training on how to gradually but consistently expose students to new ways of learning while maintaining the rigor of age-appropriate, language- and literacy-integrated science instruction. Research should consider how the interaction between educational norms, students' perception of what learning looks like, and PSTs' attempts to alter that vision can meld together into productive instruction for all students. This is particularly true given that many students have been exposed to a particular type of instruction over a long academic career and may be particularly resistant to new forms of instruction (Ellis, 2015).

Finally, PSTs' ability to manage student behavior was another factor affecting their implementation of language- and literacy-integrated science instruction as outlined in the TELLIS framework. Behavior management has long been acknowledged as a challenge for new teachers, with studies indicating that it is a learned skill that takes time and practice to develop (LePage, Darling-Hammond, Akar, Gutierrez, Jenkins-Gunn, & Rosebrock, 2005). While training on how to manage student behavior in general is critical for all PSTs, when considering the ability to implement language- and literacy-integrated science instruction specifically, it is important for PSTs to consider how their attempts to control student behavior, particularly related to student talking, and how the classroom climates they create, support or constrain their ELs' ability to participate. For example, in Erin's class, she was so focused on silence during whole class discussions that she often cut off on-task discourse that may have been the only way her ELs felt comfortable participating. Conversely, in Rachel's class the norms of participation were so welcoming but relaxed that, while even ELs felt comfortable participating in whole-class discussions, the constant level of talking often made it hard for Rachel to focus her students' attention, and possibly to even be heard. Because of the student-centered nature of the TELLIS strategies, it is necessary that in addition to being taught how to foster scientific discourse in their classrooms, PSTs also receive explicit instruction on how to manage such conversations so that students have structured opportunities to engage in the discourse of science while maintaining an on-task and engaged lesson.

In sum, instructional frameworks like TELLIS can support PSTs in enacting language- and literacy-integrated science instruction in their science classrooms. Science teacher educators and researchers need to consider how to most effectively provide this type of instruction to PSTs to ensure that *all* students have access to the language-rich, rigorous science and engineering practices outlined in the NGSS. At the same time, teacher education does not occur in a vacuum. As this study points out, PSTs must navigate the contexts of their field experiences when learning to teach, and at time those contexts might contradict reform-oriented instructional practices espoused in teacher education programs (Thompson et al., 2013). As a result, PSTs need more training in how to navigate the contextual factors in student teaching classrooms that challenge their abilities to implement reform-oriented, language- and literacy-integrated science instruction. Indeed, even when MTs are open to PSTs trying new strategies in the classroom, the long-instituted norms of the classroom (and school generally) can create friction between the tools PSTs want to use to reach their object, and their community's receptiveness to doing so. As was the case with Erin, too great of a disconnect between teacher preparation instruction and field experiences can lead PSTs to simply adopt the instruction present in the field placement classroom and miss out on opportunities to practice reform-based practices espoused in university methods courses (Horn et al., 2008). However, Horn and colleagues argue that a slight misalignment between what PSTs learn in their method courses and what they experience in field experiences can become fodder for identity development that ultimately supports learning. That is, by providing explicit supports for mediating learning in teacher preparation programs and field experience activity systems, and the tensions between them, programs can support PSTs in developing their teacher identities (Horn et al., 2008). Thus, both teacher educators and researchers need to attend to this friction and identify ways to support PSTs in learning from it.

Limitations

Despite the rigor of the qualitative methods applied to analyze this study's data, there were limitations. First, because of the unique nature of individual PSTs' instruction and the limited use of the TELLIS Instructional Integration scoring rubric on PST instruction prior to the analysis, the rubric was in an iterative stage of refinement throughout its use as an analytical tool in this study. Indeed, one of the outcomes of this study was a more refined version of the rubric based on the participants' lessons. Despite this shortcoming, care was taken to analyze all lessons using the same and final version of the rubric to ensure consistency across lesson analysis and alignment with the data instrument presented in this manuscript.

By nature of the case study methods employed, the results of this study are not generalizable beyond the three PSTs' experiences. However, a strength of the case study analysis and use of activity theory in this study was that these methodological decisions provided a deep look at how the contexts in which PSTs teach support or hinder their ability to take up key instructional practices. In this way, this research not only addressed *if* PSTs could implement language and literacy integrated science instruction into their student teaching placements, but highlighted reasons as to *why* this might be the case. While future research is needed to determine if similar findings are evident in other contexts, these findings provide a starting point for teacher educators and researchers to consider as they design and implement secondary science PST training for teaching in linguistically diverse classrooms.

Conclusion

As schools become more linguistically diverse and standards call for increased attention to how language is used to do science, it is becoming increasingly imperative that all secondary science teachers are trained in how to teach language- and literacy-integrated science in linguistically diverse classrooms. This study suggests that, while PSTs are able to implement reform-based practices to an extent in linguistically diverse classrooms, more attention needs to be paid to how the contextualizing factors of those classrooms, including division of labor, norms, and community, impact PSTs' willingness to enact language- and literacy-integrated science, both in their student teaching placements and ultimately in their own classrooms. Attending to these factors can help teacher preparation programs prepare PSTs to meet the challenges that might otherwise constrain their attempts to enact language- and literacy-integrated science instruction, and can result in more equitable science learning for all students.

Research in the field of preparing secondary science PSTs for language- and literacy-integrated science instruction is still in its nascency. Interventions like TELLIS need to be furthered studied in teacher education programs to determine their efficacy across numerous settings. Further, studies need to investigate the long-term impacts of such training on PSTs' eventual instruction as teachers in their own classrooms, as well as on how that instruction impacts student learning. Finally, more research is needed to consider how the contextual factors associated with instructional implementation, especially MT training and competing institutional norms, can be supported or mitigated to encourage more alignment with language- and literacy-integrated science instruction. In doing so, researchers and teacher educators can take positive steps towards ensuring PSTs are prepared to meet the NGSS claim that science really is "for all" (NGSS Lead States, 2013).

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Tables

Table 1
Study Participants Self Descriptions

	Participants		
	Ana	Erin	Rachel
Gender	Female	Female	Female
Race	Hispanic	White	White
Age	24	27	22
Multilingual Repertoire	Bilingual English-Spanish	Fluent English, novice French and German	Bilingual English-Spanish, some ASL
Prior Teaching Experience	Teaching assistant in a special education-inclusive classroom	Instructor for 2 years in non-traditional environmental educational settings	Professional tutoring
Instructional setting	Tracked high school biology class **Race:** 7 Black, 8 Latino, 5 White, 5 Other **Languages Spoken:** Nepalese, Spanish, Arabic, Jamaican dialect **EL WIDA levels:** 2-4 **Learning Differences:** a few students with IEPS, but mostly 504s	Heterogeneous 6th grade general science class **Race:** Mostly White **Languages Spoken:** Nepalese, Spanish, Punjabi dialect **EL WIDA levels:** 5-6 **Learning Differences:** a few students with IEPS	Heterogeneous 7th grade life science class **Race:** 8 White, 6 Black, 3 Hispanic, 1 mixed race **Languages Spoken:** Spanish **EL WIDA levels:** 2-3 **Learning Differences:** Two students with IEPs; one student identified as gifted
Mentor Teacher (teaching experience / years teaching ELs)	Ms. Johnson (22 years/21 years)	Ms. Smith (12 years/12 years)	Ms. Raymond (25 years/13 years)

Note. The data in this table were reported by participants. Descriptors reflect the terminology they used. Mentor teachers provided data about their teaching experience. The remainder of the data, including demographic data for students in instructional settings, is based on PSTs' reports and was often recalled by memory, which is a limitation of this data. EL WIDA levels are based on results from an annual assessment that measure students' English language proficiency. IEP=individualized education program; ASL = American Sign Language

Table 2

Data Sources Used to Answer Research Questions

Research Question	Data Sources

To what extent did secondary science PSTs enact the TELLIS instructional framework during their student teaching experiences?	• Teaching Performance Assessment (TPA) Video Footage
	• TPA lesson plans and reflections
	• PST interviews
	    ○ Interview 1 (Part I, questions 4 & 5; Part II question 5)
	    ○ Interview 2 (question 9)
	• Mentor Teacher interviews (questions 15, 17-19)

How is PSTs' participation in different activity systems (i.e., their student teaching placements) associated with their enactment of the TELLIS instructional framework during their student teaching experiences?	• PST interviews
	    ○ Interview 1 (Part I, questions 2 & 3)
	    ○ Interview 2 (questions 7-12; 14-16)
	• Mentor teacher interviews (questions 4-8; 10-14)
	• PST student teaching reflections

In what ways do the mediating elements (i.e., tools, division of labor, rules, and community) of the student teaching activity systems operate within the system to support or constrain implementation of the TELLIS framework?	• PST interviews
	    ○ Interview 1 (Part I, questions 2 & 3)
	    ○ Interview 2 (questions 7-12; 14-16)
	• Mentor teacher interviews (questions 4-8; 10-14)
	• PST student teaching seminar reflections

Note. While individual interview questions are highlighted as sources for each research question, the semi-structured nature of interviews allows for data to come from any part of the interview.

Table 3

TELLIS Instructional Integration Scoring Rubric

Component	0: Not present	1: Beginning	2: Implementing	3: Extending
Discourse Inherent to Science **Score: ____** Teachers provide students with opportunities to observer and engage in discourse used for scientific purposes (i.e., argue from evidence, make observations, develop conclusions)	Teacher does not provide students with opportunities to engage in scientific discourse	Teacher provides opportunities for students to engage in discourse, but not through authentic scientific tasks or in the service of "doing" science. Opportunities occur in limited contexts **Examples:** turn and talk to report an answer to a question; answering an I-R-E question whole class	Teacher provides multiple opportunities for students to gain exposure to and practice how language is used to make and communicate scientific meaning (i.e., to "do" science) through authentic scientific tasks. **Examples:** Students discuss a scientific phenomenon with their peers, engage in scientific argument from evidence, report results.	Teacher provides multiple opportunities for students to engage in substantive, authentic conversations about complex scientific ideas or concepts. Structures are in place to ensure all students are participating. Teacher supports' students' metalinguistic awareness of scientific discourse and how language is used when doing science **Examples:** Same as Implementing but with discussion about how language is used to do a given task (i.e., scientific argument from evidence). Structures such as student roles or students holding unique information necessary for task performance support language use by all participants.
Opportunities for Literacy Development **Score: ___** Teacher provides opportunities for students to read and write for scientific purposes	Teacher does not provide students with opportunities to engage in reading or writing in the science classroom	Teacher provides students opportunities to read or write but not in the service of authentic scientific tasks **Examples:** writing lecture notes or reading test questions	Teacher incorporates authentic reading and writing tasks that engage students in scientific practices and meaning-making **Examples:** writing a scientific explanation, argument, procedure, etc.; reading a scientific article, procedure, conclusion, etc.	Teacher incorporates and supports students' metalinguistic awareness of linguistic features during authentic reading and writing tasks that engage students in scientific practices and meaning-making. **Examples:** Same as Implementing but with highlighting of linguistic features of a reading or writing (e.g., structure of an argument or science article, attention to passive voice, etc.) that supports students' understanding of the genre
Preferred Language as an Instructional Support	Teacher does not encourage or provide opportunities for the use of students'	Teacher support of preferred language integration is implicit and cursory, with no active encouragement of preferred language	Teacher takes actionable steps to explicitly encourage the use of preferred language as a tool for students to use to make meaning and express understanding during	Teacher explicitly encourages the use of preferred languages to make meaning during scientific tasks and to express understanding. Teacher

Score: __ Teacher encourages use of students' preferred languages during class activities and integrates preferred languages as able through instruction or instructional resources.	preferred language during instruction and meaning-making.	use and decontextualized mentions of cognates for vocabulary building. Preferred language is not actively positioned as a tool for meaning-making. **Example:** Tools (such as bilingual dictionaries, access to Google translate) are available but not actively encouraged; teacher "allows" use of preferred language but does not encourage it; teacher occasionally incorporates a cognate while teaching	authentic scientific tasks individually or in small group settings. Tools to support preferred language use might be highlighted and encouraged. **Example:** Teacher tells students to use preferred language or, if bilingual, engages in meaning-making conversations with students in a preferred language. Preferred language is used in individual or small groups settings to make meaning, but share-out to the whole class is expected to be done in English. Teachers may encourage the use of Google translate or bilingual dictionaries to support understanding.	disrupts bilingual norms by positioning use of preferred languages as an equally important way to make and share meaning in the science classroom, as opposed to as a vehicle for English expression. **Example:** Teacher not only encourages preferred language use but positions it as an equally important way of making and sharing meaning. Use of preferred language may extend beyond individual or small group settings and is welcomed as an equal form of expression.
Contextualized Learning **Score: ____** Teacher connects content and classroom activities to students' lives, interests, and funds of knowledge.	Teacher makes no connection to students' lives, interests, or funds of knowledge.	Teacher makes brief or broad connections to students' lives, interests, or funds of knowledge but in a cursory way that does not frame or guide instruction. **Example:** funds of knowledge as exemplars or add-ons	Teacher makes consistent and explicit connections between scientific content and students' lives, interests, and funds of knowledge. Student input is elicited and integrated into the planned curriculum. **Example:** PST infuses the lesson with recent events that are related to students' immediate contexts	Teacher makes consistent and explicit connections between scientific content and students' lives, interests, and funds of knowledge, and uses that information to frame the lesson. Teacher elicits and is responsive to student input, adapting curriculum to align with student responses. **Example:** Student input is responded to as it arises and is used to guide lesson trajectory (i.e., student input is guiding the lesson, rather than being integrated into original lesson)
Strategies for Language Understanding and Use **Score: ____** Teacher integrates ESOL or other strategies designed specifically to	Teacher does not integrate EL strategies to support students learning.	Teacher integrates strategies but integration lacks awareness of the full (i.e., input and output) linguistic demands of the content OR serves to simplify content (rather than amplify support).	Teacher uses EL strategies relevant to the full (i.e., input and output) linguistic demands of the lesson and to the needs of the students as a group in order to support ELs' language understanding and use and to provide access to and opportunities for engagement in rigorous scientific content.	Teacher uses EL strategies relevant to the full (i.e., input and output) linguistic demands of the lesson and to the needs of individual students in order to support ELs' language understanding and use as they engage in rigorous scientific content. Observable evidence of how the teacher is using scaffolding to support

support students' abilities to understand and use the language of the classroom.		**Example:** Integration of a strategy that is not directly related to supporting linguistic needs; strategies serve to simplify content or practice so that ELs are not participating to the same extent as other students.	**Example:** Chosen strategies are appropriate for the task and general level of support required.	student growth towards more independence is present. **Example:** PST provides supports with reference to the needs of individual students; supports are slowly removed as students develop.
Rigorous, Age-Appropriate Science and Engineering Practices for Learning and Doing Science **Score: ___**	Students are not asked to engage in science and engineering practices for learning and doing science.	Students are asked to engage in science and engineering practices for learning and doing science, but do so in a cursory way that lacks rigor or does not align with grade-level expectations. **Example:** Students are asked to write a prediction but are not asked to support their prediction with reasoning; students complete "cookie cutter" lab with little scientific reasoning	Students are asked to engage in age-appropriate, rigorous science and engineering practices for learning and doing science as part of the lesson. **Example:** Students engage in authentic scientific investigation; students develop arguments from evidence or create models based on scientific principles.	Engagement in authentic, age-appropriate, rigorous science and engineering practices for learning and doing science drives the entirety of the lesson and provides students multiple opportunities to make meaning as they "do" science. **Example:** The entirety of the lesson is based around students' engagement in scientific practices, i.e., students identify or are presented with a question at the beginning of class and engage in scientific practices to generate evidence and develop conclusions backed by evidence.

Table 4
Extent to Which PSTs Enacted TELLIS Instruction

	Discourse	Literacy	Multi-lingualism	Context-ualization	Strategies	Rigor
Ana						
Lesson 1*	1	2	2	0	1	2
Lesson 2	1.5	2	2.5	1	1.5	1
Lesson 3	1.5	1.5	2	2	1	2
Lesson 4	1	2	2	1	1	2
Average	*1.3*	*1.9*	*2.1*	*1*	*1.1*	*1.8*
Highest Score	**1.5**	**2**	**2.5**	**2**	**1.5**	**2**
Erin						
Lesson 1	1.5	1.5	0	2	2	1
Lesson 2*	2	1.5	0	2	1	2
Lesson 3	2	0	0	2	2	2
Lesson 4	2	2	0	1	1.5	2
Average	*1.9*	*1.3*	*0*	*1.8*	*1.6*	*1.8*
Highest Score	**2**	**2**	**0**	**2**	**2**	**2**
Rachel						
Lesson 1	2	1.5	0	2	2	2
Lesson 2	1	1.5	0	2.5	2	1
Lesson 3	1.5	2	0	1	1.5	2
Lesson 4	1	1	0	2	1.5	.5
Average	*1.4*	*1.5*	*0*	*1.9*	*1.8*	*1.4*
Highest Score	**2**	**2**	**0**	**2.5**	**2**	**2**

Note. 0 = Not present; 1 = Beginning; 2 = Implementing; 3 = Extending; * indicates the lesson recording was incomplete due to technical issues.

Figures

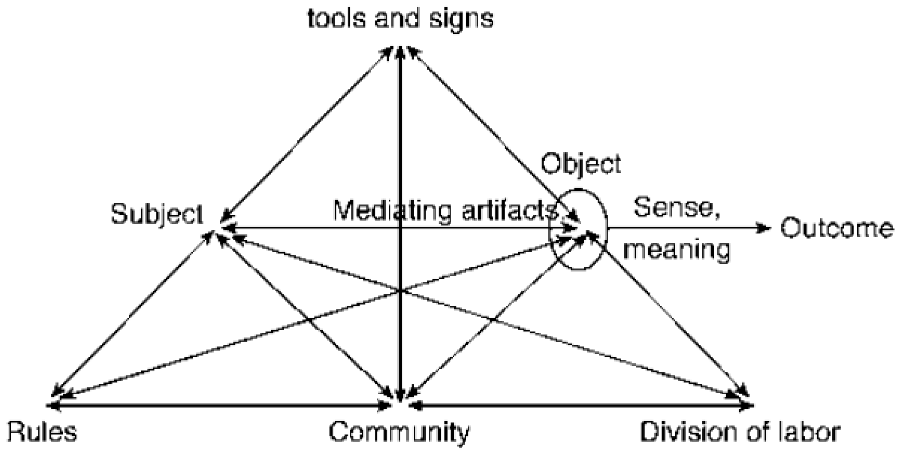


Figure 1. CHAT model (Engeström, 1987, p. 78)

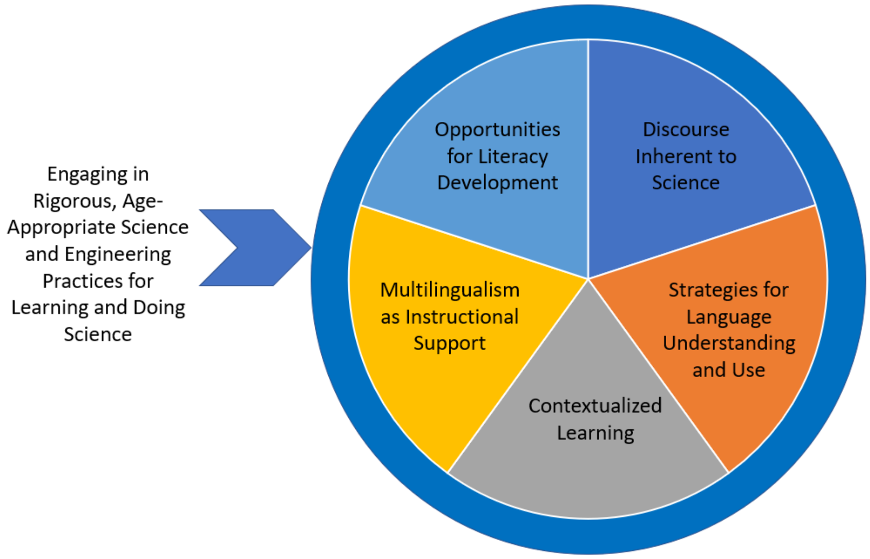


Figure 2. TELLIS instructional framework.

Appendix A

Example Language and Literacy Integrated Science Methods Lesson

Science Instructional Method: Predict-Observe-Explain Model
Targeted TELLIS Component: Discourse Inherent to Science

Summary of Science Instructional Method: This lesson is designed to introduce PSTs to the Predict-Observe-Explain (POE) model of inductive science learning (Alexander, Haysom, & Bowen, 2010). In the POE model, students are presented with a challenging question that is answered through an experiment. Prior to the experiment, students are asked to ***predict*** what they think will happen during the experiment and why. Then, students ***observe*** what occurs during the experiment, either as conducted by the teacher or through their own enactment. Finally, students work with their peers to ***explain*** using evidence what happened, with the ultimate goal of answering the initial challenging question. The POE model lends itself to the use of scientific discourse because students are making meaning through scientific activity and interaction with peers. Students to need to use language as they make predictions, record and discuss observations, and develop and justify with evidence their explanations.

Summary of Lesson: This lesson was adopted from McCarthy's (2014) lesson on air pressure. During this lesson, PSTs engage as students to answer the question, *how does a straw work?* Following an introduction to the overarching question and the experiments (see Steps 1 and 2, below), PSTs participate in one of two concurrently running experiments that are designed to work in tandem to answer the overarching question. In this enactment of the lesson, two groups of three students were assigned one of the two experiments, so that each experiment was completed by two separate groups. The lab sheets that guided the experiments (see below) provided numerous opportunities for students to engage in discourse throughout the POE sequence. Each lab table was also provided with 8x11 sheets of sentence frames for optional use during their discussions with their peers (see below). Following the completion of the experiments, one group from each experiment met together to share what they had observed and to explain their results. Then, the two groups had to work together using both groups' findings to answer the target question, *how does a straw work*? In this particular rendition of the lesson, the instructor stopped the lesson here and briefly discussed the PSTs' findings to the lab. Then, PSTs participated in small-group and whole-class meta-pedagogical discussions about the POE method and all of the TELLIS strategies, with an emphasis on the opportunities provided in the lesson for using discourse inherent to science. PSTs discussed how the lesson as a whole provided opportunities for science and language development, and highlighted and responded to the challenges that might arise when using POE and discourse inherent to science in linguistically diverse secondary science classrooms.

Steps in the Lesson

Step 1: Orientation and Motivation

(Hold up a straw) How many of you have seen one of these before? What is it? How many of you have used one of these before? For what do we use it? According to the some estimates, we use 500 million drinking straws in the United States per day. Have you ever stopped to think about how these work? Today we will.

Step 2: Introducing the Experiment

We use straws often, yet it is rare that we ever stop to think about how they work. Today we're going to do a lab where we try to answer the question, *how does a straw work?* As with most things, there is a scientific answer to this question.

Steps 3-6: Prediction-Observation-Explanation Cycle

Two groups of three will do the finger over the opening activity and two groups will do the drinking from a straw activity. They will progress through their lab sheet and then prepare to share their findings with one of the groups doing the opposite lab (see lab sheet for details). When they are done sharing, they will individually answer on their lab sheets the target question "How does a straw work" using the information they collected and their peers' reports. Then, they will have a small group discussion in which each person shares his/her idea and the group argues with evidence to come to a group conclusion about how straws work. Each group would submit their conclusion on Peardeck for the class to review.

Step 7: Providing a Scientific Explanation

This part will be talked about but not actually completed. The instructor will note that it is important for students to compare their findings to what scientists have to say on the topic. There are a variety of ways the instructor can support the students in doing so, including:

- Asking students to surf the internet to find scientific explanations for the phenomenon
- Identifying a reading on the topic for students to read and find the answer
- Showing a video (something like this video that gives good visuals, though don't start it until 00:15, and mute it to provide commentary.
- Explain it herself: "If you were to ask a scientist our question, how do straws work, she would tell you that it all has to do with air pressure. . . "

Finally, extend students' learning by asking them what the purpose of the hole in the top of a water bottle with a straw is.

Predict-Observe-Explain Instructional Model
Experiment One

<u>Main Question</u>:
How does a straw work?

<u>Materials</u>
Goggles, 1 straw, 1 plastic cup, Water, 1 straight pin or pushpin, food coloring

<u>Part 1</u>

Predict:

- What will happen when you place your finger over the top of the straw and lift the straw out of the water? Explain why you think this will happen. Be sure to use scientific language (see language chart [predicting] for help).

- SHARE your predictions and your reasoning with your team. Look for similarities and discuss the differences. Remember, there is no such thing as a bad idea! After your discussion, think about your prediction again. Did your prediction change based on what your heard from your peers? If so, write your new prediction here.

Observe:

- Fill your cup about halfway with water and place your straw in the cup. You may add 3 drops of food coloring to better see your water.
- With you finger covering the top of the straw, lift the straw out of the water. Do this several times. Record your observations.

Explain:

- Explain what you observed. Why do you think that happened? Be sure to use scientific language (see language chart [explaining or drawing conclusions]). Draw a model of your explanation.

- Is your prediction supported by your observations/data?

Part 2

- Now, poke a hole in the straw about 2 cm from one end of the straw.
- Place the straw in the cup of water, ***with the hole you poked above the water***.

Predict:

- What will happen when you place your finger over the top of the straw and lift the straw out of the water as before? Explain why you think this will happen. Be sure to use scientific language (see language chart [predicting] for help).

- SHARE your predictions and your reasoning with your team. Look for similarities and discuss the differences. Remember, there is no such thing as a bad idea! After your discussion, think about your prediction again. Did your prediction change based on what your heard from your peers? If so, write your new prediction here.

Observe:

- With you finger covering the top of the straw, lift the straw out of the water. Do this several times. Record your observations.

Explain:

- Explain your observations. Be sure to use scientific language (see language chart [explaining or drawing conclusions]). Draw a model of your explanation.

- Is your prediction supported by your observations/data?

Part 3

- Turn the straw upside down.
- Place the straw in the plastic cup ***with the hole you poked under the water***.

Predict:

- What will happen when you place your finger over the top of the straw and lift the straw out of the water as before? Explain why you think this will happen. Be sure to use scientific language (see language chart [predicting] for help).

- SHARE your predictions and your reasoning with your team. Look for similarities and discuss the differences. Remember, there is no such thing as a bad idea! After your discussion, think about your prediction again. Did your prediction change based on what your heard from your peers? If so, write your new prediction here.

Observe:

- With your finger covering the top of the straw, lift the straw out of the water. Do this several times. Observe, and record your observations.

Explain:

- Explain your observations. Be sure to use scientific language (see language chart [explaining or drawing conclusions]). Draw a model of your explanation.

- Is your prediction supported by your observations/data?

Prepare to Report!

Your team will need to share your findings and conclusions with a team who did a different lab activity. *Each person on the team will need to share one part of the report.* Take the time now to prepare your team's report. Jot down notes to remind yourself of what you want to say when it's your turn. Remember to use scientific language (see language chart for help).

1. Provide an overview of your activity. What did you have to do?

2. Describe your observations/findings. How did the water behave when there was no hole versus when there was a hole above the water versus when there was a hole below the water?

3. Provide your team's conclusions for the water's behavior.

Question: How does a straw work?
Answer (based on your observations and what you learned from your peers):

Predict-Observe-Explain Instructional Model
Experiment Two

Main Question:
How does a straw work?

Materials
Goggles, 1 straw, 1 plastic cup, Water, 1 straight pin or pushpin, food coloring (if you want)

Part 1

- Fill your cup about halfway with water.
- Place a straw in the cup.

Predict:

- What will happen when you sip through the straw? Explain why you think this will happen. Be sure to use scientific language (see language chart [predicting] for help).

- SHARE your predictions and your reasoning with your team. Look for similarities and discuss the differences. Remember, there is no such thing as a bad idea! After your discussion, think about your prediction again. Did your prediction change based on what your heard from your peers? If so, write your new prediction here.

Observe:

- Sip through the straw.
- Record your observations.

Explain:

- Explain what occurred. Be sure to use scientific language (see language chart [explaining or drawing conclusions]). Draw a model of your explanation.

- Is your prediction supported by data/observations?

Part 2

- Remove the straw from the water.
- Use the pin to poke a hole in the straw about 2 cm from one end and place the straw in the cup ***with the hole you poked above the water.***

Predict:

- What will happen when you sip through the straw? Explain why you think this will happen. Be sure to use scientific language (see language chart [predicting] for help).

- SHARE your predictions and your reasoning with your team. Look for similarities and discuss the differences. Remember, there is no such thing as a bad idea! After your discussion, think about your prediction again. Did your prediction change based on what your heard from your peers? If so, write your new prediction here.

Observe:

- Sip through the straw.
- Record your observations.

Explain:

- Explain what occurred. Be sure to use scientific language (see language chart [explaining or drawing conclusions]). Draw a model of your explanation.

- Is your prediction supported by data/observations?

Part 3:

- Turn the straw upside-down so that ***the hole you poked is in the water***.

Predict:

- What will happen when you sip through the straw? Explain why you think this will happen. Be sure to use scientific language (see language chart [predicting] for help).

- SHARE your predictions and your reasoning with your team. Look for similarities and discuss the differences. Remember, there is no such thing as a bad idea! After your discussion, think about your prediction again. Did your prediction change based on what your heard from your peers? If so, write your new prediction here.

Observe:

- Sip through the straw.
- Observe, and record your observations.

Discuss and Explain:

- Explain what occurred. Be sure to use scientific language (see language chart [explaining or drawing conclusions]).

- Is your prediction supported by data/observations?

Prepare to Report!

Your team will need to share your findings and conclusions with a team who did a different lab activity. *Each person on the team will need to share one part of the report.* Take the time now to prepare your team's report. Jot down notes to remind yourself of what you want to say when it's your turn. Remember to use scientific language (see language chart for help).

1. Provide an overview of your activity. What did you have to do?

2. Describe your observations/findings. How did the water behave when there was no hole versus when there was a hole above the water versus when there was a hole below the water?

3. Provide your team's conclusions for the water's behavior.

Question: How does a straw work?
Answer (based on your observations and what you learned from your peers):

Let's Talk!

Agreeing	**Disagreeing**
I agree with ______ because______ _______'s point about ______ was important because… The evidence for ______ is strong when you consider that ______ . _______ and I are coming from the same position because ________	I see it differently because _______ The evidence I've seen suggests something different. Some of that is fact, but some of it is opinion as well. For example, _________ I agree that _______, but we also have to consider that_____. We see _______ differently.
Building On _______ mentioned that_______ . I think _______. Yes–and furthermore, _______ The claim that _______ is interesting because _______ Adding to what _______ said, _______	**Summarizing** Overall, what I'm trying to say is _______. My whole point in one sentence is _______. More than anything else, I believe that _______
Comparing and Contrasting ______ is similar to _____ in that _____. _______ is different than ____ because _____. There are many similarities/differences between ___ and ___. For example, _____ Similarities/differences between ____ and ____ include____.	

Adapted from the following sources:
https://www.teachthought.com/critical-thinking/sentence-stems-higher-level-conversation-classroom/
http://www.thinksrsd.com/wp-content/uploads/2014/02/CER-Sentence-Starters-CER.pdf
http://literacy.dpsnc.net/five-pillars/writing/sentence-frames

Let's Talk Science!

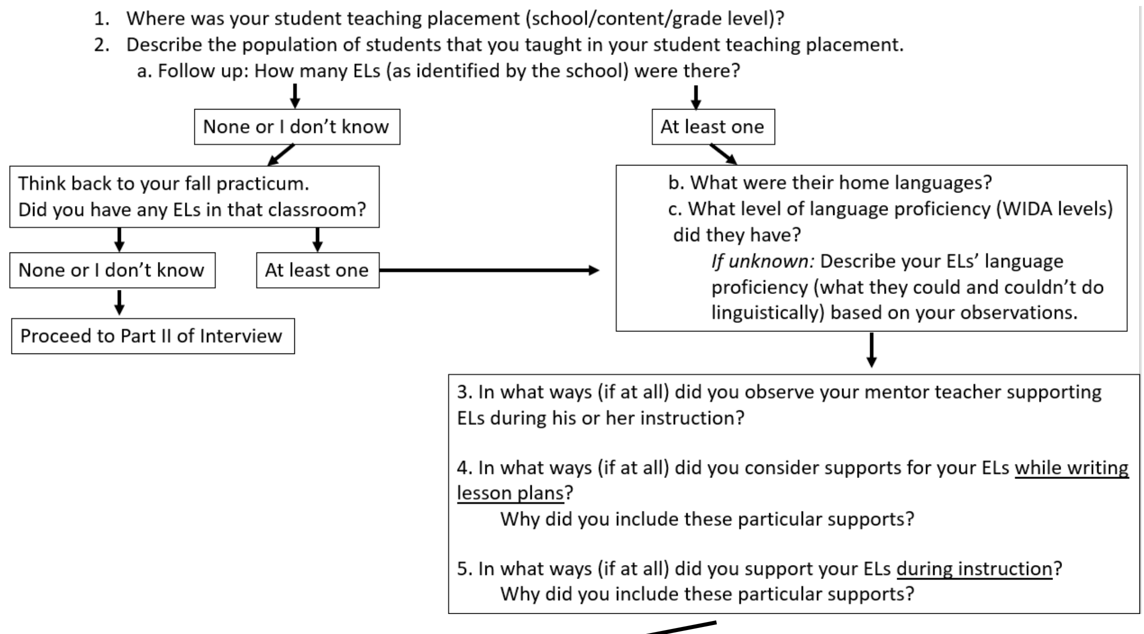
Predicting I predict _____ because______ I think _____ will ______. Because I already know ____, I predict … Because ______, I predict that…	**Making Observations** I observed that ______. I noticed that _______. When _____, I observed ______
Reporting Results From my experiment I found ____________. The data show that ________. The results of my experiment show that _______. In the text we found that __________.	**Drawing Conclusions** Based on ________, I can conclude ______ The data indicated ____. Therefore, I conclude… Based on the data, my hypothesis/prediction is ____ because ______ I conclude that ______. I believe this because______ My findings suggest that_____, so I conclude ______
Explaining _____ behaved this way because _____. _____ occurred because ______. _____ means _____ because _____.	**Arguing from Evidence** I think _____. The evidence I have to support my idea is____. The data suggest that _____. Therefore, I think ____. As we just saw in the experiment, ____ does ____ due to ______. Based on _____, I think ____. I don't think the evidence supports ___ because ____

Adapted from the following sources:
https://www.teachthought.com/critical-thinking/sentence-stems-higher-level-conversation-classroom/
http://www.thinksrsd.com/wp-content/uploads/2014/02/CER-Sentence-Starters-CER.pdf
http://literacy.dpsnc.net/five-pillars/writing/sentence-frames

Appendix B
PST Interview 1 Protocol

<u>Part One:</u>

Tell participant: *The first set of questions will address your experience in your recently completed student teaching placement. English Learners refer to students who do not speak English as their first language AND have been identified by the school as an EL (often meaning that the student is still developing the language skills needed to be fully successful in school).*



<u>Part Two:</u>

Tell participant: *This next set of questions will address the preparation you received for teaching ELs in secondary science classrooms.*

1. How well-prepared do you feel to teach ELs in a linguistically diverse secondary science classroom?
    a. What influenced those feelings/made you feel that way?
2. Do you think you can be an effective teacher of ELs in a linguistically diverse classroom? Why or why not?
3. What does language and literacy-integrated science instruction mean to you?
4. *(show framework of language and literacy-integrated science instruction)* Can you briefly describe each of these components to me and how each would be used in the science classroom?
    a. Which of these do you think is easiest to incorporate in a linguistically diverse classroom and why?
    b. Which is hardest and why?
5. (For those with ELs in their classrooms)
    a. Which of these did you integrate most often? Why?

   b. Which did you integrate least often? Why?
6. In your opinion, what does good science instruction look like for ELs?
   a. *(alternative wording)* If you were teaching in a linguistically diverse secondary science classroom with numerous ELs, what strategies might you use to support your ELs' learning?

How does language and literacy-integrated science instruction for ELs align with or not align with your understanding of quality, rigorous science instruction?

Appendix C
PST Interview 2 Protocol

The first questions I'm going to ask you are going to be directly related to the lessons I observed you teaching.

1. I observed the following lessons [describe lessons]: Was this lesson typical of how you taught this class during your student teaching experience? Why or why not?
    a. Participant One only: The second lesson I observed was not your own. What would you have done differently if you had been teaching this topic? Why?

2. How if at all was this lesson different from the lesson you taught your students in your other blocks (classes with non-ELs)?

3. What specific strategies did you integrate into this lesson to support your ELs?

4. Participants One and Two for second lessons only:

    a. What do you think went well?
    b. What could have gone better/what would you have done differently?
    c. How well did your students learn?
    d. How well did your ELs learn?

5. Participant Two only: I noticed that you would sometimes engage with your Spanish speakers in Spanish, and sometimes in English. Why did you make the pedagogical choice to sometimes speak in Spanish, and other times speak in English (what informed your decision)?

6. Participant Two only: Do you have a doc camera?

The next set of questions will deal with your teaching during the student teaching experience generally and do not need to specifically speak to the lessons I observed.

1. Please describe the demographics of the class that I observed.

2. How do those demographics support and/or not support your ability to effectively instruct ELs?

3. What strategies did you use most often to support the ELs in your classroom? Why did you choose those strategies?

4. What role did your MT take while you were teaching? The aid?

5. How receptive do you think the MT was to your planning and instructional ideas?

6. What were your MT's perspectives on the components of language and literacy integrated science (show framework)?

7. Consider your instruction while you were student teaching. In what ways was it different than how you hope to teach when you are in a classroom of your own? In what ways was it the same?
    a. No consider these same questions with regards to instruction of ELs.

8. I am going give you slips of paper with factors written on them that may have affected how effectively you were able to teach your ELs, for better or worse. Please organize them in order from greatest impact on your ability to effectively teach ELs (positively or negatively), to least impact.
    a. School culture/climate
    b. MT expectations
    c. Classroom demographics
    d. The ELs themselves
    e. Multilingual methods course
    f. Science methods courses
    g. Language and literacies course
    h. Experience working with ELs
    i. Past life experiences
    j. Past educational experiences (as a K-12 student)
    k. Beliefs about good science instruction
    l. Resource personnel (aids, ESL teachers, etc.)
    m. Resources
    n. Curricular expectations (e.g., SOLs)
    o. Knowledge of another language
    p. Classroom behavior

9. Is there anything missing that should be added (bring strips of paper to do so)?

10. Ask probing questions about each item. Why did you put X first? Y last? Tell me more about Z

The last question has to do with your perspective on the future.

1. Now that you are at the end of your teaching preparation and have had experience in science classrooms, what sort of class do you see yourself teaching in the future (grade level, demographics, level, etc.)? Why?

Appendix D

Mentor Teacher Interview Protocol

The first set of questions have to do with your own teaching experience and beliefs.

1. How many years have you been teaching?
    a. What subject areas?
    b. What grade levels?
    c. What school(s)?
2. How long have you been teaching classes with ELs in them?
3. How confident do you feel in your ability to effectively teach ELs in your classroom? Explain.
4. Describe the demographics of the classes you taught last year.
    a. Did you teach any ELs?
    b. If so, do you know what their English proficiency is (e.g., their WIDA levels)?
        i. If no, is there a reason for not knowing (e.g., student hasn't been tested)?
        ii. If no, can you describe their language proficiency based on your own observations?
5. What does good science instruction look like to you?
6. What does good science instruction for ELs look like to you?
7. In practice, in what ways did you try to meet the needs of your ELs?
8. *Show TELLIS framework*. This is the framework we worked with in our science methods course. *Explain each component*.
    a. In considering your experience teaching science to ELs in your high school classrooms, what is your perspective on these components?
    b. Which if any of these do you think you do the most in your classroom?
    c. Which if any do you think you do the least or wish you could do better?

The next set of questions have to do with [your school] in general.

9. How are students placed in science courses (tracking)?
    a. Which courses did you and [PST] teach?
    b. What are the requirements for students to be placed in those classes?
10. How does [school] work with ELs? What systems do they have in place? Resources? ESL teachers?
11. What is [school's] stance on using home languages in the classroom?
12. What training, if any, has [school] provided you for teaching science to ELs?

The next set of questions directly relate to [PST's] time as your student teacher.

13. What were your expectations for [PST] during her student teaching experience?
14. What role did you take when [PST] was teaching?
    a. What was the division of labor like when she was lead teacher?
15. Describe [PST's] instruction (big picture).
16. How well prepared was [PST] to meet the needs of the ELs in your classroom? Explain.

17. In what ways did you see [PST] attempt to meet the needs of his/her ELs through his or her *lesson planning*?
18. In what ways did you see [PST] attempt to meet the needs of his/her ELs through his or her *instruction*?
19. *Show TELLIS framework again and quickly summarize components*. Which of these did you see [PST] integrate best? Which were a challenge for him/her or did s/he not use?
20. In your opinion, how effective was [PST] in teaching science to the ELs in your classroom?
    a. What did s/he do well?
    b. With what did s/he struggle/ what are areas for growth?