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Supporting Science Learning for English Language Learners

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Abstract

This study focused on two fourth-grade science classrooms with English learners (ELs), exploring how teachers supported students' science and language/literacy learning in different language contexts. Three a priori research-based practices recommended for supporting science learning framed our exploration: (a) negotiation, opportunities for individual and social construction and critique of knowledge; (b) embedded language, opportunities for language and literacy learning as a natural aspect of science; and (c) non-threatening learning environments, opportunities for social apprenticeship and interaction. We provide insights into how science instructional practices supported ELs' science and language learning. One key implication is that enacting these three principles of practice in students' first language (Spanish), when less linguistic scaffolding is required, creates more opportunities to focus on disciplinary content and exploration of students' ideas. The second key implication is that using open-ended questions and extending prompts and questions through exploration-based lessons was an effective way to support and guide ELs (and all students) to rich understandings of key concepts. A third key implication is that although teachers delivered instruction in two different languages, when they enacted these principles, they fostered student engagement and interest in science. Effective implementation of these practices outweighed the language of delivery.

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Keywords: *science learning; English language learning; negotiation; embedded language; non-threatening environments*

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Introduction

Expanding science instruction so all students access and engage in science learning is an important goal of many science standards. These standards often present science as a set of practices that students engage in through writing, talking, thinking, and reading as they learn science concepts and skills. Engagement in these practices increases students' understanding of science content knowledge as well as the nature of the discipline of science (Francis & Stephens, 2018; MacDonald et al., 2017). Embedded in these authentic experiences of science is the language of science. Research (Grapin et al., 2019; Hand et al., 2018) has shown that the language elements of science are essential to carrying out scientific inquiry. Authentic science experiences in elementary classrooms improve students' learning of science as they engage with science content and practice using language (Hand et al., 2018) and high-quality integration of language and science instruction can result in student gains in science understanding, vocabulary, and writing (Ardasheva & Tretter, 2017; Chen et al., 2016).

Deciphering science texts and comprehending science concepts may be particularly difficult for English learners (ELs) as academic language and scientific terminology may be abstract, complicated, or overly technical (Symons et al., 2017). Engaging ELs in science instruction that deliberately includes a focus on disciplinary language may improve ELs' academic achievement and understanding of the academic language of science (Lee & Stephens, 2020). With increasing numbers of ELs in classrooms, all teachers are encouraged to support language learning while teaching content. However, science teachers may not feel confident about teaching language (Hand et al., 2018; Johnson et al., 2016). Rather than teaching language in isolation, content teachers should focus on providing opportunities to develop language while engaging in science learning. This content-based language instruction allows teachers to cover both science content objectives and necessary language objectives (Gottlieb & Ernst-Slavit, 2014). Lee et al. (2013) stress that teachers should strive to "encourage and support language use in the service of making sense of science" (p. 231); focusing on language in science will support science learning (Lee & Stephens, 2020). When teachers communicate to their students explicitly what the language of science entails and how it is used, students may be better able to both understand and use the language of science (Grapin et al., 2019).

Guided by three a priori research-based practices, this study focused on two fourth grade science classrooms with ELs where we explored teachers' support of students' science and language/literacy learning in different language contexts. Ms. Pole (all names are pseudonyms) instructed in English with supports in Spanish, primarily through cognates and bilingual books. By contrast, Ms. Martinez taught half the day in Spanish (science and mathematics) and the other half in English (language arts and social studies) with periodic bridging across languages (Beeman & Urow, 2012). By studying the use of these practices during science instruction in contrasting classrooms, we investigated the roles these practices play in furthering ELs' language development and scientific understanding.

Study Background

A number of researchers (Francis & Stephens, 2018; Lee & Stephens, 2020; MacDonald et al., 2017) recommend science instruction that provides opportunities for ELs to develop their language skills while engaging in science learning. Strategies to support this integration can include: (a) *negotiation*, opportunities for individual and social construction and critique of knowledge; (b) *embedded language*, opportunities for language and literacy learning as a natural aspect of science; and (c) *non-threatening learning environments*, opportunities for social apprenticeship and interaction (Ardasheva et al., 2015; Salloum & BouJaoude, 2017; Symons et al., 2017). Here we briefly define these three research-based principles recommended for supporting science and language learning for all students, but particularly for ELs. For an in-depth grounding of these practices across the literature for teaching ELs, science education, teacher preparation, and multicultural education, see Ardasheva et al. (2015).

Negotiation

As students and teachers move between the various types of language present in a science lesson, which may include everyday language, scientific terminology, and technical explanations, they need opportunities to negotiate between these various languages (Grapin et al., 2019; Francis & Stephens, 2018). Reconciliation between the different discourses occurring when teaching and learning science requires "negotiation as a means to construct understanding" (Hand et al., 2016, p. 849). Constructing explanations and engaging in argument based on evidence, two recommended science and engineering practices, require negotiation among students and between students and the teacher. Salloum and BouJaoude (2017), for example, found that teacher-student interactions focused on explicitly connecting new content to prior academic experiences or funds of knowledge through negotiation contributed to enhancing ELs' conceptual understandings. Discourse dominated by the teacher, on the other hand, shifted emphasis of instruction from inquiry-based thinking to less demanding cognitive processes such as memorization, which contradicts the expectations of current science instruction. Wu et al. (2019) reported similar benefits of negotiating meaning through multiple language modalities (visuals, natural language, mathematical expressions, manual-technical operations).

Embedded Language

As Hand et al. (2018) stress, oral language, reading, and writing are essential aspects of scientific practices. Constructing and understanding graphs, equations, tables, diagrams, and models are also critical pieces of doing science (Hand et al., 2016). When language instruction is embedded in science instruction, students have opportunities to practice language skills as they carry out science learning, improving in both areas (Lee et al., 2013). Work in this area (Ardasheva & Tretter, 2017; Grapin et al., 2019; Puzio et al., 2016) shows that employing implicit science vocabulary instruction allows ELs opportunities to define academic terms in their own words and based upon their developing understandings. Embedded language strategies provide instruction in science vocabulary and engagement in scientific discourse by simultaneously supporting science content learning and developing academic discourse skills needed for comprehending, participating, and achieving in science (Llosa et al., 2016). Symons et al. (2017), for example, found that embedding metalanguage and grammar analysis into science instruction turned ELs into active readers able to effectively interact with complex, information-rich and organizationally dense science texts. Hand et al. (2016) and Aguirre-Muñoz and Gregory (2019), two studies conducted in, respectively, English-medium and dual-language contexts, reported the benefits of enhancing science and literacy achievement through language embeddedness for authentic purposes.

Non-Threatening Environment

Accommodating classroom environments where ELs demonstrate their understandings through multiple means of expression and varied assessment formats can enhance language and content learning (de Araujo et al., 2018; Grapin et al., 2019). When ELs have opportunities to engage in science in a supportive classroom environment, researchers have observed improvement in their language development as they enact scientific practices such as asking questions, carrying out investigations, and devising explanations (Ernst-Slavit & Pratt, 2017). Salloum and BouJaoude (2017) found that creating student-centered learning environments helps bridge language differences between the student, the teacher, and the content via "a constructive partnership and sense of community" (p. 26). Francis and Stephens (2018) highlight strategies for teachers to use in supportive classroom environments where ELs are actively learning science and language skills such as allowing students who speak the same native language to support each other and using cognates to establish connections between first and second languages (L1 and L2). González-Howard and McNeill (2016) found that students were more likely to engage in science when working in small groups and when given the opportunity to use native language supports. Non-threatening, nurturing environments fulfilling students' cognitive, linguistic, and socioemotional needs contribute to higher academic achievement and motivation to learn science among bilingual students (Kadir et al., 2018).

Research Questions

In order to bridge theory to practice, we documented how the principles of negotiation, embedded language, and non-threatening environments, employed by two experienced teachers, supported ELs' science learning. Research questions driving this case study were:

1. How do teachers enact negotiation, embedded language, and non-threatening environments to support ELs' science learning?
2. What differences, if any, might be observed in how these principles of practice are enacted in a Structured Immersion (SI) versus a Developmental Bilingual Education (DBE) classroom?

Methodology

We used multiple-case study methodology (Yin, 2012) to explore the instructional approaches of two teachers in two different instructional contexts. Through in-depth investigation employing classroom observations, recordings, classroom artifacts, and teacher interviews focused on how the teachers integrated science and language instruction, we were able to identify successful science instructional practices for ELs. Additionally, comparisons between the SI and DBE classrooms allowed for identification of a larger variety of uses for these strategies in supporting ELs' and all students' science learning.

Participants, Context, and Units of Instruction

This study focused on two fourth-grade classrooms in a high-poverty elementary school located in the U.S. Pacific Northwest where 95% of students receive free and reduced-price lunch. The school serves large populations of EL (59%) and migrant (37%) students. The school provides DBE for Spanish-speaking ELs who earn high scores on standardized tests and places low-scoring Spanish speakers and non-Spanish-speaking ELs in an SI program. Both female teachers in this study have worked with 100+ ELs over their careers and have had GLAD (Guided Language Acquisition Design) professional development.

Structured Immersion (SI) Classroom

Ms. Pole taught in an SI classroom of 20 students (eight girls and 12 boys), with 17 classified as ELs. Students' home languages included Spanish, Russian, Arabic, and Thai. Ms. Pole had over 6 years of teaching experience, a bachelor's degree in education, and extensive professional development in teaching ELs. During the time of the study, she served as a GLAD coach for her school and was working on her master's degree in educational leadership. Her classroom was decorated with student work and collaboratively created charts, maps, and posters of chants and songs. Students sat in table groups of mixed-ability, mixed-gender, and mixed cultural background that changed every two months. Ms. Pole grouped beginner and more advanced English speakers who shared the same L1 together. In addition to table groups, a large carpeted area served as a gathering space for the whole class, and a small table in the back of the room was reserved for teacher-led small group instruction.

The solar system unit, from which one lesson is focal for the present study, spanned a six-week period and consisted of two to three lessons per week which lasted between 30 to 150 minutes. There was no textbook or adopted science curriculum for this unit; the teacher used materials she had gathered from other sources or written herself. This Earth and space science unit focused on fostering students' understanding of the Earth's systems in comparison to those of the sun, the moon, and other planets in our solar system, as well as on the professions associated with Earth and space science. Multiple resources were used during the unit, such as charts, trade books, graphic organizers, and various models of the solar system. Ms. Pole, who borrowed books from the library and other sources, curated a classroom set of books on astronomy, including bilingual books, specifically for this unit. These books were on prominent display for students to access easily during independent reading time. The unit targeted key science practices, including building models; and obtaining, evaluating, and communicating information from informational texts; and constructing explanations.

Developmental Bilingual Education (DBE) Classroom

Ms. Martinez taught in a developmental bilingual (Spanish/English) classroom of 27 students (13 girls and 14 boys). Eleven students were classified as ELs, while the rest of her students had tested out of this designation. All of her students had Spanish as a home language, with home countries including Mexico, Ecuador, Cuba, and El Salvador.

Ms. Martinez, originally from Mexico but raised in the Pacific Northwest, was in her fifth year of teaching. She had bachelor's degrees in business administration and Spanish, held a teaching certificate, and was working on her master's degree. Like Ms. Pole's, Ms. Martinez's classroom was furnished with student work and collaboratively created charts written in both Spanish and English, reflecting the class's bilingual focus. The classroom library's book baskets and displays contained a number of books in both languages.

In Ms. Martinez's classroom, students sat in heterogenous table groups of varying language ability and mixed genders; a spacious carpeted area at the front, near the whiteboard and teacher's easel enhanced the room. Here, Ms. Martinez gathered students for whole class mini-lessons, discussions, and read-alouds. The whiteboard typically displayed the day's schedule and learning targets and was surrounded by collaboratively made charts. Part of the front wall served as the "bridge" area, based on Beeman and Urow's (2012) work, and was part of the school's bilingual education program. Terms, displayed in both English and Spanish, and specific "bridge time," supported students learning of key terminology in both languages.

During the time of the study, students were engaged with a unit focused on electric circuits (approximately eight weeks, 2–3 lessons per week). Typically, instruction began with a mini-lesson for the whole class and then students completed in-class activities in groups. While Ms. Martinez had access to a science kit, which included a teacher's guide and student reader, these texts were in English only, so she created much of the material in Spanish herself. Key science topics included creating a circuit with a light bulb, understanding conductors and insulators, and learning the symbolic language of electricity. Students also read and drew diagrams for wiring circuits and constructing flashlights.

Data Collection

Data sources included audio-recorded classroom observations (for a larger study, each teacher was observed over half a year across content areas), researchers' field notes, pre-/post-observation interviews, and classroom artifacts. We observed each teacher during two or three complete science lessons. For this study, we selected one science lesson for in-depth analysis. Observation notes were taken using Ankrum et al.'s (2014) semi-structured observation protocol (duration, settings, materials, assignments, assessments, running notes). Artifacts from observed lessons included photos of student work, teacher materials, and photos of classroom materials which helped us understand the teachers' purposes, processes, and outcomes of instruction.

Interviews lasted between 60 and 90 minutes and included knowledge, experience, and value questions (Patton, 2001). The first interview focused on the teachers' perspectives of their educational contexts (teacher, students, and school background; learning goals; and instructional supports available to students). In the second interview, the teachers reflected on overall successes and challenges of the science instruction observed; this interview also served as a follow up to clarify questions that emerged from observations. Researchers' notes were taken during observations and during formal and informal interviews.

Data Analysis

All interview recordings and observation notes were transcribed; observations in Spanish were also translated. We analyzed and triangulated data using the three essential principles of practice centering our study as a priori themes (*negotiation*, *language embeddedness*, and *non-threatening learning environment)*. Enacted practices observed under each theme were coded and categorized iteratively. Table 1 provides our coding schema.

Table 1. *Coding Schema: A Priori, Research-Based Themes for EL Science Education (Ardasheva et al., 2015) and Emergent Codes With Examples From Teacher Observations*

Theme	Definition	Codes and examples of enacted practices observed
Negotiation	Opportunities for individual and social construction and critique of knowledge	• *Conceptual learning:* student-student and student-teacher discussions, questions, feedback, consulting experts, public sharing of knowledge • *Disciplinary skills:* working collaboratively to obtain, evaluate, and communicate information; construct and use models; read tables; locate evidence to support claims; construct explanations
Embedded language	Opportunities for language and literacy learning as a natural aspect of science	• *Fluency strategies:* extended oral language development, metacognitive conversations, choral reading • *Vocabulary strategies*: previewing, reviewing, meaningful use • *Writing strategies:* annotating, paraphrasing, summarizing • *Reading strategies*: previewing text, identifying textual features, setting purpose for reading, highlighting key information
Non-threatening learning environments	Opportunities for social apprenticeship and interaction	• *Fostering an enthusiasm for science*: using inquiry-based approaches, supporting risk taking and mistakes • *Verbal encouragement:* praising, inviting and uptaking contributions, humor • *Comprehensible input/output:* modeling, enacting, resources • *Building positive relationships and shared norms of behavior*: encouraging student-student support, all ideas valued

Findings

Structured Immersion (SI) Classroom

We observed multiple instances of the three key principles of practice in Ms. Pole's classroom. In one of her "planetary expertise" lessons, in which students worked in small groups to become experts on a particular planet, the teacher engaged her students in scientific sense-making through individual negotiations (*reading text, highlighting, annotating*) and group negotiations (*asking and answering questions, categorizing, arguing from textual evidence and from text-to-text/self/world connections*) while preparing students for public negotiation of their expertise (*presenting their planetary expertise to the whole group*).

In this lesson, a close reading of a text in a teacher-led small group, Ms. Pole involved students in negotiating with "expert information." Here, the text, the teacher, and, at times, more knowledgeable peers played the role of the "expert." The text was one of the two reading options of the day about the planet Mercury, which students had selected as a group to research across the whole unit. The text introduced basic information about the planet (e.g., distance from the sun, surface features, Earth's satellite exploration of Mercury); an accompanying table, 'Mercury Quick Facts,' summarized key numbers (e.g., average temperatures, day and year lengths in Earth's days). Ms. Pole had a chart paper stand with a blank concept map with five nodes: "Mercury" (in the middle) and "location," "characteristics," "motion and predictable patterns," and "interesting facts" (in the four corners). The chart paper provided enough space in between the nodes to invite writing. Photos at the top of Figure 1 capture teacher and student highlights and annotations of the Mercury text; photos at the bottom of Figure 1 capture results of the students' negotiating with the "expert," the completed concept map with essential information from the text negotiated and captured in teacher (chart paper) and student (individual notes) writing. Selected classroom vignettes below demonstrate the negotiation events that unfolded as students read excerpts from the text, initially following along with the teacher and later taking turns.

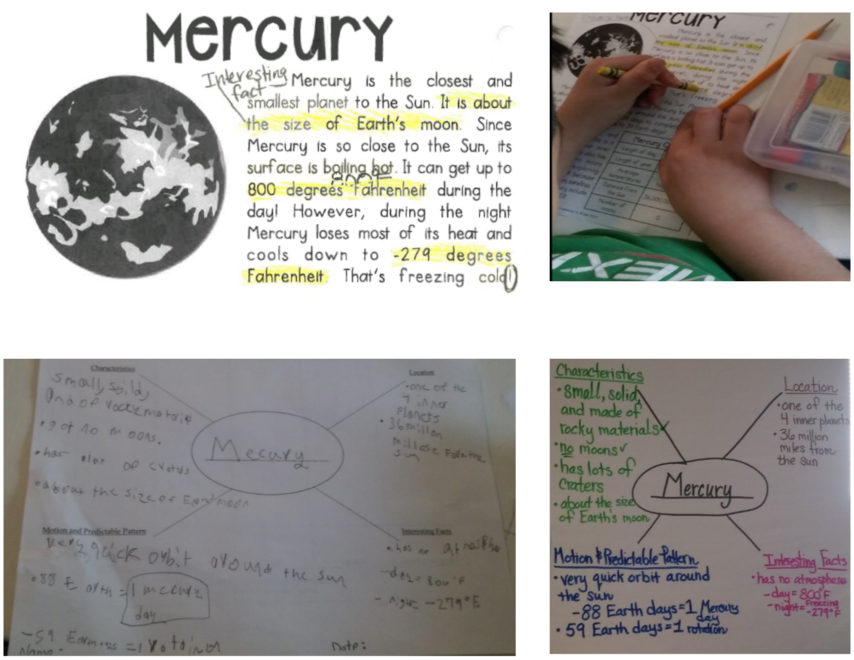

Figure 1. Negotiating meaning with text, self, and others. Teacher annotation (top right), student annotation (top left), student graphic organizer (bottom left), expert group cognitive map (bottom right).

Text Preview and Selection

To begin, Ms. Pole engaged her students in previewing two texts on Mercury, focusing on salient text features. She modeled naming text features for one of the texts ("let's preview our text... let's take a look at the diagram, looks like there is a little caption"). She then invited students to locate prominent text features on their own. A student noted that he saw the "Mercury Quick Facts" table, which students first identified as a "side box" or a "side bar." Linking to a familiar, everyday meaning as well as to the students' initial responses ("It is like a box ... we are sitting at one right now"), Ms. Pole reminded them that the "box with all this information" is called a "table," clarifying the meaning of this polysemous word commonly found in science.

The teacher then asked students to select one text for reading. After listening to and recognizing (repeating/paraphrasing) students' arguments for text choice (e.g., "this one has more facts"), she provided hers as a summary, "So, let's then read this text to practice reading tables." By setting up the purpose for reading (expert group, concept map with nodes/headings), inviting student voice (choice of text), and previewing key language demands of the text (students will be referring to the "table" as they read), the teacher modeled important language and literacy strategies and also laid the foundation for open-channeled discussions of the text.

Highlighting Text

After the text preview and selection stage, Ms. Pole asked students to read the first part of the text together and used this opportunity to model pacing, intonation, and following along with the reading using her finger.

T: Let's talk about anything in that text we need to highlight, things we're unsure what they mean. Ana, what do you think? [Ana signals uncertainty with her body language.] Keep thinking, I'll come back to you.

S: Uhhhhh.

T: Yes, Matt.

S: Right here. [student points to something he wants to highlight.] It's about the size of the Moon.

T: You want to highlight that? Why do you want to highlight that? Let's ALL do it!

S: Because I thought it was an interesting fact, because I thought there was no other planet in our system the size of our moon.

T: So, when we go to the expert groups, do you think this should be highlighted as an interesting fact?

S: Yeah.

T: Ok, let's use our pencils and draw a little arrow to it and write "interesting fact."

[Following the teacher's modeling, the students highlight the phrase "It (Mercury) is about the size of the Earth's moon" with a yellow marker. Next, the teacher comments] "Which tells us that it is pretty small" [and draws an arrow noting the information as an "interesting fact."]

In this excerpt, the teacher served as an expert by modeling the essential science literacy practices of obtaining, evaluating, and communicating information. As reading progressed, Ms. Pole demonstrated interrogating the text, highlighting, and labeling key information while preparing students for categorizing information after reading using the concept map. Importantly, she established a critical idea: initial negotiations with the text may be exploratory. Some readers may need to "keep thinking" a bit longer and perhaps re-read the text to process information, understand what is important, or question the text (seen in the next vignette); responses of others may be only tentative in nature (e.g., focusing on “the size of the moon” when the main topic is Mercury). The teacher also modeled the importance of multiple negotiations by suggesting that the student-selected text “be highlighted as an interesting fact” for further group work. As seen in the concept map completed by the end of the lesson (Figure 1), “the size of the Moon” factoid was re-negotiated through open discussion to a “characteristic” of Mercury (i.e., the planet’s size in comparison to that of the moon) rather than “an interesting fact.”

Constructing Explanations

In this vignette, the teacher and students discussed Mercury’s day and night temperatures and its lack of atmosphere, all information that students later categorized as “interesting facts.” The teacher served as an expert by exhibiting the essential science literacy practices of obtaining, evaluating, and communicating information, asking questions, and constructing explanations.

T: OK, is there anything else we are unsure of? Ana?

S: Oh, I didn’t know what that word was.

T: Ooohh. I was hoping someone would mention that. Let’s go ahead, highlight that word.

S: “Which word, ‘Fahrenheit’?” [pronounces the word effortlessly]

T: “Fahrenheit.” Let’s highlight, go ahead and highlight all the way from “eight hundred degrees Fahrenheit.” Remember when we we’re reading our text this morning we talked about that word?” [students nodding and uh huh-ing] But it was not spelled out like that. What did it say?

S: “F.”

T: It just said, “F” for short. But we have not seen this whole word spelled out like that, have we? Let’s go ahead and write it just the way we saw it in our other text: eight, zero, zero … eight hundred. And remember that little degree symbol?

S: Little zero, and then “F.”

T: Uh huh, and then there is an “F.” [the teacher models writing “800° F” above the text’s line reading “800 degrees Fahrenheit”]

T: And what did we say degrees Fahrenheit is? What does that mean?

S: How hot.

T: Aha, how hot, how cold—that is how we measure temperature. So, 800° F during the day. How cold at night?

S: Very cold, it loses its heat.

T: That’s right, it loses all the heat at night. Why do you think it loses ALL of its heat? Think about what we’ve talked about in class… did you get any clues? [thinking time] Remember how the Earth…

S: Because it has no atmosphere.

T: Let’s all look at Edgar and say, “BINGO”! [students look and say BINGO!]

T: Yeah… and let's highlight 279° F negative. Negative, that's less than zero (she gestures this idea of "below" by moving her hand down low); it is negative 279° BELOW zero. It's freezing cold, like it says here in our text.

S: So, if outside, would water really freeze?

T: For sure it'd freeze, yes.

Ss: Cold enough to die? So, it could kill?

T: Yes, very cold. What kind of sentence does it end with? Think about our types of sentences? [she points to a chart with different kinds of sentences posted in the room; a student gets up and walks to the poster and back]

S: Ex-… clamatory.

T: Exclamatory. Circle the exclamation point. [models] So, when we read this, shall we read it like this? [models very flat reading]

S: That's freezing cold! [reads with an appropriate intonation]

T: So, we need to use a what?

S: An exclamation point!

The discussion started with Ms. Pole going back to Ana to check if she had discovered something she was unsure of and Ana pointed out a word she was not familiar with. The teacher was quick to point out that it was not the word per se that was unfamiliar, but rather its written form (spelling). The teacher used this moment to both connect to prior learning (symbolic representations for 'Fahrenheit' and 'degree' encountered in earlier readings) and to current learning (Mercury's day and night temperatures) while continuing to model text annotation techniques by asking students to highlight the word's context. Because the teacher invited her students' contributions (e.g., "Anything else we are unsure of?" "I was hoping someone would mention that." "What does that mean?"), students generously supported one another by providing the word's meaning (line 18), pronunciation (line 5), and notation (line 14).

These contributions also pushed meaning negotiations further as one student made a connection between day and night temperatures, which led to a conversation about atmosphere and its function (when present) in a planet's system. This also allowed students to consider the possible effects of Mercury's negative temperatures on life. The teacher also capitalized on this fact, capturing students' attention (lines 32–33) to review the corresponding evaluative sentence's type, punctuation, and intonation ("That's freezing cold!"). This, and her focus on terminology ("Fahrenheit" [lines 5–18], "degree symbol" [lines 13], "negative" [lines 27–29], and modeling pronouncing "exclamatory") when she noticed a student stumble over the word [line 37] exemplified the teacher's practice of seamlessly embedding academic language teaching as students negotiated science meanings. None of these practices of language embeddedness and meaning negotiation would have been possible without the teacher first creating a non-threatening learning environment by frequently inviting, praising, and "taking-up" (repeating, paraphrasing) students' contributions (e.g., lines 6, 22, 26). In this manner, Ms. Pole modeled the kind of interaction she wants her students to have when they work in their small groups, that is, student-student interactions that lead to science content and language learning. In fact, in one of her interviews she mentioned that ELs need to share ideas with each other: "I've learned [that ELs]… have to talk to one another; they need less of me talking and they need more of each other talking." She also highlighted the need for an open classroom environment and that student-to-student negotiations allowed her to gain a better understanding of her students' progress:

> I can really tell from the kids, not just what answers they are getting, but I can see where are the misconceptions, what do I need to reteach and I am thinking or planning out in my head what mini-lesson I am going to start tomorrow, or they still aren't getting this so tomorrow.

Developmental Bilingual Education (DBE) Classroom

All three key principles of practice were also observed in Ms. Martinez's bilingual classroom. During an inquiry-based lesson in which her students created a circuit, each practice was observed multiple times, as shown in the following vignettes.

Making and Discussing Predictive Models

During the first part of the lesson, Ms. Martinez gave each pair of students a boxed kit with the items needed for making a circuit: small light bulb, wire, and battery. Before attempting to make a circuit, she asked students to first explore the objects, prompting, "En su papel, van a dibujar una pila y un foco. Pero piensen en todo lo que está en un foco, todas las diferentes partes." [On your paper, you are going to draw a battery and a light bulb. But, think about everything that is in a light bulb, all the different parts.] A moment later she continued by asking them to predict how the light bulb would work: "Dónde creen ustedes que se va a prender el foquito? En dónde se transmite la electricidad? Dónde está el conductor ó por dónde no? Cuál es el aislador? Pues, van a pensar en eso." [Where do you all think that the light bulb will turn on? Where is the electricity transmitted? Where is the conductor or where isn't it? Which is the insulator? Well, you are going to think about this.] As students began working, Ms. Martinez joined one of the groups. When one of the students seated there, Juan, remarked, "I can't do this!" Ms. Martinez gently reminded him that his model did not need to be perfect: "Está bien. No te preocupes, no tiene que ser perfecto." [It's okay. It doesn't have to be perfect.] Such a reminder that mistakes are okay was one way she helped to create a non-threatening environment. She also supported students' efforts by reminding them that their models needed arrows and labels, "Recuerden, tienen que identificar. Pónganle flechitas para decir qué parte es el conductor, qué parte el es aislador." [Remember, you have to identify. Put little arrows to show what part is the conductor, what part is the insulator.]

As students began to draw their predictive models, another student wondered, "Maestra, pero cómo lo vamos a encontrar?" [Teacher, but how are we going to find it?] Ms. Martinez responded by saying, "Ah, ahorita vamos a pláticar sobre eso." [Ah, now we are going to talk about that.] This question led to quite a bit of discussion, as Ms. Martinez worked to support students' ideas about conductors and insulators in various ways, including continuing to ask questions, helping them make connections to prior learning, encouraging talk with each other, and pushing them to be focused in their thinking.

As the conversation continued, she guided their thinking by reminding them of a previous class discussion, "Porque recuerden que platicamos que todas las cosas que tienen electricidad tienen una parte segura. Porque si no, sería seguro agarrar una pila?" [Because remember that we have talked about how all electrical things have a safe part. Because if not, would it be safe to grab the battery?] When the students agreed that it would not, she continued, helping them make the connection between safety and insulators as well as the electrical current and conductors: "Entonces, hay una parte que es un poquito más segura, que va a ser el aislador, que no va a pasar energía, que no va a hacer daño. Y una parte de donde sí, que va a ser el conductor en donde si puede pasar la electricidad." [So, there is a part that is a little bit safer, that is the insulator, that doesn't allow energy to pass through, that will not harm you. And, there is a part that does, that will be the conductor, where electricity can pass.] She then invited students to continue to talk about where they thought the electrical current would flow in the battery.

At this point, another student chimed in, sharing that his dad made batteries to charge cars. Following up on this, Ms. Martinez gently pushed his thinking by asking him, "Pero, qué partes, específicamente de la pila?"

[But, which parts, specifically, from the battery?] She went on by asking students to think about how a battery has to be put in the right way in order to work and again asked them where they thought the electricity would pass, indicating the top (positive end) of the battery. This prompted another student to mention the positive and negative symbols, saying, “Sí, porque la pila así aquí dice más (+) y la metes por dónde dice menos (-), si no, no puede funcionar.” [Yes, because here the battery says plus (+) and you put it where it says minus (-), otherwise, it can’t work.] Ms. Martinez asked, “Entonces, nada más por arriba ó piensan ustedes que también por abajo? Yo no sé. Ustedes, qué piensan? [So, only through the top part or do you think through the bottom also? I don’t know. What do you all think?]

Asking students to make predictions about the various items and to represent their ideas by drawing and labeling their own diagrams was one way that Ms. Martinez encouraged the students to begin to understand how a circuit might work. Students had to examine the battery and the light bulb closely and consider where the conducting and insulating parts of each object were as a first step in thinking about how they would create the circuit. By doing so, they created a predictive model of their thinking, an important scientific practice.

Ms. Martinez talked about how her students often struggled with the sophistication of terminology in science: “With science, some of the terminology is so… high level that’s where it gets them.” To address this, we often saw embedded language practices and heard her explain how the use of diagrams and pictures helped students understand science terminology:

> They look at the vocabulary words and they see it, but they… I can see that they just don’t understand what they mean. And so, using a lot more of like “Okay, so this part, this is what it does” and more diagrams, a lot more diagrams. Some of it using real pictures.

She also pushed for conceptual understanding of the processes involved. More than just being able to say that something is or is not a conductor, the students were gaining an awareness of why or why not. Their growing understandings were embedded within the context of the discussion, the examination of the objects, and the labeling of their pictures.

The environment throughout the lesson was non-threatening. Ms. Martinez verbally encouraged students to draw, reminding them that their pictures did not have to be perfect; she encouraged students to share their thinking through open discussion, fostering enthusiasm for learning science from each other. We asked about students working in small groups, and Ms. Martinez responded:

> One of the things I try to do is not talk the whole time… I try to have them try to work it out, try to give them a lot more time to talk… that’s how I just try to maximize [learning], getting them to talk, seeing what they know, working with each other, see how they work, see how they can explain it to the other person.

Using Evidence to Support Claims

Once the students finished predicting and labeling insulators and conductors, they moved on to discussing light bulbs. The following vignette shows Ms. Martinez encouraging students to think carefully about the various parts of the light bulb and about which parts were conductors and which parts were insulators. This dialogue has been translated into English.

At the beginning of this excerpt, Ms. Martinez used questions to engage students in a discussion about which parts of the light bulb are conductors. She also encouraged them to carefully examine the object (line 1). This prompted Student 1 to point out the base because she knew that was where a light bulb gets screwed into a socket. Rather than accepting this as her final answer, however, Ms. Martinez continued to push her thinking by asking her for specific information.

After students agreed that the gray part of the light bulb would transmit the current, the teacher asked whether that meant it was a conductor or an insulator. The teacher continued to probe further by asking about what happens once the current is inside the light bulb (lines 14–15). When one student predicted that it will be the “antennas,” Ms. Martinez used this opportunity to connect back to the two terms—conductor and insulator—and to identify which one the filaments represent. When students mistakenly identified filaments as insulators, she directed their attention to a chart paper where she had previously written the two terms and their definitions. After re-reading the definitions, students agreed that filaments are conductors.

T: Which part of the light bulb do you think? Looking at all these parts, from where can the electricity run? What is a conductor there?

S1: I say that from the bottom because when you put in a light bulb, it goes like this [indicating that the base of the light bulb is the part that gets placed into a socket] and the current goes through here [pointing to the very bottom].

T: But, In which part? Because there is a gray part, there is a black… why do you think it happens?

S1: I think that from the gray part.

S2: I think from the gray.

T: From the gray. Then, put an arrow where you think that is going to pass through. If you think that the electricity passes through there, is it going to be a conductor or insulator?

S3: Conductor.

T: But if it is going to enter through here, which part of the inside makes it turn on? In which of those parts will it continue to run?

S1: Well, the antennas.

T: The antennas, is that what you think? Then you are going to put the arrows and you are going to put what, that it is a conductor or an insulator? What do you think?

S3: An insulator

T: Maria says that it is an insulator, what do you think, Roberto?

S2: Insulator

T: Insulator. What do you think, Juan?

S1: Insulator.

T: Then, let’s see the poster of the two words…

S2: [Reading a teacher-made chart] Insulator does not allow electricity.

T: Then, is it going to be the insulator? If an insulator doesn’t allow it to run? What is it going to be?

S3: No, the conductor.

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"You are Already Scientists!"
In the excerpt below Ms. Martinez's students are manipulating the wire, battery, and lightbulb, trying to make the lightbulb light up:

Ss: Teacher, what happens if we are finished?

T: Did you already make it light up?

Ss: No.

T: Then, you haven't finished. The battery, the lightbulb, and the cable.

S1: I am really afraid.

S2: Do it! Nothing will happen.

S1: And what if it does?

T: It will light up. I assure you. Think. Where are the insulators?

S1: Teacher, this won't burn us?

T: It is not going to burn you.

S1: What if it burns us!

T: Nothing is going to happen. Keep going. Keep trying. Keep working together, see how you can do it—together.

In the vignette above, students share being afraid of getting "burned" by the circuit. Although apparently they were teasing one another and Ms. Martinez, this dialogue shows they were thinking about possible outcomes of creating a circuit. Because none of the students had so far made their circuits work, they asked the teacher if they had all the materials needed. They also asked her if she had tried it. After some clarification and further probing, the dialogue continued:

S1: Let's see if cutting it works because the electrical current sometimes explodes.

T: No, it is not going to explode

S2: And if we give it one of these? (Indicating cutting it.)

T: (Laughing)

S3: Teacher, do you want to turn us into scientists?

T: You? Of course! You are already scientists starting from now on!

Throughout the lesson Ms. Martinez embedded the new terms, often emphasizing the words within a context of inquiry. By asking students to support their ideas orally, visually, and in writing, she helped them to meaningfully engage in scientific discourse. Moreover, by encouraging students to discuss their ideas and initially accepting these ideas, even if inaccurate, Ms. Martinez fostered a non-threatening environment necessary for students to take risks. Finally, by encouraging students to make their circuits work and playing along with students' exaggerated fears of getting burned or causing an explosion, Ms. Martinez created a playful atmosphere that made risk-taking safe and fun. The students appeared comfortable sharing their ideas with her and supporting them with their observations. Clearly enjoying themselves, they eventually teased Ms. Martinez that she wanted to "turn them into scientists." These positive, playful, and supportive interactions cultivated her students' enthusiasm for doing science.

Discussion and Implications

This study examined how teachers foster opportunities for students to negotiate meaning, embed language into instruction, and create non-threatening learning environments to support ELs' science learning. Next we look at the similarities and differences enacted in Ms. Pole's SI classroom and in Ms. Martinez's DBE classroom.

Similarities in Fostering Opportunities

The teacher-student and student-student interactions involving negotiation in both classrooms focused on conceptual learning (e.g., discussions, prior learning connections) and disciplinary/multimodal skills development (e.g., building models, seeking evidence), which support science argumentation. Both teachers emphasized and encouraged students' thinking rather than arriving at the "correct" answer, an approach associated with improved science and literacy (Lee & Stephens, 2020). Both teachers also pushed students' thinking by inviting further consideration of answers and delving deeper into the concepts. For example, Ms. Pole asked students to think more about temperature by extending the discussion to atmosphere and Ms. Martinez pushed her students' thinking by asking them to predict and discuss each circuit component. Examples of negotiated disciplinary/multimodal skill development included building models, categorizing information, and seeking evidence to support their thinking.

Embedding language instruction means providing students with opportunities to read, write, and use oral language while engaging in science (MacDonald et al., 2017). For example, ELs need opportunities to define academic terms in their own words and languages, based upon their emerging understandings (Grapin et al., 2019). Providing ELs the opportunity to practice language skills as they carry out science learning is an effective way to support improvement in both areas (Lee & Stephens, 2020). Also critical to doing science are constructing and understanding graphs, equations, tables, diagrams, and models, visuals which inherently include language use in their creation (Hand et al., 2016). We saw examples of students using embedded language during oral language and literacy activities in both classrooms. Ms. Pole utilized a concept map to help her students organize their recently acquired learning where they placed new concepts and ideas in categories which enhanced their understanding. Ms. Martinez asked her students to construct predictive models of where the insulating and conducting parts of the battery and lightbulb would be. In doing so, the students' developing understandings of these terms and processes were supported by their diagrams and discussions of the parts of the circuit, rather than being presented as isolated terms and definitions. At the discourse level, students in both classrooms developed their oral language skills as they engaged in extended and animated discussions about justifying their decisions, discussing the potential risks of their work as well as different ways of solving problems.

Importantly, the negotiation and embedded language practices observed across the two classrooms were nurtured through the establishment of a non-threatening environment. Both teachers created a supportive, non-threatening environment by fostering an enthusiasm for science, using encouragements, supporting comprehensible input/output, and building positive relationships and shared norms of behavior. The inquiry-oriented approach to lessons served to foster students' enthusiasm for science. In Ms. Pole's classroom, students discovered new ideas about planets by reading and selecting the information they wanted to include in their graphic organizer. In Ms. Martinez's classroom, students were figuring out how to make circuits work. In both lessons, risk taking and making mistakes were encouraged as students' approximations were accepted. Both teachers also built positive relationships and shared norms of behavior to promote inquiry, as seen by how Ms. Pole encouraged her students to build upon one another's ideas and how Ms. Martinez encouraged her students to figure out a solution together.

Differences in SI and DBE Classrooms

While students in both classrooms were simultaneously learning language and science, Ms. Pole's students were learning in their L2, increasing their cognitive load. While both teachers encouraged their students' negotiation of meaning through oral discussions, they differed in two key regards. Ms. Pole more explicitly focused on the L2 (stopping to define terms, discussing text features), provided modeling, and offered more structure (creating the concept map ahead of time and pre-determining categories of information). She also differed in the type of questions she asked. Whereas Ms. Pole tended to ask many why questions, (e.g., "Why do you think it loses all of its heat?") encouraging students to modify, confirm, or contemplate their thinking by providing more L2 scaffolding, Ms. Martinez's main way of guiding the students in their L1 was through asking a sequence of questions, building on students' answers, and prompting them to carefully observe the objects at hand. Her questions (e.g., how circuits worked, which parts of the battery and lightbulb acted as insulators and conductors, and where the electricity was transmitted) encouraged students to analyze, generalize, and make inferences. Through questions, both teachers encouraged students to think deeply about concepts and terms in science and gather evidence to support their thinking. Clearly, in these two classrooms, teacher questions were used to promote language and content learning rather than to assess recall of information.

While both teachers created a non-threatening learning environment, they accomplished this in different ways. Ms. Pole achieved this by allowing her students extra "think time" and using praise (e.g., "Oooh, I was hoping someone would mention that!" "BINGO!"). The fact that Ms. Pole's students were learning science through their L2 may have mitigated her efforts as simultaneously learning content and language may raise the cognitive demand for the ELs thus causing higher affective filter (Lee & Stephens, 2020). Ms. Martinez, on the other hand, created a non-threatening learning environment primarily through the use of the home language and ongoing humor. Learning science in Spanish validated students' cultural and linguistic assets and allowed them to strengthen both their everyday and academic languages (Gottlieb & Ernst-Slavit, 2014). These Spanish language and literacy skills, as research has shown (Collier & Thomas, 2017; Marchman et al., 2020; Phillips Galloway et al., 2020), will also transfer to English, which enables bridging between the two languages. Humor in this classroom also contributed to students feeling more comfortable and open to learning.

Implications

Why is it important to examine the similarities and differences in how these principles of practice are enacted across two different language classrooms? Our exploration shows that these practices can be enacted by different teachers, in different languages, and in different types of programs, yet with important similar outcomes: fostering enthusiasm for and engagement with science while learning both the language and content of science (i.e., discourse and concepts).

In Ms. Pole's classroom, instruction was delivered in English, an L2 for her students; her lesson reveals more attention to explicit language instruction in terms of key vocabulary, sentence structures (exclamatory versus declarative), text features, and pronunciation. However, in Ms. Martinez's classroom, because students were learning in Spanish, their L1, there were more opportunities for students to explore science concepts and processes without having to, in addition, focus on learning a second language. Although the lesson centered around electric circuits, Ms. Martinez spent less time with the students discussing key English language features. As cognates to their English counterparts, the key terms "aislador," "conductor," "positivo," and "negativo" easily applied to the class bridging time later, in English. Moreover, the use of the L1 by students and teacher allowed for greater comfort and informality. Thus, one key implication of our study is that enacting these three principles of practice in students' L1, when less linguistic scaffolding is required, may lead to more opportunities to focus on disciplinary content and the exploration of students' ideas. We recommend teachers support their students' exploration of content in their primary, home language; allowing students to work in their native language will improve science engagement (González-Howard & McNeill, 2016)

Both teachers engaged their students in learning the discourse of science as they were engaged in the task at hand. The use of open-ended questions and extending prompts through exploration-based lessons, whether through the investigation of a text or an observed phenomenon, is an effective way to support and guide ELs to rich understandings of key concepts (Ernst-Slavit & Pratt, 2017; Pritchard & O'Hara, 2017). Hence, another key implication of our study is the value of using open-ended questions and extending prompts through exploration-based lessons, whether through the investigation of a text or an observed phenomenon as an effective way to support and guide ELs (and all students) to rich understandings of key concepts. Teachers should engage their students in learning science by modeling doing science (asking questions, making observations, identifying patterns) themselves and explicitly describing these practices.

Additionally, both teachers encouraged students to interact with and share ideas with one another, not just with the teacher. Therefore, a third key implication is that although instruction was delivered in two different languages, when teachers enacted these principles, they fostered student engagement and interest in science. Effective implementation of these practices outweighs language of delivery. This implication leads to recommendations that teachers focus on meaningful participation in science by focusing on language as a tool for communication rather than a content objective (Tretter et al., 2019).

Finally, since all teachers are language teachers, we see that the implications from our study call for the preparation of teachers who can assist all students, including ELs, in engaging in science practices that involve both scientific sense-making and language use. To maximize student learning, field experiences and coursework should include opportunities for pre-service teachers to engage in authentic science learning themselves, which encompasses awareness and identification of the academic language needed, the use of strategies to support students' understanding of scientific terms (Ardasheva, 2017), and use of graphs, equations, tables, diagrams, and models (Hand et al., 2016). A focus on language in science will empower future teachers to integrate language and science instruction with resulting gains in science understanding, vocabulary, and writing (Chen et al., 2016).

Conclusion

At a time when U.S. classrooms are becoming increasingly diverse, greater attention on the quality of education for ELs is needed, particularly in a subject like science, where professionals from culturally and linguistically diverse backgrounds continue to be underrepresented working in scientific fields (Fouad & Santana, 2017). Our study elucidates important implications for teacher education and professional development by highlighting key principles of practice and specific strategies that support ELs in developing their language and content knowledge. By showcasing these practices in the context of two different language classrooms, we propose that while teaching in students' first language is an important and effective way to support their development in the discourse of science, a wide array of effectual practices exist for engaging students and fostering their interest and enthusiasm for science regardless of the language of instruction. This is significant considering that, regrettably, the vast majority of ELs in the U.S. learn in SI classrooms, not in bilingual classrooms. Our study offers strategies for ensuring that, despite the language program in which they find themselves serving their EL students, teachers can utilize effectual strategies to foster science and content learning.

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