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Culturally sustaining systemic functional linguistics praxis in science classrooms

Ruth Harman[a], Cory Buxton[b], Lourdes Cardozo-Gaibisso[c], Lei Jiang[a] and Khanh Bui[a]

[a]Language and Literacy Education Department, University of Georgia, Athens, GA, USA; [b]College of Education, Oregon State University, Corvallis, OR, USA; [c]Instituto de Educación, Universidad ORT Uruguay, Montevideo, Uruguay

ABSTRACT
The Next Generation Science Standards (NGSS) call for students to exhibit an in-depth understanding of scientific inquiry practices, including direct observation, creative design thinking, and argumentation based on evidential learning. To support academic equity for multilingual learners, these new expectations require reconceptualization of science teacher education and classroom instruction, whereby emphasis is placed on incorporating the linguistic and cultural repertoires of learners through multimodal and open-ended learning activities. To support this shift in practices, this paper presents a culturally sustaining systemic functional linguistics (CS SFL) framework for science teachers and multilingual classrooms. CS SFL praxis emphasizes three intersecting areas: language development, knowledge development, and cultural sustenance.

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Introduction

Since their inception, the Next Generation Science Standards (NGSS Lead States 2013) have received both praise and criticism for the shifts in teaching and learning that they are meant to foster. While these standards have been critiqued on several fronts (e.g. Ravitch 2013; Rodriguez 2015; Sharma and Buxton 2015), they have also made significant contributions to a new vision of science education that highlights students' evidence-based meaning-making and multimodal communication of these ideas. One of the positive features of these standards is that they require all content area teachers, as well as teacher educators, to think deeply about how to integrate language and disciplinary knowledge instruction to benefit all students, including multilingual learners[1] (Zygouris-Coe 2012).

In the case of science instruction, most US states now follow the NGSS in representing science as the three-dimensional integration of disciplinary core ideas, science, and engineering practices, and crosscutting concepts, while viewing language in a supporting functional role (Lee 2018). This integration is essential for meeting the goals and objectives of NGSS but also raises challenges in teaching multilingual learners who need linguistic and

CONTACT Ruth Harman rharman@uga.edu University of Georgia, 315 Aderhold Hall, Athens, GA 30601, USA
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cultural scaffolding embedded within the three-dimensional learning model. To address this, Van Horne and Bell (2017) propose moving beyond the 3D model, suggesting that *interests* and *identities* should be additional dimensions of a robust science learning model if we take seriously the idea of valuing students' cultural and linguistic connections to science learning. For example, the descriptions and drawings of concrete observations in nature that serve as appropriate data in elementary grades can readily be made accessible to multilingual learners through simple linguistic scaffolds and links to students' lived experiences. However, by middle school and beyond, key science concepts become increasingly abstract, involving scales and frames of reference that may not be readily visible through concrete observations or with ready connections to community funds of knowledge (Buxton et al. 2019). Thus, secondary grades students must gain new experiences and perspectives, new language(s), and new reasoning skills if they are to learn how to shift recursively between abstract concepts and their concrete instantiations in the natural world.

Despite longstanding efforts to focus science instruction on active inquiry and collective problem solving, K-12 science instruction has continued to focus on learning discrete concepts as facts to be memorized. Inquiry processes, if taught at all, are conceptualized separately from the focus of content instruction (Bunch 2013). Language support (e.g. word walls, sentence starters, and graphic organizers) has tended to front-load the teaching of technical and disciplinary vocabulary as separate from participation in scientific exploration and classroom discourse (MacDonald, Miller, and Lord 2017). Today's NGSS require students to engage in a range of science practices that are linguistically demanding, while also provide new opportunities for multilingual learners to gain an integrated view of science and language learning (Lee 2018).

Relating to the overall theme of this special issue, we consider what it means for science instruction with multilingual learners to be both culturally and linguistically responsive. From a more traditional funds of knowledge perspective (González, Moll, and Amanti 2006), this requires seeking out knowledge and skills that students are gaining in their homes and communities and then looking for connections to better understand the school science curriculum. Adopting the broader, culturally sustaining perspective (Paris and Alim 2017) can help us see how students recursively take what they are learning in school and apply it to make new meaning of their out-of-school interests and passions as well as the other way around (see Vazquez Dominguez, Allexsaht-Snider, and Buxton 2018).

Culturally sustaining science practices can also serve to challenge the supposed divide between academic discourse that is often equated with intelligence and knowledge in the science classroom. Indeed, the question of language integration within NGSS is an open and lively question, with some arguing that language-rich contexts promoted by NGSS should be sufficient to develop and support new disciplinary understandings and language use (Stage et al. 2013). Others, however, propose that disciplinary understanding needs to be developed within explicit macro-level scaffolding of the discourse of science (e.g. Hakuta, Santos, and Fang 2013).

In terms of the integration of culturally and environmentally diverse perspectives in the science curriculum, educators most often evade dealing with the issue (e.g. how students from a given cultural background might understand energy cycles or ecological stewardship in ways that conflict with a Western science-informed worldview). Instead, educators tend to privilege what are seen as value-free perspectives, where one truth is given to explain and understand natural scientific processes (Bang and Medin 2010). From a CS SFL perspective, social phenomena are never seen as value neutral, and should be made explicit as culturally embedded in much the same way that the language of science should be explicitly considered.

The purpose of this paper is to provide an explanation and illustration of CS SFL pedagogical design (Harman and Burke 2020; Harman and Khote 2018) that we have tailored for science classrooms (hereafter, CS SFL in Science). We first provide the theoretical tenets that underlie our framework for multilingual classrooms with an emphasis on three intersecting areas: language development, knowledge development, and cultural sustenance. We then use the context of a large science teacher professional development initiative to illustrate how our praxis integrates all three areas through the application of systemic functional linguistics, legitimation code theory (LCT) (Maton 2013), and culturally sustaining pedagogies.

Theoretical framework

There is a long history of representing science in school as if it were an acultural, objective, and static body of laws rather than an emergent human enterprise of discovery (Stanley and Brickhouse 1994), making science more resistant than most school subjects to adopting culturally sustaining pedagogies. Added to this are the underexplored consequences of the absence of culturally sustaining science teaching and culturally diverse science teachers on future employment and social mobility for multilingual students (Amos 2010). Indeed, the persistent bias in regard to what multilingual students can and cannot learn in schools is a mindset which oftentimes intensifies deficit-based thinking in schools and classrooms (Fergus 2017). Yet, social, linguistic, and cultural aspects of teaching have rarely been incorporated successfully into teacher education programs (Agee 1998; Samura 2017).

The model of culturally sustaining pedagogy (CSP) developed by Paris (2012) and Paris and Alim (2017) challenges educators to integrate and sustain cultural and linguistic repertoires of students in classroom discourse. Paris and Alim (2017) also posit that, 'culturally sustaining pedagogy exists wherever education sustains the lifeways of communities who have been and continue to be damaged and erased through schooling' (p. 1). In other words, this approach demands that educators focus on minoritized students as the center of knowledge co-construction and classroom instruction. Our CS SFL in Science framework, described below, is informed by the urgent demand of CSP to disrupt dominant discourses and practices that lead to academic and social inequity.

CS SFL in Science

Based on empirical CS SFL work in K-12 and teacher education (e.g. Harman and Khote 2018; Harman and Burke 2020) and a literature review that focused on the learning/teaching of multilingual learners in science classrooms (e.g. Hakuta, Santos, and Fang 2013; Lyon et al. 2016; National Academies 2018), three principles undergird our CS SFL in science approach to instruction: (1) deliberate dismantling of walls between school and community knowledges of science (Tolbert 2015); (2) an SFL-informed approach to curriculum design and instruction (Jakobson and Axelsson 2017); and (3) a systematic set of discourse strategies that support learners in moving recursively from concrete understandings of new concepts to metaphorical reasoning and articulation of the scientific principles at work (Gibbons 2006). As illustrated in the innermost circle in Figure 1, we developed key principles of our praxis through immersion in theories of CSP/funds of knowledge; SFL theory of social semiotics; and Maton's (2013) LCT. Respectively, these theories supported our understanding of the relationship between culture, language, and knowledge in designing the praxis. As illustrated in Figure 1, these tenets supported us in developing a set of practices (e.g. drawing on community discourse practices, designing multimodal activities, using systematic discourse strategies) through the use of an embodied learning and teaching cycle (see Siffrinn and Harman 2019).

As we discuss below, teachers can apply each of the three theoretical principles in Figure 1 to support multilingual learners in making culturally and linguistically sustaining connections to the NGSS vision of science learning.

Dismantling walls: embodied teaching and learning cycle

Through the use of an embodied SFL-informed teaching and learning cycle (TLC), educators can incorporate cultural, semiotic, and material resources that teachers, students, and their families bring to the classroom with the goal of re-mixing these resources to deepen

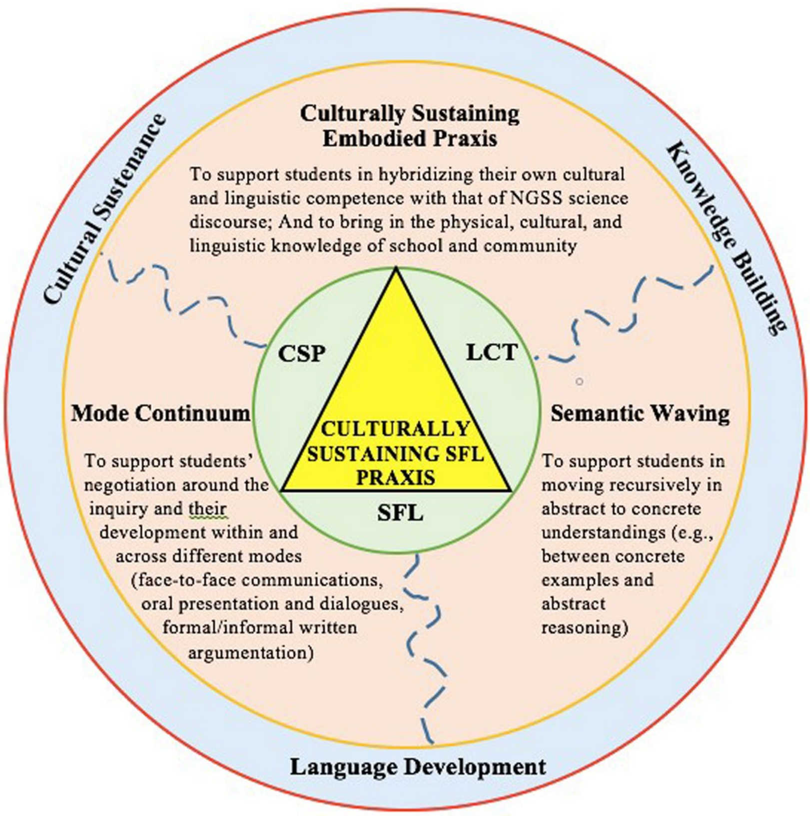

Figure 1. Culturally sustaining SFL praxis. The circular diagram shows the process from the inner point (establishment of the core praxis) to the larger circle (achievement of the goals).

disciplinary understanding (National Academies of Sciences 2018). The first phase in the TLC, referred to as *deconstruction or building the field,* supports learners in activating their cultural and multilingual knowledge base about the topic. In the second phase, called *joint construction*, students are encouraged to physically engage in inquiry around the topic while simultaneously verbally articulating understandings with the active participation of peers and teachers. In the final independent stage of the cycle, students *apply* their understanding to a new scenario by enacting a follow-up investigation or writing about it hypothetically. This cycle of instruction and interaction also allows teachers to evaluate how students are appropriating both new knowledge and expanded semiotic resources (Fang et al. 2014).

Mode continuum

Engaging in the three-dimensional framework of science learning within the NGSS, while attending to Van Horne and Bell (2017) additional dimensions of interest and identity, requires much more than text-based learning. Educators need discourse and multimodal strategies that support learners in shifting within and across modes, such as face-to-face negotiation and written argumentation. From an SFL perspective, we view this as a mode continuum, or a shift in channels of communication. The change in mode necessitates a different use of language in terms of ideational, interpersonal, and textual meanings (Gibbons 2009; Jakobson and Axelsson 2017). For example, when students are working in lab groups focused on direct investigation or observation, it can be satisfactory to refer to objects by pointing or using deictics (i.e. *this or that*). In a written lab report, however, such vague and highly contextualized discourse is no longer adequate, and students must learn to articulate their reasoning by interweaving abstract and concrete language. Herbel-Eisenmann (2004), for example, argued that attention to a mode continuum 'helps teachers consider how communication contexts relate to students gradually gaining facility with disciplinary-based ways of communicating' (p. 4).

Importantly, this mode continuum connects closely to a change in the type of discourse strategies and linguistic resources that learners will use to convey their meaning. Semantic waving, described next, focuses explicitly on the need in scientific discourse for a recursive move from more concrete explanations (such as based on a shared classroom experience) to more semantically dense and abstract articulations of the phenomenon (such as through deriving a formula or graph to generalize from a specific case).

Semantic waving

A common occurrence in content-area instruction is that educators who lack training in second language acquisition tend to over-simplify grade level-appropriate disciplinary discourses, believing that this will make the content more easily accessible for multilingual learners (Gibbons 2006). Our study of Maton's (2013) LCT points to a way out of this dilemma, demonstrating how content-area teachers can use semantic waving to better support understanding. Semantic waving refers to the organic patterns in all disciplinary discourse that moves recursively from dense and abstract language (*movement up the semantic wave*) to less dense and concrete articulation of those ideas (*movement down the semantic wave*) and then pushes back *up the semantic wave* again. This kind of semantic waving is clearly visible in studies of scientists' professional practices, and thus, is not a simplification of science for educational purposes (Latour and Woolgar 2013). In other words, unlike popular stereotypical representations of the language of science as exclusively dense and technical, actual scientific discourse is similar to any other form of discourse in that it moves iteratively between concrete and abstract evaluation and reasoning.

In sum, we believe a CS SFL in Science praxis approach can support multilingual and multimodal meaning-making with explicit attention to scaffolding learners in moving across modes and articulating semantic waves, within culturally sustaining learning environments. The next sections of the paper provide illustrations of ways in which our professional development initiative did align, and other ways in which it did not align, with the key tenets of our CS SFL in Science framework.

Using a CS SFL in Science framework to analyze a professional development initiative

Our CS SFL in Science framework had its genesis in a two-year-long collaboration between science educators and applied linguists that began as part of a broader research and development project. The broader NSF-funded project (described more fully in Buxton et al. 2015; Cardozo-Gaibisso and Harman 2019) was a research–practice partnership among university researchers and school partners in two school districts in the Southeastern US. The science educators in that project invited three applied linguists with training in CS SFL to join their research group. Our collective aim was to develop a CS SFL in Science framework based on a retrospective exploration of the more extensive professional development NSF-funded initiative that could be used to guide subsequent research (Buxton et al. 2019).

The broader Language-rich Inquiry Science with English Language Learners through Biotechnology (LISELL-B) project engaged 40 middle school and high school science teachers over a three-year period in a range of professional learning options in both traditional and novel learning spaces. Teachers came from two school districts characterized by rapidly changing student demographics-driven largely by Latinx migration from Mexico and Central America. Our teacher professional learning model embodied our belief that producing sustainable changes in teachers' practices requires engagement in diverse learning spaces, with teachers having agency both in terms of which professional development activities to attend, and what classroom practices to subsequently enact with their students (Buxton et al. 2015). Thus, each teacher in the LISELL-B project took part in a personalized selection of pedagogical activities that included multilingual family workshops, teacher institutes, summer enrichment academies for multilingual learners, and workshops focused on exploring students' science writing, all of which assisted in their developing new understandings about multilingual communicative practices (Buxton et al. 2019).

Across these professional learning spaces, teachers learned to apply a pedagogical model composed of six instructional practices grounded in broader literature on developing meaning-making and communication skills needed to attain academic success in science (Kuhn 2005). These six practices were: (1) coordinating hypothesis, observation, and evidence; (2) controlling variables to design a fair test; (3) explaining cause and effect relationships; (4) using models to construct explanations and test designs; (5) using general academic vocabulary in context; and (6) owning the language of science.

As part of the corresponding research activities, a series of constructed response science assessments were developed to measure students' ability to apply the six science practices in a series of science investigation scenarios. Assessments were given to all students in participating teachers' classes at the start and end of each school year for the three years of the project. All teachers kept a task log where they recorded use of project practices, and they also participated in annual focus group interviews in school teams. These interviews addressed a range of topics including teachers' evolving ideas about the language of science, science investigations, meaningful science assessments, and instructional support for multilingual learners in making meaning in science. Selected focal teachers participated in additional individual interviews regarding their classroom application of project pedagogical practices.

For the subsequent CS SFL investigation described here, we focused on data from a subset of three teachers from the broader project, purposefully selected based on their high levels of engagement over the course of the project as well as their representing the three middle school grade levels and corresponding science disciplines in our state (6th grade Earth science, 7th grade life science, and 8th grade physical science). We selected the class period for each of these teachers with the highest percentage of multilingual learners and then conducted additional analyses of constructed response assessments for students in those classes. Thus, data for this paper include a subset of data from the larger study: interview transcripts from three focal teachers over two years of project participation; task logs of those teachers' use of project practices for the same years; field notes from professional learning sessions and classroom observations; assessments from start and end of the 2015–2016 school year from those teachers' class periods with the highest percentage of multilingual learners; and finally, the constructed response assessments themselves.

In the following sections, we illustrate key aspects of the CS SFL in Science framework by highlighting both strengths and weaknesses in different aspects of the professional development initiative in terms of how we addressed (or failed to address) the cultural, linguistic, and disciplinary interests of multilingual learners.

Family workshops as culturally sustaining embodied praxis

As discussed in our conceptual framework, one of the key elements we have come to believe necessary in a CS SFL framework is the use of an embodied SFL-informed TLC (Siffrinn and Harman 2019). The TLC incorporates and sustains the cultural, semiotic and material resources that learners and their communities bring to the classroom (National Academies of Sciences 2018). In our view, the *Steps to College through Science* bilingual family workshops component of the professional learning initiative clearly included the culturally sustaining and embodied praxis aspect of CS SFL in Science. The aim of these family workshops was to recognize and incorporate the sophisticated linguistic and cultural repertoires of Latinx students and family members into the curriculum while making the richness of these resources visible to teachers. The workshops leveraged all participants' repertoires to facilitate dynamic, meaningful, and relevant talk as well as multimodal graphic representations around participatory science investigations with connections to career pathways enacted through an embodied TLC. These workshops also modeled various ways in which the teachers could subsequently encourage multilingual meaning-making in their science classrooms, even if they themselves were monolingual English speakers.

Thus, one of the family workshops focused on generating scientific explanations about asthma and breathing, the community of immigrant families, students, and teachers discussed the causes, diagnosis, and treatment of breathing difficulties in different parts of the world. They collected empirical data about their own breathing using peak flow monitors, graphed data collected, and used those data to make and test hypotheses about factors that influence people's respiratory health. This activity fully engaged the wide range of workshop participants and supported deep inquiry and understanding, both of a crucial socio-scientific issue, and of a scientific process of hypothesis testing. The use of culturally sustaining approaches allowed us to integrate participants' personal histories and linguistic resources into a topic with community relevance. As Mr. Dulsey,[2] our 8th grade focal teacher, described it:

> They [the students] were genuinely excited about their parents doing this activity with them at the school and I was like wow that's because when I thought about it, I haven't had many experiences in my personal life to do educational experiences with my parents, so, I'm like wow, it would've been kinda cool (Mr. Dulsey's interview, 2016)

Teachers became part of the diverse community of multilingual learners, families, and educators engaged in a joint and embodied construction of culturally relevant scientific knowledge. They could also see a collapse of the supposed divide between the academic language of schooling and the vibrant hybrid practices of minoritized multilingual communities (Flores and Schissel 2014).

Mode continuum

Drawing from our analysis of student constructed response assessments (see Buxton et al. 2019; Cardozo-Gaibisso et al. 2019), we found that most students in the initiative, and particularly multilingual learners, did not learn to effectively switch from concrete interactive language modes such as the embodied mode in the class discussion excerpt below to the more abstract and objectified patterns of language typically enacted in science writing and assessments. Indeed, we found students often remained stuck in using a spoken language mode. For example, one of the assessment questions asked students to think and write about an experiment related to weight lifting. One student responded, 'Could have two people and make them do a different type of weight lifting to see which one gets stronger' in the assessment booklet. The student continued to use the language of interaction (e.g. could have two people, make them do) to describe their process in conducting this experiment. This lack of flexible adaptation in the interpersonal meaning system (maintaining colloquial use of dropped pronouns and truncated sentences) made it more difficult for the student to articulate their findings by 'using more semantically dense language that constructs abstractions and theoretical entities' (Fang and Schleppegrell 2008, 19).

In the following example from our 6th grade Earth Science focal teacher's classroom, the teacher and students engaged in imaginative inquiry about constructing earthquake-resistant buildings, highlighting a potentially powerful embodied mode of discussion. However, the episode was cut short without the follow-through that could have better supported multilingual learners in transitioning their embodied communication to written reasoning that would be important for fully engaging in the subsequent class science investigation:

1. Ms. Bambridge: (students are standing in a circle) So imagine that we are in an earthquake. Use your bodies and show me how you would move if you were in an earthquake. (students shake and wobble and some fall to the ground). Now, imagine that you are a building in an earthquake and show me how you would move. (Most students stand stiffly this time with their arms at their sides and they lean and shake, and some students fall over). So, what was the difference between a person in an earthquake and a building in an earthquake?
2. Silvia: People bend but buildings break.
3. Ms. Bambridge: Can you say more about what you mean, Silvia?
4. Silvia: I mean like we're bendy, so we can fall down and be ok and get up again. But a building can't bend. If it falls down it breaks and can't get back up again.
5. Edgar: Cause our body has joints that move (swings his arms around) but a building doesn't have joints, so it can't move (makes his arms rigid)
6. Ms. Bambridge: Wow, that's really interesting. So today we are going to be engineers and we're going to design buildings that won't fall down in an earthquake. We are going to design earthquake-resistant buildings.

Imaginative and interactive discourse is an important domain in the CS SFL in Science classroom but does not, in and of itself, fully support multilingual learners in communicating their evolving knowledge of secondary grade-level science concepts, such as seismic waves or engineering design challenges, as they might be represented on a science assessment. If teachers are not aware of this large gap between discourse 'elicited by direct observations of science phenomenon and explanatory written genres that called for more taxonomy and nominalization' (Cardozo Gaibisso, Allexsaht-Snider, and Buxton 2017, 9), this can negatively impact the academic trajectory of students. While teachers may be well-meaning in efforts to make complex ideas accessible to multilingual learners, this perspective risks 'dumbing down' curriculum that multilingual learners receive. Data analysis from the larger study showed similar patterns in students' written answers on end-of-year assessments: students immersed in direct inquiry and observations often used direct imperatives (e.g. Move the light), which showed their enthusiastic embrace of inquiry processes but lack of awareness on how to shift from this dialogic discourse into explanatory written genre.

Despite these limitations, we were also able to identify some aspects of the project curriculum materials that supported students in thinking more systematically about multimodal communication and register switching. Figure 2 shows an example of the last page of the science lab guide for the asthma and peak flow investigation mentioned earlier. Each lab guide ends with what we referred to as the *lab notes template.* The lab notes template asks students to synthesize ideas from a completed investigation with a partner, first orally and then in writing, working across modes.

As Figure 2 illustrates, students were asked to explain their thinking using language that 'a younger brother or sister would understand' and language that 'your science teacher would use'. This aligns with the CS SFL in Science approach by supporting awareness of language use as a pliable configuration depending on audience and context.

LISELL-B

Peak Flow Investigation

LISELL-B Lab Notes

Practice: Coordinating Hypothesis, Observation & Evidence

What was your **Hypothesis** about a factor that influences peak flow?	Describe the **Observations** you made to test your hypothesis.	What **Evidence** supported or challenged your hypothesis?

Use **your own words** to describe how you used your **observations** as **evidence** to support or revise your **hypothesis**.

Use **scientific language** to describe how you used your **observations** as **evidence** to support or revise your **hypothesis**.

Peak Flow Investigation 4

Figure 2. Lab notes template page from asthma and peak flow investigation guide.

Overall, however, in our reflective exploration of the various professional development contexts of the project, it was found that we, as teacher educators, often failed to guide teachers towards more fully meeting their students' needs through explicit attention to the mode continuum.

Semantic waving: emerging applications

In explaining how she engaged one-on-one with multilingual learners prior to our professional learning initiative, Ms. Connor, our 7th grade focal teacher, explained what she used to do:

> [I] used like more symbols maybe to explain things, like *increase* (points her hand upwards), *decrease* (points her hand downwards) instead of the language and then… I, we would put them in the front row so for a task they wouldn't know to raise their hand like, what does this question mean… just more availability I guess (Focus group interview, 2016).

In line with this teacher's description of her past practice, various researchers have found that educators are likely to dilute disciplinary discourses in the misguided belief that this will make disciplinary content more easily accessible for multilingual learners (Derewianka and Jones 2016; Gebhard 2019; Gibbons 2006). Thus, our focal teacher began by using simplified symbols and gestures instead of language in the hope that this would make the concepts more accessible to her multilingual learners. Such strategies can be effective if accompanied by grade-level explanations of the concepts, but in practice, this often does not occur. Instead, we observed many teachers in the project using concrete representations, such as hand gestures and pictures, to the exclusion of linguistically complete explanations of the disciplinary context.

The new NGSS vision for science classrooms conceptualizes teaching and learning as highly experiential, multimodal, and language rich. However, gradual immersion in the disciplinary discourse of science still necessitates instruction that includes both accessible congruent descriptions of phenomena and complex metaphorical reasoning supported by concrete examples. As Larsson (2018) stated, 'science teachers tended to seldom repack, or model upward shifts and create waves by returning to more condensed and complex meanings' (63). Without access to more abstract ways of reasoning and arguing, students can remain fossilized in reading and writing science at a more elementary school level (Christie 2005).

Maton (2013) highlights how a focus on the interconnection of abstract concepts and authentic phenomena can foster an increased motivation for students to learn to think and communicate in abstract ways. The following excerpt from another observation in the classroom of our 6th grade focal teacher, Ms. Bambridge, points to the value of semantic waving for multilingual science meaning-making, especially for students who may benefit from a different approach than the one afforded by more typical classroom science interactions:

> Students were engaged in a group investigation, testing and comparing several varieties of bottled water and tap water, with some lab groups conducting blind qualitative taste tests and other groups using Vernier probes to take quantitative measures of the pH, hardness, and turbidity of the various water samples.

1. Erika: It says, (reading the handout) connect the conductivity probe to measure the total dissolved solids, or TDS.
2. Rodney: what's that mean, TDS?
3. Erika: that's the total dissolved solids – TDS. Get it?
4. Rodney: ok…

5. Erika: but how's it go in? (struggles with how to connect the probe)
6. Rodney: Here… you gotta take the other one out and plug this one in here… (takes probe from Erika and connects it)
7. Brianna: I just wanna know if it's got bacteria or lead, like that Michigan water. We're still doing that one, right?
8. Erika: Sure, but we need to do them in the order it says in the table.
9. Rodney: (swirling the probe and looking at the readout): It's 30…. 30 M-G-L
10. Erika: That's milligrams per liter (records the data)
11. Ms. Bambridge: (passing by the lab group): Are you getting your measurements ok?
12. Rodney: Yeah, we got the pH and the… umm…. TDS but we still need to do the bacteria and lead tests….

Here, we can see the value of semantic waving in supporting students' science meaning making. Erika, more competent with the use of higher semantically dense terms such as *total dissolved solids, milligrams per liter* guided her lab partner, Rodney, to take up and use that language. This only happened, however, after Rodney in Line 6 used highly concrete terms to discuss using the probe to measure the water. Line 12 shows that Rodney was then able to push back up the semantic wave in his response to the teacher's passing question.

In a post-activity debrief with our teacher educators, Ms. Bambridge reflected on the importance of using the structured language support and investigation kits provided by the program[3] to guide her students in moving from spontaneous investigation to a broader understanding of the overall inquiry. The activity kits, which provided necessary physical materials to conduct the project investigations, became important components in teachers' efforts to shift classroom discourse structures. As Ms. Bambridge described:

> I usually use heterogeneous grouping when I want students to work together on activities with science texts…. I mix the academic levels and linguistic proficiencies because I want them to teach and learn from each other…. But sometimes I see that these groups favor the learning of students who are more my academic leaders. So the students who think of themselves as academically strong usually steer these group conversations and dominate the work, so of course these students are learning the most in the process…. [But] since I started using the [project] investigations more regularly this changed the way that groups are working in my classroom. The language practices in the kits definitely influenced the student roles within those groups. When the materials in the kits get handed out in the groups, I saw a lot of examples of students taking new roles. Like in the water investigation, Erika – she's usually a leader during classwork – she seemed to struggle more with the science investigation components of the kits, like using the probes. Other students, who are maybe normally more passive in class, took the lead not just in performing the tests like with the probes, but also guiding and leading in the group conversations. (from classroom observation, 1/26/2017)

As the teacher noted, semantic waving is not a fixed instantiation of entry and exit points that must always be guided by the teacher. The classroom vignette illustrates one way in which semantic waving *can* occur since 'semantic waves do not necessarily begin and end on relative highs (…) Beginning from concrete, simpler meanings may offer a more engaging way into and out of the central focus of an activity or topic (Maton 2013, 19). Student groups can engage in less organized semantic moves among data, theoretical concepts, and concrete examples, as well as those directed by teachers.

We note that at the time we developed the materials for the broader research and development project, we were not yet aware of Maton's (2013) work on semantic waving. As we subsequently reflected on our design of curriculum, professional development workshops, and assessments, we found instances when we did intuitively use a pattern of semantic waving. For example, our sequencing of questions in our assessments moved from concrete descriptions of a phenomenon (e.g. a child planting a flower) early in the assessment to more abstract constructs (e.g. engine combustion) in later items. However, the use of semantic waving in our design was erratic and not aligned with a clear understanding of what it could afford. As we engage in designing our next iteration of this project, we intend to build semantic waving more explicitly into our work.

Discussion

This paper has provided an overview of the CS SFL in Science framework developed during a retrospective analysis of a broader project with secondary grades science teachers who were shifting their approach to science teaching to align with the discourse and investigation practices of the NGSS. Overall, we found that even within projects like ours which were created with the aim of supporting multilingual learners in culturally and linguistically responsive ways, we needed to focus more systematically and purposively on the three issues of knowledge development, language development, and cultural sustenance. We believe that science educators more broadly need to do the same.

In our *post hoc* study of the project practices and contexts, our overarching research goal was to do more than just enhance understanding about what conditions and practices may lead to improving multilingual students' science learning. We wished to build creative understandings of how best to engage in 'the process of supporting diverse learners in communicative and literacy tasks that move them towards linguistic and cultural equity that supports their emotional and social wellbeing' (Khote 2018, 154). Lessons learned from the study have implications for teacher educators, curriculum developers, and researchers, as well as for classroom teachers

First, our model points to the importance of using a culturally sustaining approach to science practice that incorporates the linguistic and cultural repertoires of students and their communities in the joint co-construction of science knowledge. For example, the culturally sustaining approaches used during our *Steps to College* through science multilingual family workshops benefitted all participants in different ways. Students were often pushed by family members to engage in science learning in Spanish, while also experiencing cultural connections to school science topics; two examples of CSP practices that classroom teachers often fail to leverage. The parents were able to experience the new NGSS vision of science education in ways that allowed them to subsequently provide better home support for their children's learning. Parents also got to participate as co-learners with their children's science teachers, strengthening those relationships and building better foundations for future family engagement in science learning. For their part, the teachers saw their multilingual students and their families as engaged science learners committed to academic success and to learning more broadly. Teachers also learned the empathy that comes from experiencing being a second language learner, even briefly, as the workshop activities were predominantly carried out in Spanish. Finally, as facilitators of these workshops, we learned that while it is possible to anticipate and plan for some of the culturally sustaining connections that can be developed for science investigations, other connections, such as those that came out of the asthma investigation, are emergent depending on the participants, and can be easily overlooked if not explicitly sought out.

Second, through our reflective study of the project's discourse practices, we now see the importance for science teachers to develop an awareness of the mode continuum that occurs when participants move from the embodied practices of experimenting with reasoning through oral or written language about science concepts under investigation. This move across modes (e.g. from direct interaction with the phenomena accompanied by cryptic comments and notes on one's observations to a more formal explanation of what occurred in a written lab notebook) needs to be supported. With training in discourse awareness, teachers and teacher educators can think more explicitly and collaboratively about how to support multilingual learners in changing from, say, the language of negotiation when planning an experiment to the language of explanation and argumentation in representing one's results. Such explicit awareness of the mode continuum, and how its application may vary across disciplinary areas, can support learners in accessing a deeper understanding of new concepts.

Third, through our observations and analysis of our project professional learning activities and student products, we have seen firsthand the limitations in student learning when they do not have access to disciplinary instruction that takes advantage of semantic waving. Some students will remain stuck at the level of concrete examples that had been adequate in earlier grades but becomes less so as students move into middle and high school. Other students will incorrectly come to see science as exclusively the domain of dense and abstract language and ideas, a discourse in which they may feel neither capable nor welcome. In other words, as teachers and teacher educators, we need to be more explicit about the value of promoting student meaning-making as 'traveling' from concrete examples to abstract explanations and back. The example we shared from the water testing investigation provides one illustration of how semantic waving supports student meaning-making around abstract concepts. However, we found examples like this one to be outliers within our broader project. Instead, teachers tended to privilege learning of discrete concepts that were either too abstract or too concrete for many students to fully grasp.

This study also suggests future research questions that need to be answered in this domain. For example, how can secondary grades science teachers better incorporate rich linguistic and cultural repertoires of their students and communities in joint co-construction of scientific knowledge? How can teachers best develop the awareness of, and strategies for supporting the mode continuum that occurs when participants move from the embodied practices of experimentation to oral or written reasoning about science concepts that have been explored? How can teacher educators learn to be more explicit with teachers about the value of promoting student meaning-making as interdisciplinary traveling from concrete examples to abstract explanations and back? What additional theorizing about disciplinary discourses, in and beyond science, can provide new insights into the linguistic resources and challenges of multilingual learners in science classrooms?

Within a broader culturally sustaining model of education, we see our CS SFL in Science framework as suggesting important new dimensions of study. For example, multilingual and multimodal meaning-making needs to be integral elements of a culturally sustaining classroom discourse. Within the NGSS science classroom of the twenty-first century, students should be encouraged and supported in making meaning by drawing upon all available resources (e.g. different languages, modalities). We see such efforts as well aligned with work by Van Horne and Bell (2017) and others to push the NGSS to be more culturally responsive by expanding the three-dimensional science learning framework to include additional dimensions such as those of identity and interest. Rigorous, equitable, and engaging science learning opportunities for all students require frequent opportunities to make meaning that is culturally and linguistically sustaining, multimodal, and characterized by opportunities to engage in semantic waving in accordance with one's purpose and audience.

Notes

1. A wide variety of terms are currently in use to describe individuals who are being educated in predominantly English language settings, but whose home language is other than English. We have currently settled on the term multilingual learners because, for us, it represents a non-hierarchical perspective that, as learners, we always flexibly use the full range of language resources we have available to make and communicate meaning.
2. All names of teachers and students are pseudonyms.
3. Our project provided participating teachers with *Language Boosters* to provide a short (15 min), high interest science text aligned with the science standards and concepts to get students interacting in dynamic and multimodal ways. We also provided them with concept cards in English and Spanish to support deconstructing the language in new investigation along with investigation guides and kits for each embodied inquiry.

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