Language Demands and Opportunities in Relation to Next Generation Science Standards for English Language Learners: What Teachers Need to Know

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This paper discusses challenges and opportunities expected as English language learners (ELLs) engage with Next Generation Science Standards (NGSS). We subscribe to a view of language learning and proficiency that is most concerned with students' ability to use language to function in the context of their lives both in and out of school. We have discussed this view of second language acquisition and its implications for the science classroom in greater detail in a separate paper. Here, we concern ourselves with learning opportunities for ELLs in an English-speaking science classroom in which NGSS have been implemented based on the National Research Council (NRC, 2011) document "*A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*" (hereafter called "the Framework").

The Framework (NRC, 2011) refines and deepens the meaning of the term "inquiry-based science" by identifying a set of science and engineering practices. These practices are both a representation of what scientists do as they engage in scientific inquiry and a necessary part of what students must do to learn science and understand the nature of science. There is a parallel between the Framework's assertion that learning science requires students to engage in these practices, and our claim that meaningful "language for use" learning occurs in contexts where students are required to communicate (speak, listen, read and write) about science. A practice-oriented science classroom can be a rich language-learning as well as science-learning environment, provided teachers ensure that ELLs are supported to participate. Indeed it is a language learning environment for all students, as the discipline itself brings patterns of discourse and terminology that are unfamiliar to most of them. In this context, teacher knowledge about language and language learning support strategies can improve the overall science learning experience of all students, especially of ELLs. We do not suggest that science teachers should function as language teachers, but rather as supporters of the language learning that occurs in a content-rich and discourse-rich classroom environment.

Next Generation Science Standards: Focus on Science and Engineering Practices

The Framework defines science learning as having three dimensions: (1) science and engineering practices, (2) crosscutting concepts, and (3) core ideas in each science discipline. The central content of the Framework document is a detailed explanation of what is intended in each dimension, how the three dimensions should be integrated in curriculum and instruction, and how these dimensions progress in sophistication across K-12.

The framework defines eight science and engineering practices:

1) Asking questions (for science) and defining problems (for engineering);
2) Developing and using models;
3) Planning and carrying out investigations;
4) Analyzing and interpreting data;
5) Using mathematics and computational thinking;
6) Constructing explanations (for science) and developing designs (for engineering);
7) Engaging in argument from evidence; and
8) Obtaining, evaluating and communicating information.

Engagement in any of the practices involves both scientific sense-making and language use. The practices intertwine with one another in the sense-making process. This sense-making is a key endeavor for students as it helps them transition from their naïve conceptions of the world to more scientifically-based conceptions. In particular, we focus here on four of the eight practices, namely 2, 6, 7 and 8. These four practices are selected for the following reasons.

First, these practices represent a major shift. Even where science has been taught in an activity rich “inquiry-based” classroom, the practices related to investigation have often been stressed without an equivalent stress on the four sense-making practices highlighted here. Particularly in the lower grades the activity often ends at the stage of recording observations, with minimal attention paid to interpreting them and almost no attention to constructing models or explanations and refining them through argumentation from evidence.

Second, these practices are deeply interrelated because each is used to support effective engagement in the others. Argumentation from evidence requires students to apply both mental and diagrammed models that clarify their thinking and to develop model-based explanations using evidence (data and observations), logic, and information obtained from outside sources or prior experience. To develop an explanation and examine its success or failure in explaining all the evidence about a phenomenon or system requires argumentation. Clearly students must obtain, evaluate and communicate information as they engage in the process of building and critiquing explanations.

Third, engagement in these practices requires classroom science discourse, which demands both receptive and productive language skills. Students read, write, and visually represent as they develop their models and explanations. They speak and listen as they present their ideas and engage in reasoned argumentation with others to refine them and reach shared conclusions. This offers rich opportunities and demands for language learning at the same time that it supports science learning. Hence these practices merit special attention in science classrooms that include ELLs.

Finally, teachers implementing these practices need an understanding both of the practices and of strategies to engage all students in them regardless of students’ English proficiency. The classroom culture of argumentation must be developed and supported to ensure that all voices are respected and included, even as the process reveals flaws in a student’s model or explanation or limitations of their language proficiency.

Intersections between Science Practices and Language Learning

The learning of school subjects takes place through the use of language in oral and written forms. This section addresses two issues: (1) language skills involved as students engage in science and engineering practices and (2) features of science text and science talk.

Language Intensive Tasks to Engage in Science and Engineering Practices

Students develop facility with all of the eight science practices by using them in a concerted way to support sense-making about a phenomenon or system. Through an iterative cycle of engaging in these practices students develop understanding of science. Language is essential to successfully engage in any of these practices and all of the practices provide language learning opportunities, particularly the four that we discuss below. Engagement in these practices in the classroom both *demands* and *affords* rich student discourse. The discourse of the science classroom, and of science textbooks as well, differs from the everyday discourse of students and from that of a mathematics or language arts classroom or textbook. It is also distinct from the professional discourse and writing of scientists though it mirrors the conventions of that discourse more closely as the students advance across the grades.

The teacher must define and facilitate a classroom culture of discourse. This culture should be inclusive, accepting contributions for their meaning and their value in the discourse however flawed or informal the language of the speaker. It should support students to maintain a spirit of shared sense-making and discovery while they question others, ask for further explanation, and provide arguments that refute an idea expressed. Most importantly for ELLs, it allows students to hear many examples of the discourse that they are expected to produce.

Below we elaborate on the four highlighted practices, stressing the language learning opportunities that they provide as well as their roles in science learning.

Developing and Using Models. Each phenomenon or system under investigation demands description via a model. In developing a model, students operate with language and diagrams as well as with observations of the system in question. The model may include reference to a graph of some data or an equation describing a relationship between quantities. Precise observation demands both precise descriptive language – of which many examples must be provided – and carefully constructed diagrammatic representation. Diagrams can display both the seen (e.g., objects) and the inferred (e.g., force arrows, energy flow across an imagined system boundary) aspects of the system. Diagrams and graphs require labels to help students communicate all that has been observed and inferred about the system.

At all grades students can produce, describe and apply models of a system under study. What progresses across the grades are the sophistication and abstraction of the models that they work with and of the language and diagrams or other representations contained within their description of their model. This progress is aided when the teacher leads students to discuss examples of models, as well as ways to describe them that incorporate higher-level features. The interplay between diagrammatic representations of models, or three-dimensional models, of a system and the language used to describe these representations both builds students' conceptual understanding of the system in question and refines their ability to talk about it. Teaching strategy and repeated practice develops students' ability to make explicit a mental model of a system or process, expose contradictions between observations and the current mental model, and modify the mental model toward a more scientifically-supported one.

The practice of developing and using models provides an initially nonverbal way to express a thought or an understanding. Using models to explain and describe systems provides students an impetus to name aspects or parts of their own model and to speak about how it explains observations. In doing so, students refine their understanding of needed scientific terminology. With a model in hand students can say "this piece here . . . ." and then have a reason to want to know that the piece is called a *cog* or a *flagellum*. This helps students to learn appropriate language in context as they express their ideas and grow in their understanding of the system under study.

Models are useful as more than a record of observation – they support the development of explanations for phenomena. As students support their explanations with reference to their models, their thinking is made more visible and explicit, both to themselves and to others. Language is the essential tool for them to engage in explanations and arguments with their peers around the model at hand. Students' ability to use language precisely is supported by the visual representation of their model. For ELLs the progression from observation of a system to modeling a system, to using language about the system, provides a rich language-learning experience where the learning is driven by the classroom discourse around the objects and ideas being considered and represented.

Developing Explanations (for Science) and Designing Solutions (for Engineering). The process of science is to make ever more precise and explicit explanations of phenomena, while engineering likewise requires precision and explicit features in a design solution. The level of explicit detail of observation and explanation required by science and engineering is not common in everyday experience; it demands a comparable level of precision in language use. Models are an important step in the development of an explanation of how something happens or of an idea for a design solution. When students are provided examples of diagrams and descriptions of models and then diagram and describe the model that underlies their proffered explanation or design, they become more explicit about their ideas. This move toward explicit detail occurs even when students do not yet have the language to be explicit if simply asked for a verbal explanation or design proposal. Thus like the process of developing models, the process of developing explanations and designs involves language development, mediated by diagrams, lists, charts and other elements of models and observations and examples of the types of verbal explanations that are the end goal of student learning.

As students are asked to explain their ideas or designs and critique those of others, including written examples, they learn from the experience of encountering multiple examples of the level of precision and detail that scientific thinking requires. Likewise students' ability to use technical terminology develops because they need the precision that it offers. This process needs teacher support but it is not helpful to insist on distinctions in terminology for which the student does not yet have access to distinctions in concept. This is particularly true for words such as *energy* that have an everyday usage broader and less defined than their scientific meaning. The development of correct scientific language usage comes from the development of scientific concepts through experience and application; it cannot be achieved by learning definitions. In this sense all students are language learners.

Engaging in Argument from Evidence. Argument is a discourse practice, whether practiced in writing or verbally. Across all disciplines an argument can be deconstructed as a claim and the logic and evidence used to support or refute that claim. What counts as evidence is discipline-specific. In science what counts as evidence is data and observations. Hence argumentation in science is not a purely verbal exercise. It is an exercise in the coordination of language and experience and thus another rich language learning opportunity.

As students analyze written examples of arguments they learn the characteristics of a strong scientific justification of a claim and they learn to identify weak support. As they engage in argument with others to arrive at a shared “best” explanation or model, they are motivated to clarify both their language and their thinking by the atmosphere of shared interest and goals.

Obtaining, Evaluating and Communicating Information. This practice, more than any other, points to reading and writing as well as to listening and speaking. It is here that the student meets the difficulties of reading and interpreting scientific writing, though typically not at the level of scientific papers. The writing in question is that of textbooks, science-related trade books, websites and popular articles about science. Each of these genres has different language conventions.

Particular challenges for ELLs arise when they are asked to read textbooks or other written materials about a science topic. Challenges can be of two types. First, ELLs may not have developed strong reading skills if their previous ESL instruction primarily focused on grammatical structures. They will therefore need support in the development of reading comprehension proficiencies. Second, the language style and complexity of texts written for science learners is different from those of other written genres encountered in other school subjects and from spoken language, as we discuss below. Thus all students need support and strategies for reading these materials.

Students need multiple opportunities to write after they have been guided in examining examples of the type of writing that is required. For example, if students are to be asked to regularly use journals to develop and express their own understanding and to engage in metacognition about it, they need to see examples of such writing. Similarly, before they are expected to give oral presentations and written reports that demonstrate what they have understood or to describe an investigation or design project, they should be given examples of such presentations and reports. The point of this work is science understanding and science communication; these exercises should not become tests of accuracy and fluency of language production. Opportunities to revise and correct are appropriate for formal reports; however, for journal writing the emphasis should be on rethinking rather than on rewriting. Nevertheless students must understand what writing that reflects thinking looks like as well as what it includes and does not include.

Features of Science Language

It is helpful for science teachers to understand that not only technical terms, but also other features of science text and science talk, may make them difficult for students to understand. All students encounter these difficulties, but problems may be magnified for ELLs who have not had access to good instruction. We here briefly review these features.

Science vocabulary. As they engage with science students need to code-switch from everyday uses of language to the language of science (Brown & Ryoo, 2008; Moje, Collazo, Carillo, & Marx, 2001). Within science vocabulary there are different types of challenges for students. First, some everyday words have science-specific meanings that are different from or more narrowly-defined than their everyday meanings (e.g., *force*, *energy*, *work*, *cell*, *space*, *fault*). Second, general academic vocabulary that is used across disciplines (e.g., *compare*, *infer*, *analyze*, *evaluate*; tier II words according to Beck, McKeown, & Kucan, 2002) present challenges. Third, discipline specific words invented and defined for science use (e.g., *gene*, *biome*, *proton*; tier III words according to Beck et al., 2002) are new to most students, even those with fluency in everyday English. Finally, even everyday words can make subtle shifts in meaning as they are used in science. For example, in everyday English, "Why did that happen?" may be asking about the motivations of those that made it happen, whereas in the natural sciences it is asking students to restrict their attention to the mechanisms and conditions that caused the effect.

Science Discourse. Each area of science has different disciplinary discourse conventions, adapted to what has proven effective and efficient for communication among experts. Learning the register of discourse of a discipline is a form of socialization into how members of the discipline talk, write, and participate in the knowledge construction. These differences are reflected in science textbooks and classroom talk, which have registers specific to a discipline and grade level. Students must absorb these differences in register as they work to construct meaning appropriate to the topic at hand.

Science discourse at any level requires students to attend to and argue about precise meanings. This demand for attention to precision and attention to detail goes beyond the meaning of technical vocabulary, to the evidence and logic of connecting cause and effect, and the validity of claims or warrants. Students must develop an understanding of the forms of this discourse as well those used in written science text.

Multiple Modes of Representation. Science information is conveyed not just through oral or textual forms but also through visual and mathematical representations, including pictures, diagrams, graphs, charts, tables, maps, and equations. Students need to master these non-linguistic modes of representation to gain an understanding of science. In addition they need to coordinate information presented through the various modes into a single coherent understanding of the material being presented or a coherent presentation of their own ideas. For ELLs the coordination of these multiple representations provides an additional path to language learning, as well as to science learning.

Science Texts. Discipline-specific texts written for learners typically have particular features that over time have been thought to provide the most effective way for the content of that discipline to be expressed. It is helpful for students to examine these features and discuss why they are used. Recent analyses of the written language of secondary science texts carried out from the perspective of Systemic Functional Linguistics have found that these text structures are complex and include lexical, syntactic, and discourse structures that are not typically present in everyday language (Fang & Schleppegrell, 2008; Halliday & Martin, 1993; Halliday & Matthiessen, 2004; Schleppegrell, 2004). Key features include:

- Authoritativeness to "suppress" human agents behind events, concepts, and discoveries and to render the scientific discourse more objective or timeless through simple present tense, passive voice, generalized or virtual participants ('scientists,' 'research team members'), and hidden evaluations ('claimed,' 'confirmed').

- Nominalization of verbs or adjectives into nouns to economically summarize sentences into one abstract noun phrase

- Long and complex noun phrases and clauses to effectively pack complex content within shorter sentences

- Technical vocabulary to use terms with specialized meanings in science lexical density to "pack" texts with more information

Supporting Science and Language Learning for ELLs

We note five areas where teachers can support science and language for ELLs: (1) literacy strategies with all students, (2) language support strategies with ELLs, (3) discourse strategies with ELLs, (4) home language support, and (5) home culture connections.

Literacy Strategies. In science classrooms, effective teachers incorporate reading and writing strategies in their instruction to promote both science learning and literacy development for all students (Douglas, Klentschy, Worth, & Binder, 2006). These strategies include activating prior knowledge, having explicit discussion of reading strategies for scientific texts, prompting students to use academic language functions (e.g., *describe*, *explain*, *predict*, *infer*, *conclude*) in science practices, requiring and exemplifying scientific genres of writing (e.g., keeping a science journal, investigation or design reports, conference posters), teaching the uses of graphic organizers (e.g., concept map, word wall, Venn diagram), encouraging reading trade books or literature with scientific themes, and providing journal writing prompts (e.g., *I observed…*, *I noticed…, I wondered…*, *I inferred…*) as part of an investigation protocol.

It is not a service to language learners to "protect" them from the demands of subject area reading. If they are to reach grade level understanding of a topic, they will need strategies for reading the relevant text and interpreting its complex sentences, as well as for linking these to diagrams, data charts and equations that appear in the same section. In supporting students to read and understand scientific texts, it is more important to provide them with strategies for sense making and ways to "decode" complex sentences and to coordinate text and diagrams than to provide vocabulary lists and glossaries. Word definitions are indeed sometimes needed but they are better learned by use in context than by memorizing a vocabulary list. Dictionary use is likewise a helpful but limited strategy. (However, ELLs should be encouraged to use an English to English dictionary to interpret unfamiliar words before resorting to a translation dictionary.)

Students are expected to learn how to describe, explain, and predict phenomena in science-specific genres of writing (Hand, Wallace, & Yang, 2004; Palincsar & Magnusson, 2001). They need to report science investigations and design projects in multiple-mode formats (e.g., those that include written description plus graphs of data, diagrams of equipment or observations). Additionally, students need to code-switch from everyday uses of language (e.g., telling or writing stories) to the language of science (Brown & Ryoo, 2008; Brown & Spang, 2008). To perform the kinds of writing tasks described here, all students, but particularly ELLs, benefit from multiple examples of the desired product, annotated and discussed by the whole class or in small groups to examine the organizational structure and particular features. For example, without teaching the passive voice as such, teachers can certainly call students' attention to the fact that all the actions in a particular paragraph have no specified agent (e.g., data are examined, conclusions are reached) and that this is a common feature of scientific writing.

ELLs' needs with respect to written materials used in science class require ongoing attention from teachers. The joint goals of science and language learning must both be considered as strategies that are chosen to assist any student in mastering a difficult reading assignment. The appropriate strategy for a student depends on the student's language level, reading level, and science comprehension level. The more the teacher is aware of all three through their observation (formative assessment) of the student, the better s/he can match the student's needs.

Language Support Strategies

To support ELLs in learning science and developing English proficiency simultaneously, teachers engage students in purposeful activities, ensure that students experience multiple examples of language in use, and call students' attention to the ways in which language is used to communicate meaning in science. They encourage students to communicate and reflect about ideas and to engage with others in sense-making talk and activity. They encourage non-linguistic modes of representation (e.g., graphs, charts, tables, diagrams, pictures), as well as language production. They guide students to comprehend, through use in context, key science vocabulary – both general academic terms (tier II words) and discipline specific terms (tier III words) (Beck et al., 2002). All these strategies for science teaching support ELLs, provided teachers ensure that these students are full members of the classroom science discourse community.

Student journals of their science activity and thinking are a major tool used in many science classrooms and they can also provide support for language learning. Students are encouraged to use their journals to record observations, develop explicit representations of their models, and analyze their experiences and understandings of what they are learning in science. This is not formal science writing; it is writing to make thinking explicit. Journals become an effective tool only if they are used regularly and if in-class time is provided for reflective writing about what has just occurred in an activity or a discussion. Early stage ELLs may gain science understanding by doing this writing initially in their first language *if they have been instructed in this language,* but should be encouraged to then restate (rather than to translate) this thinking in English. As language proficiency in English develops, the student should be encouraged to transition to thinking and writing in English.

Discourse Strategies. Discourse strategies can be used to enhance ELLs' understanding of academic content (i.e., adjust the level and mode of communication). Discourse strategies focus specifically on the teacher's role in facilitating ELLs' participation in classroom discourse (Gibbons, 2006). A major challenge for teachers is in how to structure activities so as to reduce the language barrier for participation while maintaining the rigor of science content and processes.

The implementation of science and engineering practices demands that students work and talk with one another, sometimes in small groups, sometimes as a whole class. Classroom management strategies for students to engage in such work begin with the establishment of a classroom culture as to what is acceptable behavior. The mode of argument from evidence must be established, with norms that ensure civil discourse and respect for all speakers. Inclusion of ELLs in the discourse must be established (by example) as a part of this culture.

Further, one of the discourse conventions should be that any participant should feel free to say, "I did not understand what you said" and ask for repetition or clarification. Whether the lack of understanding is at its root linguistic or whether it depends on the conceptual clarity of what has been said, the respectful back and forth of questioning and responses will lead to the further development of understanding of science concepts and of the language needed to discuss them.

Teachers need to recognize ELLs' varying levels of developing language proficiency and adjust norms of interaction with a student accordingly, for example, by using clearer enunciation or longer periods of wait time. They provide students with multiple redundancies of the same concepts, for example, using synonyms or paraphrases of difficult language, repeating and rephrasing main ideas, or recasting and elaborating on students' responses (Gibbons, 2006). If they have beginners in their classes, they determine which students can and cannot understand whole class explanations and they provide alternatives for those who need such alternatives. They use multiple modes of representation (gestural, oral, pictorial, graphic, and textual) to communicate meanings. They amplify rather than simplify their presentations, expressing concepts in multiple ways (van Lier & Walqui, 2010).

A student with an idea to share will want to express that idea. Often the language used to do so will not be "correct" either in the sense that the words used are not the correct technical terms, or that the grammar of the sentences is non-canonical. If these normal characteristics of emerging English are corrected, the discourse becomes stilted and the student's urge to speak is suppressed. A teacher needs to mediate such discussions to ensure that poorly-expressed ideas are being heard and considered by others, not to ensure that the students speak correctly. Asking questions to elicit amplification or clarification of an expressed idea is an effective strategy. Asking students to restate in their own words an idea just expressed by another provides chances to speak, to clarify an idea, and for the teacher to check whether other students have followed what was said. This exercise can begin with a good idea that was well expressed, or one that was poorly expressed. Either way, the repetition and ensuing discussion reinforce the idea and the language needed to talk about it. Both precision and correctness in language use develop from repeated experiences, and from models offered by the teacher in summarizing or interpreting a student's statement.

Home Language Support. It is important to draw a distinction between home language instruction (i.e., bilingual education) and home language support (Goldenberg, 2008). Even in the absence of bilingual education programs or fully-trained bilingual teachers, ELLs' home language can be used as instructional support for their learning of academic content and processes in English.

In the science classroom teachers can build upon and make use of students' home language to support science learning in English. If teachers share the same home language as their students they can use the home language to communicate and reinforce key science vocabulary and concepts (Hudicourt-Barnes, 2003). They can also allow students to communicate using combinations of their first language and English, referred to by Garcia (2009) as "translanguaging." If teachers do not speak students' home language, the home language can still be supported through a number of strategies. In the beginning of a lesson, teachers may introduce key science terminology in both the home language and English. Teachers may highlight cognates as well as false cognates between English and the home language. For example, Spanish and other Romance lexicon are often derived from Latin, the primary language of science. Bravo, Hiebert, and Pearson (2007) found that approximately 88% of key science words selected for instruction were cognates in Spanish and about half of them were high-frequency words in Spanish. Such cognates are likely to be known by Spanish speakers, even those with limited schooling in their first language.

In a bridge period for students entering with very limited English, teachers may encourage bilingual students to assist them in their home language as well as in English, allow ELLs to write about science ideas or investigations in their home language, and invite family and community members to participate as local experts in classroom literacy events. When students are asked to engage with other students in their common home language, a small group discussion is preferable to a single student "translation," which may transmit the conceptual errors of the speaker. The small group should also be asked to communicate their conclusions to others in English.

Home Culture Connections. While making connections to ELLs' home language is quite concrete, the notion of making connections to their cultural experiences in relation to academic content can be more abstract and subtle. Since science has traditionally been regarded as "culture-free," incorporation of home culture into science instruction is often ignored. Most science educators need a better understanding of how to articulate connections between home culture and school science (Lee, 2002; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001).

The literature on cultural congruence indicates that students participate in classroom interactions in ways that reflect culturally-based communication and interaction patterns from their home and community (Gay, 2002; Villegas & Lucas, 2002). Teachers need to know how different students might be more or less familiar with the participation norms that are expected in science classrooms, what interactional patterns are common among different groups of students, and how these patterns might foster or constrain students' participation in science classrooms. Teachers must balance considerations of culturally-based patterns of communication and interaction with the risks of applying stereotypes or over-generalization based on students' cultural backgrounds. Teachers make the norms and expectations for classroom discourse explicit and look for opportunities to honor the full range of student discourse patterns when appropriate. For example, cross-talk (talking simultaneously with other speakers to add to what they are saying) is completely acceptable in some cultures, while it is considered rude and disruptive in other cultures including the cultural norms in most U.S. schools (Lee & Fradd, 1996).

The literature on funds of knowledge indicates that the lived experiences of students at home and in the community can serve as intellectual resources for academic learning (González, Moll, & Amanti, 2005; Moll, 1992). In science classrooms teachers ask questions that elicit students' funds of knowledge related to science topics (Solano-Flores & Nelson-Barber, 2001). They use cultural artifacts and community resources in ways that are academically meaningful and culturally relevant. These cultural connections can be of great assistance as ELLs strive to integrate prior experiences with new academic expectations. For example, Rodriguez and Berryman (2002) worked with high school students in predominantly Latino and impoverished school settings in a U.S.-Mexican border city. Using a curriculum unit on investigating water quality in their community, the students engaged in authentic science as they explored how this topic was socially relevant and connected to their everyday lives. Having come to see science as relevant to their lives, students saw scientific investigations as worthwhile for themselves and for students in other schools in the region.

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