EL STEM COMMITTEE REPORT: Secondary Science Education for English Learners

Sara Tolbert, PhD.,
Associate Professor, University of Arizona
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Introduction

Over the past few decades, research, theory, and practices informing science education for English learners have changed and developed, largely in accordance with parallel progressive movements in science education, language and literacy education, TESOL education, and bilingual education. At the core of these intersecting movements are the ideas that that the actual doing of science is, in essence, a deep, meaningful engagement with disciplinary language and literacy practices (Lemke, 1990), that language and science learning are reciprocal and interrelated endeavors (Stoddart, Pinal, Latzke, & Canaday, 2002), and that English learners' funds of knowledge and language practices must be engaged as resources for new language and content learning (Garcia, 2009; Gonzalez, Moll & Amanti, 2005; Rosebery & Warren, 2008). A recognition of the fundamental and synergistic relationship between language, literacy, and science learning has important implications for ELs in science classrooms. The focus of this section is on the implications for ELs in secondary classrooms, who are denied opportunities to learn science when English proficiency is positioned, either through implicit or explicit norms and policies, as a prerequisite for access to secondary science courses.

In secondary settings, the majority of English learners were born in the United States and most are long-term ELs, meaning they have been receiving ESL services in US schools for at least six years and have some familiarity with the English language (Batalova, Fix, & Murray, 2007; Menken & Kleyn, 2010; NCES, 2002; Solis & Bunch, 2016). Achievement gaps between ELs and non-EL students actually increase from elementary school to secondary school (NCES, 2016) and ELs are graduating from high school at lower rates than other minoritized groups such as (non-EL) Latino students, Black students, or low-income students (Promise Alliance, 2017). Research across a variety of state contexts has shown that EL students are often systematically excluded from rigorous or advanced coursework in science due to the misconception that they must be proficient in English before they can be successful in content area classes (Callahan, 2017; Gándara & Hopkins, 2010; Rios-Aguilar, Gonzalez-Canche, & Moll, 2010). This exclusion has had severe consequences on educational opportunities for English learners and has been referred to as a form of linguistic apartheid (Combs, Iddings, & Moll, 2014). English learners fare far better in terms of both content and language measures as well as requirements for graduation and college admissions when they have opportunities to learn rigorous academic content, such as that found in advanced secondary science courses (Callahan, 2005, 2017; NCES, 2002).

Science education for English learners, at all levels, requires a shift from instructional approaches and models grounded in the idea learning English should be a discrete and separate enterprise from learning science (Stoddart, Pinal, Latzke, & Canaday, 2002). A key challenge facing English learners in secondary science courses is simultaneously learning complex scientific concepts, low frequency technical vocabulary, disciplinary literacy forms and functions (e.g., communicating findings through technical reports) in a new language *while also acquiring* the

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new language (Solís & Bunch, 2016). These are quite daunting tasks for students, particularly if they are not receiving instruction in classrooms with teachers who are prepared to provide responsive and appropriate language scaffolds (Bunch, 2013). Rather than focusing on more mechanical learning outcomes like grammar and syntax, however, language learning goals and outcomes should focus on ELs' abilities to use language for scientific sense-making and communication across a variety of contexts, including oral (speaking), aural (listening), and written (reading, writing) language forms (Hakuta, Santos, & Fang, 2013; Quinn, Lee, & Valdés, 2012). In the same vein, language should be appropriate and responsive to the EL student's level of English proficiency, with key learning goals being "the productive use of core science ideas" and "the productive use of language while engaging in authentic scientific practices and texts" (p. 71, Tolbert, Stoddart, Lyon, & Solis, 2014).

Secondary Science Education for English Learners: Integrating Scientific Sense-Making with Disciplinary Language Practices

All students benefit from responsive and supportive science learning contexts that attend to the integrated nature of language use and science learning. The difference is that ELs are much less likely to be successful in school science without those supports. Tolbert et al., (2014) provide a practice-based framework, *Secondary Science Teaching with English Language and Literacy Acquisition* (SSTELLA), for the integration of language and science in secondary classrooms. The SSTELLA framework is designed to be incorporated across instruction in a variety of secondary classroom contexts, including bilingual science classrooms and sheltered science classrooms, as well as science classrooms in which teachers serve both ELs and non-ELs, and ELs who have been reclassified. In SSTELLA, "the focus is not for science teachers to teach 'language' as a separate entity, and certainly not for them to teach ELA, but rather to rethink how they teach science," capitalizing on the linguistic affordances of the discipline (p. 41, Solis & Bunch, 2016).

Tolbert et al. (2014) articulate four dimensions of responsive and supportive learning contexts for English learners in secondary science classrooms (see Lyon, Tolbert, Solis, Stoddart, & Bunch, 2016, for an elaborated description of each dimension). These include: (1) *Contextualizing Science Activity*-framing learning experiences in meaningful and relevant socioscientific and/or real world issues that elicit and leverage students' funds of knowledge; (2) *Scientific Sensemaking*-making explicit connections to overarching core ideas, phenomena, or driving questions while engaging students in scientific practice as they draw on multiple sensemaking resources to grapple with those core ideas; (3) *Scientific Discourse*-actively engaging students in both written and oral as well as productive and receptive forms of scientific discourse; and (4) *Language and Literacy Development*-ensuring that ELs are well supported to participate fully in the aforementioned dimensions, e.g., through promoting students' use of their home languages (even if/when the teacher is not proficient in these languages), translanguaging, purposeful grouping and cooperative structures, student-centered learning, facilitating student understanding and use of technical vocabulary, and providing appropriate language scaffolds. In SSTELLA, expanding opportunities for English learners in 21st century classrooms also means providing learning experiences that prepare ELs to participate more fully in personal and civic problem-solving (Tolbert, 2016). As part of regular classroom instruction, EL students should engage often in understanding science-related societal problems that affect local communities.

In one example of a lesson that incorporates the SSTELLA framework, EL students (along with non-EL students) learn core ideas about natural selection through studying the antibiotic resistance of MRSA (Lyon, 2016). The multi-day lesson is designed with attention to the NGSS standard, HS-LS4-2, Biological Evolution: Unity and Diversity, whereby the performance expectation is that students will be able to use evidence to explain how evolution results from population growth, differential reproductive success, competition, and heritable genetic variation. The lesson also addresses WIDA English language proficiency standards (Standard 4, Grades 9-12), Common Core State Standards for Literacy in Social Sciences, Sciences, and Technical Subjects (Writing 2: Grades 9 to 10), and productive and receptive language functions as outlined in the Framework for English Language Proficiency Development Standards corresponding to the CCSS and NGSS (CCSSO, 2012).

During the lesson series, students construct an explanatory model that draws on the theory of natural selection to describe a real world problem, the antibiotic resistance of MRSA. The overarching objective is that students will "explain how the species Staphylococcus aureus changed so that over 60 percent are methicillin resistant" (p. 40, Lyon, 2016). Essential to this framing context is the elicitation of students' own experiences with having relatives or friends in hospitals. After sharing their own experiences in hospitals (e.g. experiencing an injury, the birth of a relative, visiting hospitalized friends and relatives, etc.), they respond to the question, "Do you think someone could be harmed from bacteria while staying in a local hospital?" (p. 36, Lyon, 2016). After discussing this question with a partner and then as a whole class, students watch a brief YouTube clip from a local news report about "superbugs." The reporter asks, "What causes these so-called superbugs?" This question frames the students' learning experiences. Students use a graphic organizer to clarify important ideas from the video, including "species of interest," "MRSA," "antibiotic", and multiple-meaning words such as "resistance."

Over the next several days, students construct an initial explanatory model, which they test, revise, and refine, as they learn the influential factors of evolution through a series of activities such as Oh Deer!, a worm-eater simulation, and so on (see Passmore, Coleman, Horton, & Parker, 2013). They then use a graphic organizer to analyze the claims, evidence, and audience in three different texts with three different purposes, all related to MRSA, before finalizing their explanatory model about "how the species Staphylococcus aureus changed so that over 60 percent are methicillin resistant." In a final activity, students are given a new set of data about resistance to the antibiotic Vancomycin commonly used to treat MRSA and are asked to "apply your own understanding about adaptation and natural selection to explain with evidence how the percentage of bacteria resistant to Vancomycin changed from 1983 to 2001" (p. 41, Lyon, 2016). As an extension of this assignment, students are asked to communicate findings to a different audience, such writing for a school newspaper or a local daycare center.

Throughout this series of activities, the teacher attends to students' simultaneous development of core ideas about natural selection and disciplinary literacy practices, in this case, constructing evidence-based scientific explanations. English learners are supported through language scaffolds such as cooperative learning structures, explicit vocabulary instruction as needed to support conceptual understanding and interpret and communicate findings, varied graphic organizers designed to hone students in on key elements and key vocabulary related to a concept, and real world contexts and students' own lived experiences as frames for learning. Students have "multiple modes of representation and thinking to use language and can practice interpreting and producing discipline-specific uses of language" (p. 42, Lyon, 2016). Walqui &

Heritage (2012) describe scaffolding for ELs in content area instruction as "the 'just right' kind of support required by students to engage in practice that helps them mature processes which are at the cusp of developing, while simultaneously engaging their agency" (p. 4). It is with this understanding of language development upon which the SSTELLA framework is founded. In the MRSA lesson, students are supported through appropriate scaffolds that progressively facilitate their construction of an explanatory model, while allowing students both "generativity and autonomy" within the academic tasks (p. 4, Walqui & Heritage, 2012).

These new shifts in approaches to content learning and language learning have important implications for how teachers (both ESL and content area teachers) are prepared to support ELs. It is not sufficient to equip teachers with a set of generic strategies to help ELs access the content of a disciplinary subject, though this is still the focus of most teacher education and professional development programs (Faltis & Valdes, 2016). Rather, teachers must learn how to support ELs to participate in and develop the language and literacy practices of the discipline (Solis & Bunch, 2016).

Programmatic and Systemic Reforms that Support ELs' Opportunities to Learn Science

This shifting focus on language and science learning for ELs as reciprocal and synergistic necessitates *well articulated* collaborations among education professionals. Though some states and districts have used reclassification as a measure of EL school success, recent research indicates that this approach does not fully portray how ELs fare in mainstream settings. Rather than prioritizing rapid reclassification of ELs so that ELs can enroll in mainstream classes,

> EL status should be designed so that it does not inhibit full access to rigorous content and interaction with English-speaking peers. In practice, this would mean ensuring that ELD classes do not prevent enrollment in other classes, that teachers are properly prepared to teach ELs within mainstream classes, [and] that English language instruction is embedded in content area classes… (p. 907, Umansky & Reardon, 2014)

Such efforts must ensure that curricular materials, policies, and instruction to support ELs attend to the simultaneous development of language, analytical practices, and disciplinary literacies as a means for increasing ELs' opportunities to learn in secondary settings. Ongoing professional development for content area educators as well as ESL educators regarding how to best support students' opportunities to learn language and content should be a key priority of district initiatives (Hopkins, Lowenhaupt, & Sweet, 2015), and district reforms and initiatives should institutionalize collaborations between language and content educators (Hopkins et al., 2015; Massachusetts Department of Elementary and Secondary Education, 2016; Umansky & Reardon, 2014). To date, there are few published examples of these collaborations in secondary education, particularly ones that have demonstrated potential for scalability, yet we know that district infrastructure plays a key role in teachers' opportunities to learn about and implement teaching practices that support ELs in content area instruction (Hopkins et al., 2015). Below, we describe a few examples of successful collaborations that could be used to inform other similar systemic initiatives.

Flores and Schissel (2014) articulate that a key problem with many state and national standards movements is that an underlying monoglossic perspective on language hinders the development of English learners' dynamic bilingualism. Furthermore, they argue that monoglossic language ideologies (i.e., positioning monolingualism vs. bilingualism or multilingualism as the norm) in standards movements constrain teachers' abilities to create heteroglossic spaces where students are encouraged to simultaneously develop and use English and their home languages as resources for sensemaking. In heteroglossic classroom spaces, teachers encourage the use of translanguaging practices (or fluid language practices, see Garcia 2009) as "legitimate forms of communication that enable emergent bilinguals to develop metalinguistic awareness that can be used as a starting point in adding new language practices to their linguistic repertoires" (p. 461, Flores and Schissel, 2014). They highlight the New York State Bilingual Common Core Initiative as example by which states can begin to shift toward articulating heteroglossic ideologies (i.e., bilingualism as the norm) in state standards and in K-12 classrooms. This initiative promotes a more dynamic view of bilingualism, affirming that "when provided appropriate scaffolding, language learners can start developing language for academic purposes at the same time that they are developing basic communication skills in their new language" (New York State Bilingual Common Core Initiative, as cited in Flores and Schissel, p. 471). Rather than providing strict guidelines or measures for *how* students should develop a new language, the New York state initiative articulates *new-language progressions* that describe how teachers can support students to engage in grade-level classroom activities at the 5 different levels of English (or new) language proficiency (entering, emerging, transitioning, expanding, and commanding).

The more effective approaches to English learners' overall academic success, including content area coursework such as science, appear to be bilingual or two-way immersion programs (Reljic, Ferring, & Martin, 2015; Rolstad, Mahoney, & Glass, 2005, 2008; Thomas & Collier, 2002). Furthermore, teachers who are bilingual and/or have been prepared through bilingual teacher education programs may be better prepared to leverage the linguistic and cultural resources of English learner students in content area instruction, including science (Hopkins, 2013; Tolbert & Knox, 2016). There continues to be a persistent nation-wide shortage, however, of bilingual teachers. Programs to recruit and prepare local residents as bilingual teachers have demonstrated some promise in fulfilling the urgent need for more bilingual teachers in schools with high populations of English learners, though these programs may face a sharp decline in enrollment resulting from restrictive immigration reform (Garcia, 2017). Given what we know about the effectiveness of bilingual programs for ELs, efforts to recruit and prepare bilingual teachers must continue. Facing a continuing shortage of qualified bilingual teachers and bilingual programs at the secondary level, particularly in science, secondary teachers who are not bilingual or who are not teaching in bilingual programs can be prepared to facilitate English learners' opportunities to learn science (Bunch, 2013; Buxton et al., 2017; Lyon, Stoddart, Bunch, Tolbert, Salinas, & Solis, forthcoming; Tolbert et al., 2014).

As part of the Massachusetts Department of Elementary and Secondary Education Rethinking Equity and Teaching for English Language Learners (RETELL) Initiative, a series of model "Next Generation" curriculum units along with recommendations for ESL curriculum development were developed through a collaboration among curriculum experts, teachers, research partners, and over 30 participating school districts. Key goals of The Next Generation ESL Project were to facilitate increased collaborations between content and ESL educators in accordance with the new focus on content and language integration, specifically in this case integrating ESL standards (i.e., WIDA) with the key academic practices of CCSS and NGSS. Two foundational beliefs guided the curriculum design collaboration:

1. Schooling should help all students reach their highest potential, encouraging critical thinking and agency so that all students can participate more directly in the societal processes that affect themselves, their families, and their communities.
2. Schooling should incorporate an asset-based approach that values the languages, cultures, and experiences that students bring to our schools. (p. 1, Massachusetts Department of Elementary and Secondary Education, 2016).

A Collaboration Tool was developed to guide language and content educators so that curricular materials and planning documents attend to the simultaneous development of language, analytical practices, and disciplinary literacies. The collaboration tool "strategically interweaves cross-cutting academic practices with linguistic prioritization strategies" and includes a "multi-component framework for integrated and contextualized language-driven curriculum development" (p. 44, Massachusetts Department of Elementary and Secondary Education, 2016). Resulting from these collaborations were the development of model curriculum units available online for teachers across preK-12 grade bands and content areas, including science). The units are designed to engage English Learners in simultaneously learning language and content while participating in critical thinking and grade-level academic practices, such as the scientific and engineering practices. Additionally, these units incorporate learning progressions research, indicating prerequisite concepts upon which the units build while also indicating students' potential alternate conceptions. Vocabulary development is contextualized and supports content learning and academic language development.

In a model high school chemistry unit (grades 9-10), Use of Bioplastics in Food Safety, students learn about the structure-property relationship of covalent molecules in the context of food packaging and food safety. Students draw on engineering practices to propose a design for synthetic bioplastic-based food packaging. The unit integrates NGSS physical science standards and engineering standards alongside CCSS ELA standards. Language objectives are included with each lesson, specifically designed to support EL student engagement with the analytic activity, e.g., Students can read and analyze text and visual depictions, write a short report, etc. Target academic language (general and technical) is identified for each lesson as well, such as "bioplastic, biodegradable, properties, density, hardness, flexibility, reactivity with acids and bases, transparency, criteria" (Massachusetts Department of Elementary and Secondary Education, 2015). Language scaffolds are appropriate and responsive to the activity, including supports such as graphic organizers, rubrics for self- and peer evaluations, text annotations, cooperative structures, etc.

The RETELL project also offers several suggestions for structural reforms to support ELs in a variety of school and classroom settings (p. 35, Massachusetts Department of Elementary and Secondary Education, 2016). These suggestions include more systematically involving ESL teacher in school leadership teams and district initiatives, creating common planning times for ESL teachers and content area teachers, providing ongoing professional development for both ESL teachers and content area teachers regarding both the integration of content and language instruction as well as co-teaching strategies, developing language focused content area curricula, paying particular attention to the schedules of EL students to ensure they have access to *grade-level* content area courses, developing strategies to engage families at school and district events, ensuring that both ESL and content area teachers are supported appropriately, e.g., with paraprofessionals and ESL coaches, and that materials, resources, and physical spaces appropriately support ELs across a variety of instructional arrangements (such as in self-contained, pull out programs, mainstreaming, etc.). The RETELL project also describes additional structures that more effectively support ELs in mainstream classes. These include ensuring that classroom spaces are thoughtfully arranged with attention to the needs of ELs in content learning (e.g., organized for small group instruction, etc.), purposeful grouping of ELs with considerations for English language proficiency, home language, etc., establishing processes and procedures for collaboration between ESL and content area teachers such as shared assessments of student learning, protocols for co-teaching, etc.

The SSTELLA framework described previously has been successfully integrated in five teacher education programs across three different states (Arizona, California, and Texas) (NSF DRL-1316834) with very different state policy contexts for ELs and for science education. These differences reflect some of the diversity in state policy contexts nationwide. Arizona, for example, incorporated a modified version of the CCSS into their state standards for math and English language arts, though not NGSS (to date). California adopted both NGSS and CCSS. Texas did not adopt either set of standards. Regarding EL instruction, Arizona requires students who speak a home language other than English and do not pass the state English language proficiency test to be assigned to a four-hour English-only structured English immersion block, where the focus of instruction is on English language and not content learning. The implications of this for EL students is (1) limited access to secondary science coursework, and (2) upon reclassification, they enter mainstream secondary science courses with little prior exposure to school science. In California, all teachers are required to receive training in EL instruction, and both Texas and California offer a variety of models for supporting ELs in content area learning, including sheltered instruction and bilingual education.

The five teacher education programs which integrated the SSTELLA framework and instructional practices also reflected considerable variation, including both undergraduate and graduate teacher preparation programs (see Lyon et al., forthcoming). The SSTELLA intervention was developed in the context of responding to these various contexts and does not, therefore, adhere to a program delivery model of teacher education and professional development. Rather, SSTELLA provides a framework that includes 9 instructional practices and set of tools upon which (1) university teacher educators and mentor teachers can draw to support novice teachers in developing responsive teaching practices; and (2) novice teachers can draw to help support EL student engagement in the disciplinary practices of science. SSTELLA researchers drew from Thompson & William's (2008) "tight but loose" approach to implementing reforms. Thompson & William argue that any "reform needs to maintain fidelity to its core principles, or theory of action, if there is to be any hope of achieving its desired outcomes" but must also allow enough flexibility to "take advantage of local opportunities while accommodating certain unmovable local constraints" (p. 2). Participating science teacher educators, cooperating teachers, and university supervisors maintained fidelity to the SSTELLA practices and overarching theoretical stance on language, literacy, and science integration through the collaborative development and use of common tools, without having to relinquish local control and flexibility over connections to state standards, sequencing of curricular activities, lesson planning, assessment and evaluation tools, etc.

Across these five programs, results from observations of 48 novice teachers in a baseline group who did not participate in SSTELLA-integrated programs compared to 82 novice teachers who participated in SSTELLA-informed teacher education programs indicate that teachers can be prepared to learn and use responsive and supportive practices for English learners (e.g., like the SSTELLA practices) in secondary science classrooms (Lyon et al., 2016; Lyon et al., forthcoming). It is clear from this work that whichever model or framework is used to support professional learning for teachers, university teacher educators, and district professionals, it must be *flexible* enough to be implemented across a variety of political and institutional contexts, and *responsive* to the student diversity among the EL and to the *disciplinary literacies and practices of science* (Lyon et al., forthcoming). Given the incredible diversity of EL students, classrooms, districts, teacher education programs, certification requirements, and local and state policies for educating ELs in secondary settings, success of any program to improve learning opportunities for ELs in science depends greatly on its ability to accommodate these differences.

Ongoing Challenges and Concluding Thoughts

High needs schools and districts face persistent shortages of qualified bilingual, ESL, and science teachers (NRC, 2010). Furthermore, secondary science teachers feel least prepared to meet the needs of EL students over any other student group (Banilower et al., 2013). Efforts to continue to effectively prepare, recruit, and retain highly qualified science teachers for instruction with ELs must remain a highest priority for federal, state, and district initiatives designed to support ELs' opportunities to learn science.

Secondary science teachers are often teaching out of the area in which they were prepared to teach, and, therefore, draw heavily from textbooks as resources for instruction (Banilower et al., 2013; Ceglie & Olivares, 2012). Though many secondary text books have been updated to include suggested instructional modifications and supports for ELs, they still focus primarily on knowledge and comprehension of science content and do not reflect current understandings about supporting ELs through language-rich contextualized inquiry (Smith, Hanks, & Erickson, 2017). We need curriculum materials for secondary science education, including but not limited to textbooks, that better incorporate current evidence-based understandings of supporting EL student engagement in disciplinary literacy and language practices.

In summary, secondary science instruction for ELs should be contextualized, communicative, practice-based, and cognitively demanding, with sufficient language supports to allow EL students' at various levels of language proficiency full participation in the classroom conversation. While bilingual and two-way immersion are the most effective models in terms of the impact on English learners' content and language achievement, English learners in non-bilingual science classrooms can simultaneously develop both language and science understandings with teachers who are well prepared to create responsive and supportive science learning contexts.

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