Received: 10 September 2022 | Revised: 13 June 2023 | Accepted: 21 June 2023

DOI: 10.1002/sce.21807

RESEARCH ARTICLE

Science Education WILEY

Teacher professional development programs integrating science and language with multilingual learners: A conceptual framework

Okhee Lee[1] | Scott Grapin[2] | Alison Haas[1]

[1]Department of Teaching and Learning Steinhardt School of Culture, Education, and Human Development, New York University, New York, New York, USA

[2]Department of Teaching and Learning, School of Education and Human Development, University of Miami, Coral Gables, Florida, USA

Correspondence
Okhee Lee, New York University, New York, NY 10012-1126, USA.
Email: olee@nyu.edu

Abstract

As the vision in *A Framework for K-12 Science Education* and the Next Generation Science Standards (NGSS) takes hold in schools and classrooms, there is an urgent need for teacher professional development (PD) programs that align with NGSS-designed curriculum materials and address the unique strengths and needs of diverse student groups, including multilingual learners (MLs). The purpose of this article is to propose our conceptual framework for PD programs that aligns with current reform efforts and is grounded in the mutually supportive nature of contemporary science and language instructional shifts. Specifically, we examine our previous NGSS-designed curriculum development project with MLs and review the literature in science education and language education with MLs. Our conceptual framework for PD programs is grounded in the perspective of *symmetry* that teacher professional learning experiences should be symmetrical to the learning experiences we organize for students. Grounded in this perspective, our conceptual framework consists of three design principles that describe how PD programs can guide teachers to (a) develop an asset-oriented view of MLs and instructional practices for recognizing and leveraging their assets, (b) integrate science and language in mutually supportive ways with MLs, and (c) develop more sophisticated instructional practices for integrating science and language with MLs over time. We describe contributions of our conceptual framework, which could generate a new research agenda and inform PD programs aimed at facilitating uptake of NGSS-designed curriculum materials in linguistically diverse science classrooms.

KEYWORDS

multilingual learners, next generation science standards, science and language integration, teacher professional development programs

1 | INTRODUCTION

A Framework for K-12 Science Education (National Research Council [NRC], 2012; shortened to the *Framework* hereafter) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013a) were developed with the vision of "all standards, all students" (NGSS Lead States, 2013b). Grounded in this vision, there is broad consensus around instructional shifts in the science education community. These shifts also have the potential to create classroom communities that promote language learning for all students, including multilingual learners (MLs), in science education (Lee et al., 2013, 2019) and across STEM subjects (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018).

Since the publication of the *Framework* in 2012 and the release of the NGSS in 2013, 20 states and the District of Columbia have adopted the NGSS, and 28 states developed their own standards based on the *Framework* (https://ngss.nsta.org/About.aspx). As this vision for science education takes hold in schools and classrooms across the nation, there is a great demand for research-based, high-quality NGSS-designed curriculum materials. Moreover, to support large-scale implementation of emerging curriculum materials, teacher professional development (PD) programs are needed. While there has been significant progress in the development of curriculum materials (e.g., see the 2021 special issue on the NGSS in the *Journal of Science Teacher Education*), development of PD programs is just beginning (Lowell & McNeill, 2022; Reiser et al., 2017).

The demand for full interventions consisting of curriculum materials and PD programs has become even more urgent due to the rapidly growing diversity of the student population in the nation. Students classified as English learners (ELs) make up the fastest-growing subset, constituting more than 10% of the public school student population or over 5 million students (National Center for Education Statistics, 2021). ELs are a heterogeneous group in terms of language background, English proficiency, literacy skills, and prior STEM learning experiences, among other characteristics (NASEM, 2018). In addition to students currently classified as ELs, students who have exited language support services, or "former ELs," often continue to require instructional attention. In this article, we use the term MLs to include both current and former ELs. More broadly, given the language intensive nature of the NGSS (Lee et al., 2013, 2019; NASEM, 2018), we emphasize the need for curriculum materials and PD programs that leverage the strengths and meet the needs of *all* students, including those who regularly use multiple languages in their homes and communities but were never classified as ELs in school.

In this article, we use key constructs and terms in the following ways. Teacher professional learning occurs through multiple avenues, including teacher participation in curriculum development and/or implementation (especially educative curriculum materials), teacher study groups, professional learning communities, teacher–researcher partnerships, and PD workshops. We adopt the following definition of PD programs from the NASEM (2015) consensus report *Science Teachers' Learning*:

> Formal professional development programs are defined as learning experiences for teachers that (1) are purposefully designed to support particular kinds of teacher change; (2) include a focused, multiday session for teachers that takes place outside of the teacher's classroom or school; (3) may include follow-up opportunities over the school year; and (4) have a finite duration (although they can take place over a period of 2 to 3 years). (p. 115)

In the NGSS community, there is a need for PD programs aligned with NGSS-designed curriculum materials that promote teacher professional learning for working with MLs/ELs. This need is highlighted in the NASEM (2018) consensus report *English Learners in STEM Subjects*:

> Teacher professional learning that is focused on supporting ELs often fails to attend to or to be explicitly aligned with reform-based curriculum. Further, when that teacher professional learning does align with reform-based curriculum, it may fail to extend beyond how to teach the disciplinary concepts and [science and engineering] practices to also focus on students' language and culture. (p. 185)

The purpose of this article is to propose a conceptual framework for PD programs integrating science and language with MLs. We begin by describing science instructional shifts, spurred by the *Framework* and the NGSS, and language instructional shifts, informed by contemporary approaches in language education (described in Section 2 of this manuscript). Then, we describe two research activities that our research team carried out concurrently to develop our conceptual framework. One research activity involved examining our previous NGSS curriculum development project with MLs (Section 3). The other research activity involved reviewing the literature in science education and language education with MLs (Section 4). Next, grounded in the instructional shifts and drawing from the two research activities, we propose our conceptual framework for PD programs integrating science and language with MLs (Section 5). Finally, we describe contributions of our conceptual framework, which could generate a new research agenda and inform PD programs aimed at facilitating uptake of NGSS-designed curriculum materials in linguistically diverse science classrooms (Section 6).

In developing our conceptual framework, we draw heavily from our previous curriculum development project. First, the project enabled us to conceptualize instructional shifts for integrating science and language with MLs (e.g., Lee et al., 2013; NASEM, 2018), which were operationalized as curriculum materials and field tested through iterative cycles of classroom implementation and revision of the materials (Lee et al., 2019). Second, the project enabled us to gain insights into professional learning as teachers were coparticipants in the development and implementation of our educative curriculum materials through design-based research (Haas et al., 2021). Third, in the emerging literature, NGSS-designed curriculum materials provide the basis for teacher professional learning and PD programs, hence constructs such as teachers' knowledge of curriculum (Penuel et al., 2023), curriculum-based professional learning (Short & Hirsh, 2020), and curriculum-based PD (Lowell & McNeill, 2022). Together, instructional shifts in science and language with MLs (Section 2) and teacher professional learning through curriculum development and implementation (Section 3), substantiated by the literature on PD (Section 4), provided the foundations for the development of our PD program (Section 5), which is the focus of this article.

Our conceptual framework for PD programs is grounded in the perspective of symmetry that teacher professional learning experiences should be symmetrical to the learning experiences we organize for students (Mehta & Fine, 2019). Grounded in this perspective, our conceptual framework consists of three design principles that describe how PD programs can guide teachers to (a) develop an asset-oriented view of MLs and instructional practices for recognizing and leveraging their assets, (b) integrate science and language in mutually supportive ways with MLs, and (c) develop more sophisticated instructional practices for integrating science and language with MLs over time. Our proposed conceptual framework is our initial model, which will be further revised and refined through our field trial of our PD program.

2 | INSTRUCTIONAL SHIFTS FOR INTEGRATING SCIENCE AND LANGUAGE WITH

Recent years have witnessed parallel instructional shifts in science education and language education. In science education, traditional approaches emphasized individual learners' mastery of discrete elements of science content, whereas contemporary approaches emphasize that students make sense of phenomena and design solutions to problems as scientists and engineers do in their work (NRC, 2012). Because contemporary approaches involve using and applying knowledge for a purpose, these approaches have been described as promoting *knowledge-in-use* (Harris et al., 2019). Thus, whereas traditional approaches focused on "what science is" or "a body of knowledge," contemporary approaches focus on "what science does" or "knowledge-in-use."

In language education, traditional approaches emphasized discrete elements of vocabulary (lexicon) and grammar (syntax) to be internalized by learners, whereas contemporary approaches emphasize that language is a set of dynamic meaning-making practices learned through participation in social contexts (Larsen-Freeman, 2007; Valdés, 2015; Zuengler & Miller, 2006). Because contemporary approaches involve using language for a purpose, these approaches have been described as promoting *language-in-use* (Lee et al., 2013). Thus, whereas traditional approaches focused on "what language is" or "a collection of words and structures," contemporary approaches focus on "what language does" or "language-in-use."

2.1 | Instructional shifts in science education

Contemporary approaches in science education grounded in the *Framework* and the NGSS highlight three key instructional shifts. First, all students, including MLs, explain phenomena and design solutions to problems. Phenomena and problems should be compelling for all students to figure out through place-based learning, especially for students who might not have had the opportunity to experience science as relevant to their daily lives or future careers (Haas et al., 2021; Lee & Grapin, 2022). In particular, local phenomena and problems involve everyday experience and language in home and community contexts (Lee, 2020; Lyon et al., 2018; Tolbert & Knox, 2016).

Second, all students, including MLs, engage in three-dimensional learning by blending science and engineering practices (SEPs), crosscutting concepts (CCCs), and disciplinary core ideas (DCIs). In particular, SEPs (e.g., develop models, argue from evidence, construct explanations) are critical for all students, especially MLs (Lee et al., 2013; NASEM, 2018). Because SEPs are language intensive, they call for a high level of classroom discourse. MLs can carry out sophisticated SEPs through their emerging English and rich meaning-making resources.

Finally, all students, including MLs, build science understanding over the course of instruction. Lessons in a unit fit together coherently and build on each other in guiding students to develop their understanding of a targeted set of NGSS performance expectations (i.e., standards; Krajcik et al., 2014; Reiser et al., 2017). Over time, students develop a deeper and more sophisticated understanding of science as they make sense of phenomena. As MLs deepen their science understanding, their language use becomes more precise to communicate the sophistication of their science understanding (Haas et al., 2021).

2.2 | Instructional shifts in language education

> Students make sense of phenomena and problems in diverse ways and use language to communicate ideas in diverse ways. In the science classroom, "children, regardless of their national language or dialect, use their everyday language routinely and creatively to negotiate the complex

> dilemmas of their lives and the larger world" (Warren et al., 2001, p. 548). For teachers, this means that "working to hear students in different ways in routine classroom interactions… requires a shift in the stances and ways of noticing and interpreting students' talk and activity." (Bang et al., 2017, p. 46)

In language education, contemporary approaches highlight three key instructional shifts (adapted from Lee et al., 2019; NASEM, 2018). As these shifts have implications for how teachers notice and interpret MLs' participation in the science classroom, each shift is discussed in relation to the instructional shifts in science education described above. First, MLs learn to use multiple *modalities* strategically. Modalities refer to the multiple and varied channels through which communication occurs (e.g., talk, text, gestures, symbols, equations, diagrams, computer code). In science education, both linguistic and nonlinguistic (e.g., visual) modalities are used to engage in SEPs, and thus all students are expected to use multiple modalities in strategic ways (Kress et al., 2014). In language education, multiple modalities support MLs to communicate their ideas. Thus, multiple modalities are essential to engagement in SEPs and particularly beneficial to MLs (Grapin, 2019).

Second, MLs learn to use increasingly specialized *registers*. Registers refer to the language used in talk and text that is associated with particular contexts of use (Biber & Conrad, 2009). Registers can range from every day to specialized. Everyday registers, in particular, constitute a key resource for engaging in disciplinary practices (Bunch & Martin, 2021; Grapin et al., 2022). As MLs build science understanding over the course of instruction, their language use becomes increasingly specialized. Such specialized registers afford the *precision* to communicate disciplinary meaning as students' science ideas become more sophisticated (Grapin, Llosa, et al., 2019).

Finally, MLs learn to use multiple modalities and registers to meet the communicative demands of different types of *interactions*. Which modalities and registers are effective for communication depends, in part, on whether interactions are one-to-one (e.g., one student communicating with a partner), one-to-small group (e.g., one student communicating with a small group), one-to-many (e.g., one student communicating with the whole class), or small group-to-many (e.g., small groups making class presentations). Specifically, specialized registers afford the *explicitness* (e.g., fewer deictic words like "it" and "here") to communicate disciplinary meaning across physical and temporal contexts.

2.3 | Summary of science and language instructional shifts with MLs

Mutually supportive instructional shifts in science education and language education highlight three key features of integrating science and language with MLs—what we call "doing science, using language." First, MLs make sense of phenomena using multiple meaning-making resources. MLs bring to the classroom rich knowledge and experiences in science as well as rich meaning-making resources from their homes and communities. This asset-oriented view of MLs in contemporary approaches is a shift from the deficit-oriented view of MLs in terms of what they were lacking (e.g., English proficiency) in traditional approaches (Haas et al., 2021; Lee, 2021). Second, MLs engage in rigorous science learning and rich language use in mutually supportive ways. The emphasis on using language to learn science in contemporary approaches differs from the emphasis on vocabulary (lexicon) and grammar (syntax) as a precursor or prerequisite to learn science in traditional approaches (NASEM, 2018). Third, over time, as MLs develop more sophisticated understanding of science, they use language in more specialized ways to communicate science ideas. Thus, science learning and language learning progress in tandem. These three key features of "doing science, using language" provide a foundation for our conceptual framework, described later.

3 | OUR PREVIOUS CURRICULUM DEVELOPMENT PROJECT

> The purpose of our previous curriculum development project was to develop a yearlong fifth-grade NGSS-designed curriculum for all students with a focus on MLs. Our curriculum development effort was a response to a need in the field, as highlighted in the NASEM (2018) consensus report: "Curriculum units designed to integrate instructional strategies that support language and content together can provide teachers with valuable tools to lead ELs to construct more sophisticated understanding of that content while also using more language to communicate their knowledge." (p. 183)

Our curriculum is grounded in the mutually supportive nature of science and language instructional shifts described above (Lee et al., 2019). The curriculum is aimed at promoting rigorous science learning and rich language use with all students, particularly MLs. Over the course of the project, the curriculum went through iterative cycles of development, field-testing, and refinement (for details, see Haas et al., 2021).

Although the central focus of the project was curriculum development, the project offered key insights into teacher professional learning. First, the curriculum materials were designed to be educative, that is, "to promote teacher learning in addition to student learning" (Davis & Krajcik, 2005, p. 3). Thus, the materials were designed to be an important source of teacher professional learning in their own right (Ball & Cohen, 1996; Hill et al., 2020; Short & Hirsh, 2020). Second, our efforts to iteratively develop and revise the curriculum over 3 years were guided, in large part, by the successes and challenges that teachers experienced as they implemented the materials in their classrooms and the feedback they provided at teacher advisory board meetings. Third, we developed draft versions of teacher PD workshops to support classroom implementation of the curriculum. As we revised the curriculum materials, we also revised the teacher PD workshops based on teacher feedback.

3.1 | Teachers as coparticipants

The project team included writers of the *Framework* and the NGSS, experts in language education, and teacher advisory board members who were fifth-grade teachers in science classrooms with MLs. Our team began by developing draft versions of the curriculum. Using design-based research (Barab & Squire, 2004; Sandoval, 2014), we field-tested the curriculum in an urban school district with a large population of MLs. Over the 3-year implementation, we worked with five teachers in Year 1, four teachers in Year 2, and eight teachers in Year 3. We added a new cohort of teachers each year while continuing to work with teachers in previous cohorts, which enabled us to observe how new teachers experienced the revised curriculum as well as how teacher learning progressed over multiple years.

Our yearlong fifth-grade curriculum consists of four 9-week units that address all 16 NGSS performance expectations in fifth grade. Before implementing the draft versions of each unit, teachers participated in teacher advisory board meetings. Each year, we held a 2-day meeting for each of the four units for a total of 8 days of teacher advisory board meetings. Each meeting consisted of two parts. The first part focused on eliciting teachers' feedback on successes and challenges with the unit they had just taught and their suggested changes for revision and refinement of the curriculum. The second part consisted of a PD workshop aimed at preparing teachers to teach the next unit in the curriculum as well as to continue developing their understanding of both the conceptual and practical aspects of teaching science aligned to the NGSS with MLs.

Following each meeting, teachers field-tested each of the four units in their classrooms. We collected data about classroom implementation using multiple sources. First, we took extensive classroom observation notes and obtained student work samples and artifacts from weekly visits of each teacher throughout the school year. Second, teachers provided brief qualitative feedback at the end of each class period, more comprehensive online feedback using both ratings and written responses at the end of each lesson, and feedback about the unit they had just implemented during the subsequent teacher advisory board meeting. Every week, members of the research team met to review their notes, summarize successes and challenges across teachers, and keep records for the subsequent cycle of revision and refinement. Collectively, these multiple perspectives from teachers and researchers complemented one another. As "coparticipants in the design" (Barab & Squire, 2004, p. 3), teachers contributed to the iterative development of the curriculum, while their coparticipation in curriculum development contributed to their professional learning.

More systematic and comprehensive analysis of teacher professional learning in our previous project is currently in progress. In the following subsection, we highlight key findings that informed our conceptual framework for PD programs.

3.2 | Findings on teacher professional learning

One finding was the importance of teachers developing an asset-oriented view of all students, including MLs (Haas et al., 2021). While teachers were generally enthusiastic about seeing MLs from an asset-oriented view, they were less confident about where and how to recognize these assets. Thus, teachers benefited from opportunities to work collaboratively as they examined student work related to specific tasks in the curriculum. In doing so, teachers uncovered MLs' sophisticated science ideas and their varied ways of communicating those ideas (e.g., multimodality, everyday register). Supporting teachers to recognize MLs' assets began with seeing teachers themselves from an asset-oriented view. As teachers made sense of MLs' work, they drew from their own unique knowledge and expertise (Haas et al., 2021).

Another finding was the importance of teachers making informed in-the-moment instructional decisions that promote both science and language learning with MLs. Contemporary approaches highlight integrating science and language in mutually supportive ways, whereas traditional approaches viewed language as a prerequisite or precursor to science. While a unique feature of the curriculum is that it offers built-in affordances for integrating science and language learning (Lee et al., 2019), teachers need to make in-the-moment instructional decisions that leverage these affordances. We found that, while teachers developed their understanding of the science and language instructional shifts undergirding the curriculum (described earlier), they were less confident about enacting these shifts in in-the-moment interactions with their students, for example, when facilitating a discussion around students' models. Also, while teachers came to understand the shifts in both science and language, they faced difficulty integrating the two sets of shifts in practice (e.g., promoting MLs' strategic use of modalities and more specialized registers [first and second language shifts] as MLs engaged in SEPs to explain a phenomenon [first and second science shifts]).

Still another finding was the importance of teachers going through learning progressions. As contemporary approaches involve instructional shifts that are academically rigorous for all students, including MLs, teachers need ample and sustained opportunities to learn how to enact these shifts. As noted earlier, we made the strategic decision to add teachers new to the project each year over the course of 3 years. This allowed us to observe differences across teachers with different years of experience implementing the curriculum. Returning teachers had a better understanding of unit phenomena, how the three dimensions could be blended to explain phenomena, and how student understanding in each of the three dimensions could be developed over time. Also, returning teachers were more adept at scaffolding students' use of modalities and registers over the course of instruction and engaging all students, including MLs, in different types of interactions that supported science learning and language learning. Beyond the science and language instructional shifts, returning teachers implemented the curriculum more independently and with less support from project personnel. Also, they used the teacher-suggested prompts provided in the lessons to inform their instruction without strictly adhering to a "script." Overall, as teachers developed more sophisticated understanding of NGSS instruction with MLs, they progressed from simply implementing the tasks and investigations (i.e., “survival mode” as expressed by the teachers) to enacting instruction with greater purpose and intentionality.

3.3 | Summary of our previous curriculum development project

Findings from our previous curriculum development project highlight the need for PD programs that support teacher professional learning for NGSS-designed curriculum implementation with MLs. Specifically, findings indicate that teacher learning experiences should be symmetrical to the learning experiences organized for students (e.g., cultivate student assets, cultivate teacher assets). Findings also indicate that PD programs should support teachers in adopting and enacting an asset-oriented view of MLs, making in-the-moment instructional decisions that integrate science and language in mutually supportive ways, and refining their instructional practices over time.

4 | LITERATURE REVIEW

> While the field of science education has focused mainly on developing NGSS-designed curriculum materials (Campbell & Lee, 2021), PD efforts to support curriculum-based teacher professional learning are still in their infancy (Lowell & McNeill, 2022; Reiser et al., 2017). With regard to MLs, the NASEM (2018) consensus report states, “Limited access to high-quality and research-based professional development specifically targeted to meeting the needs and building on the strengths of ELs in STEM remains a substantial obstacle to ELs' success in STEM classrooms”. (p. 180)

In developing our conceptual framework, we turned to relevant areas of literature. We selected key journals that met at least one of the following two criteria: (a) journals representing the major professional associations that influence the field and (b) journals with high impacts (for details about the broader literature review that addressed multiple topical areas, including PD, see Buxton & Lee, 2023). When taken together, these journals provided a robust look at how PD for teaching MLs in science has been represented in the literature. While we note as a limitation of this approach that these journals did not fully capture the literature, they did capture the most visible and impactful work that continues to shape the literature in each field, across fields, and education research broadly.

We reviewed 13 journals organized into four groups. The first group of journals was specific to the field of science education: *International Journal of Science Education*, *Journal of Research on Science Teaching*, *Journal of Science Teacher Education*, and *Science Education*. The second group of journals was specific to the field of language education with MLs: *Bilingual Research Journal*, *International Journal of Bilingual Education and Bilingualism*, and *TESOL Quarterly*. The third group of journals was high-visibility journals in topical areas: *The Journal of the Learning Sciences*, *Journal of Science Education and Technology*, *Journal of Teacher Education*, and *Teaching and Teacher Education*. The final group of journals included the three major journals of the American Educational Research Association: *American Educational Research Journal*, *Educational Researcher*, and *Review of Educational Research*. These high-visibility journals address the full range of topics in education research and have an influence on all education fields, including science and language education with MLs.

From these selected journals, we conducted a manual search of all issues from 2014 (after the release of the *Framework* in 2012 and the NGSS in 2013) through 2021. To select relevant articles, we looked for key constructs and terms related to PD (e.g., teacher PD, teacher professional learning, teacher change, educative curriculum materials, teacher study groups, professional learning communities, teacher-researcher partnerships, PD workshops) across content areas, including science and language, with preservice and practicing teachers.

In this section, we describe three bodies of literature that informed our conceptual framework for PD programs integrating science and language with MLs: (a) core features of effective PD, (b) PD for NGSS implementation, and (c) PD for mainstream teachers of MLs in science and other content areas. We include the literature that addresses practicing teachers but not preservice teachers, considering that the characteristics and contexts differ vastly between the two groups (e.g., university coursework and field experience with preservice teachers compared with various types and durations of PD opportunities with practicing teachers). However, for the literature on PD for mainstream teachers of MLs across content areas (the third body of literature), we expanded our focus to preservice teachers, as there was limited literature involving PD programs for practicing teachers. After describing each body of literature, we summarize the findings and detail how these insights informed our conceptual framework.

4.1 | Core features of effective PD programs

Numerous syntheses have offered ways to conceptualize features of effective PD. The most recent literature on PD is the work by Desimone, Garet, and colleagues (Desimone, 2009; Garet et al., 2001). Desimone (2009) nominated five core features to guide research on PD: (a) a focus on content knowledge and how students learn that content (content focus); (b) opportunities for teachers to engage in active learning (active learning); (c) coherence in terms of the consistency of teacher learning with teachers' knowledge and beliefs and the consistency of what is taught in PD with school, district, and state reforms and policies (coherence); (d) sufficient duration in terms of the number of contact hours and the span of time over the course of PD (duration); and (e) collective participation of teachers from the same school, department, or grade level (collective participation).

Desimone (2009) characterized the findings from this expansive literature as "an empirical consensus on a set of core features and a conceptual framework for teacher learning" (p. 192). The NASEM (2015) consensus report, *Science Teachers' Learning*, also referred to this literature as "the consensus model of effective PD" (p. 118). In addition, this model of PD is used in the NRC (2015) consensus report, *Guide to Implementing the Next Generation Science Standards*, and a meta-analysis of PD programs with STEM teachers (Hill et al., 2020). Thus, the core features of effective PD programs continue to inform PD programs in science and across content areas.

4.2 | PD for NGSS implementation

As the vision of science teaching and learning in the *Framework* and the NGSS involves key instructional shifts, curriculum materials serve as artifacts to illuminate this vision and as essential resources to guide classroom implementation (Short & Hirsh, 2020). Though NGSS-designed curriculum materials take different conceptual approaches, they share common features based on the science instructional shifts described earlier (i.e., phenomena, three-dimensional learning, coherence; see the 2021 special issue on the NGSS in the *Journal of Science Teacher Education*). Curriculum as a research agenda in contemporary approaches is a shift from curriculum as a means to do research in traditional approaches. Grounded in NGSS-designed curriculum materials, an emerging literature on teacher professional learning broadly and PD programs specifically indicates four areas of research. As the NGSS community is reasonably well defined with a broad consensus, findings within each area are generally consistent. As a result, for each area, we start with an overall finding and provide an illustrative study.

The first area of research addresses teacher professional learning as teachers use educative curriculum materials (DeBarger et al., 2017; Marco-Bujosa et al., 2016; Roblin et al., 2018). Findings indicate that teacher supports embedded in curriculum materials promoted instructional shifts aligned with the vision of the *Framework* and the NGSS, helped teachers make sense of their own growth in teaching, and improved students' understanding of science. These studies provided the foundation for constructs currently in use to describe teacher professional learning, including teachers' knowledge of curriculum (Penuel et al., 2023), curriculum-based professional learning (Short & Hirsh, 2020), and curriculum-based PD (Lowell & McNeill, 2022). For example, Marco-Bujosa et al. (2016) examined how middle school science teachers planned for instruction utilizing the same reform-oriented science curriculum and, specifically, how the teachers interpreted and learned about argumentation from the curriculum.

The second area of research addresses professional learning as teachers engage in professional learning communities or teacher-researcher partnerships (Friedrichsen & Barnett, 2018; Juuti et al., 2021; Marshall et al., 2021); Thompson et al., 2019). These studies took place in the context of codesign and implementation of curriculum materials, with the exception of Friedrichsen and Barnett (2018), which examined a professional learning community's first-year adoption of the NGSS without the support of curricular resources. Findings indicate that professional learning communities or teacher–researcher partnerships enhanced professional learning through collectively designing, enacting, and reflecting on curriculum development and classroom implementation. For example, Thompson et al. (2019) examined how a professional learning community comprised of middle school teachers and researchers worked on the improvement of Ambitious Science Teaching Practices and developed instructional practices and tools supporting model-based inquiry. Through a research-practice partnership, teachers and researchers routinely coplanned, cotaught, and codebriefed science lessons via improvement cycles. Thompson et al. proposed three key components to a practice-based theory for how professional learning communities negotiated tools as a part of the improvement of instructional practices: anchoring improvement in a particular tool and practice, supporting variation in teacher learning, and making teachers' pedagogical reasoning explicit.

The third area of research, constituting the majority of the studies in our literature review, addresses PD programs that are intended for implementation of a specific set of NGSS-designed curriculum materials (Castronova & Chernobilsky, 2020; Edelson et al., 2021; Hayes et al., 2019; Kang et al., 2019; Reiser et al., 2017; Schneider et al., 2022; Sherwood, 2020). In these studies, curriculum materials had been developed, which were followed by PD programs for curriculum implementation. The studies used the existing literature on PD programs, especially the five core features (Desimone, 2009), as the consensus model of effective PD. However, Hayes et al. (2019) state, "Research on how these approaches (i.e., the core features) translate into specific PD strategies, and their role in… instructional change, is less clear" (p. 118). Findings indicate that effective PD programs provided teachers with opportunities to analyze concrete examples of instructional shifts in action, plan changes to their own instructional practices, and reflect on how those practices played out in their contexts. Within our literature review, Reiser et al. (2017) was the only study that addressed an NGSS-based PD program with design principles. They implemented a two-pronged program for scaling three-dimensional science PD across a state: (a) 24 teachers developed expertise in three-dimensional learning and facilitating teacher study groups and (b) these peer facilitators led 22 teacher study groups to engage in three-dimensional science activities, analyze student learning, and investigate classroom interactions. They conducted initial summer PD but did not involve classroom implementation. They proposed "design principles that draw on an emerging consensus about the features that best support teacher learning" (Reiser et al., 2017, p. 282). It is noted that the first three design principles addressed teacher professional learning, whereas the final two design principles addressed the context of teacher study groups and peer facilitators, respectively.

Design Principle 1: Situate teacher learning in tasks requiring sense-making of classroom cases.

Design Principle 2: Focus PD on the high-leverage practices of argumentation, explanation, and modeling.

Design Principle 3: Help teachers connect what is new about the science, student thinking about the science, and pedagogical supports for the science.

Design Principle 4: Organize teacher study groups working to apply the reforms to their own classroom practice.

Design Principle 5: Develop peer facilitators' expertise in knowledge-building facilitation.

Findings also indicate the importance of teachers doing as students do (i.e., the notion of symmetry). For example, Reiser et al. (2017) PD program was premised on the idea that "a necessary prerequisite in helping students engage in practices [SEPs] is for teachers to be able to engage in these practices themselves" (p. 288). The notion of symmetry also undergirds the large-scale intervention by Schneider et al. (2022):

> A key feature of [the program's] professional learning is for treatment teachers to experience what their students will be doing during their science activities, including using the driving question board, asking their own questions, building models, developing evidence-based explanations, and conducting experiments, not as students but as adult learners. The intent here is to guide and support the teachers in new ways of teaching often found to be challenging. (p. 113)

The fourth area of research addresses contexts for teacher learning, including organizational contexts or resources in schools and districts (Allen & Heredia, 2021; Allen & Penuel, 2015; Anderson et al., 2018). Findings indicate that PD, professional learning, and instructional shifts interacted with and were shaped by the organizational and sociocultural contexts of education systems, from students and teachers to schools, school districts, and states. For example, Anderson et al. (2018) scaled up NGSS-designed curriculum materials across multiple states. They described, "A core goal of our PD was to engage teachers and PD leaders in productive sense making that helped teachers make progress toward rigorous and responsive science teaching practices" (p. 1045). The PD course of study and research-practice partnerships addressed issues of identifying organizational resources, addressing conflicting norms and obligations, and building practical knowledge in schools and districts.

4.3 | PD for mainstream teachers of MLs

The literature on PD programs using contemporary approaches to integrating science and language with MLs is limited for multiple reasons. First, the NGSS were released in 2013, and state adoption of standards takes time. Second, developing and studying curriculum-based PD programs involves first developing NGSS-designed science curriculum materials. Third, the time span between the release of the *Framework* (in 2012) and the NGSS (in 2013) and the release of the NASEM consensus report (in 2018) did not provide sufficient time for research on contemporary approaches to integrating science and language with MLs to emerge. Finally, integration of science and language based on contemporary approaches requires mutual understanding and sustained collaboration between science education and language education in terms of conceptualization, operationalization, and implementation of PD. PD programs based on contemporary approaches are likely to accelerate with the recent release of the WIDA 2020 Edition of the English language development standards (WIDA Consortium, 2020), which are closely aligned to the NGSS (Grapin & Lee, 2022). Across the US, 36 states, DC, and four territories have adopted the WIDA 2020 Edition, and almost all of the states have also adopted the NGSS or adapted the *Framework*.

Given the limited literature, we expanded our review by including (a) preservice science teachers and (b) teachers of MLs across content areas. These studies are grounded in a variety of frameworks for conceptualizing the orientations, knowledge, and practices that teachers need to "think in new ways about the integration of disciplinary language instruction with disciplinary content instruction" (NASEM, 2018, p. 173; see, e.g., Bunch, 2013 on *pedagogical language knowledge* for reform-oriented teaching of MLs). Among the studies included, we identified three areas: (a) studies that address teacher preparation with preservice teachers of MLs in science education, (b) studies that address PD with practicing teachers of MLs in science and other content areas, and (c) literature reviews on teacher preparation and PD with MLs across content areas. As this literature review covers multiple areas of research across preservice and practicing teachers and across science and other content areas, the topics studied and questions addressed vary widely. As a result, for each area, we provide a brief description of each study.

It is noted that studies of science education with MLs that do not directly address teacher preparation or PD are not included in our review, for example, Buxton and Caswell (2020) addressing science instruction. A more comprehensive review of the literature on a range of topics, including science teacher education to support ELs, between 2007 and 2013 is described in Buxton and Lee (2014). An updated review of the literature on a similar range of topics, including teacher preparation and professional learning to support MLs, between 2014 and 2021 is described in Buxton and Lee (2023). These two literature reviews present the evolution of the field, for example, the same research team shifting from more traditional (Lee et al., 2016; Llosa et al., 2016) to contemporary approaches (Lee et al., 2013, 2019).

First, several studies addressed teacher preparation with preservice teachers of MLs in science education. Three studies examined how to prepare preservice teachers with models for integrating science and language with MLs. Valdés-Sánchez and Espinet (2020) described a model for science teacher education that highlighted the development of teacher professional identity. The study examined how one elementary teacher's professional identity as a teacher of science and language evolved through coteaching experiences with science teachers. Heineke et al. (2019) provided a nuanced analysis of one preservice high school science teacher's efforts to support MLs' language development through engagement in rigorous, authentic science experiences. Rutt and Mumba (2020) developed a language- and literacy-integrated science instructional framework grounded in SEPs. After participation in 2 semester-long courses, 11 secondary science preservice teachers integrated more practices in their instructional planning (e.g., designing lessons with built-in opportunities for literacy development). One area of difficulty was contextualizing instruction, as preservice teachers struggled to identify and integrate MLs' unique cultural and linguistic resources into instruction (see also Lyon et al., 2018; Tolbert & Knox, 2016 in the next paragraph).

Two other studies within this area focused on how preservice teachers learned to contextualize science topics in real-world phenomena and problems. Tolbert and Knox (2016) found that preservice elementary science teachers contextualized science instruction with MLs primarily using two categories of contexts: local ecological contexts and multicultural contexts. In a multi-institutional project to redesign science methods courses, Lyon et al. (2018) guided teachers to create contextualized spaces for language and literacy development that were connected to MLs' lived experiences (e.g., local ecologies, home activities, community events, global contexts, socioscientific issues). While preservice teachers had opportunities to experience key instructional practices (e.g., framing lessons with a driving question), there was less opportunity for pedagogical development around these practices.

Second, three studies addressed PD with practicing teachers of MLs in science and other content areas. Capitelli et al. (2016) examined how one elementary teacher came to integrate her PD experiences in an NGSS-aligned teacher learning project with her classroom experience and, over time, created a hybrid model of instruction for integrating science and language. Huerta et al. (2019) examined teachers' attitudes toward MLs in science education, specifically their attitudes toward linguistic diversity and research-based pedagogy related to science instruction with MLs. Molle (2021) investigated how a team of three content teachers of MLs learned to integrate content and language during a 1-year PD program. While the program promoted the teachers' uptake of language-focused content instruction, teachers wrestled with what they perceived to be a tension between content learning and language development.

Finally, three studies conducted literature reviews on teacher preparation and/or PD with MLs across content areas. Based on Feiman-Nemser's (2001) framework for teacher learning tasks, Rutt et al. (2020) identified key tasks for preservice teachers learning to teach MLs in science classrooms specifically. They found that developing preservice teachers' science content knowledge and supporting them in examining their initial beliefs about teaching science in linguistically diverse classrooms were understudied topics in the literature. Based on the linguistically responsive teaching framework proposed by Lucas and Villegas (2013), Solano-Campos et al. (2020) reviewed the literature on preservice teacher preparation to teach MLs across content areas and found that studies focused predominantly on shifting teachers' orientations (e.g., their beliefs about what MLs are capable of) and less so on promoting teachers' pedagogical knowledge and skills. Viesca et al. (2019) reviewed the literature on teacher development and teaching for MLs across content areas. Their review painted a "complex portrait" of quality content teaching for MLs (p. 312) that involved the interplay of orientations (e.g., attitudes, beliefs, and perspectives), pedagogy (e.g., how to integrate content and language in instruction), and context (e.g., education policies).

4.4 | Summary of literature review

As the three bodies of literature have developed separately and the literature on PD for NGSS implementation and PD for mainstream teachers of MLs is in its infancy, we drew insights from each body of literature to guide our conceptual framework. First, while the literature on core features of effective PD indicates structural features of PD (Desimone, 2009; Garet et al., 2001), the content of PD should be contextualized within contemporary perspectives on learning in the relevant fields, such as science education and language education with MLs.

Second, the literature on PD for NGSS implementation highlights the need to design PD that supports implementation of NGSS-designed curriculum materials. Educative curriculum materials played a key role in helping teachers make instructional shifts to meet the vision of the *Framework* and the NGSS (first area of research). Some studies examined professional learning through professional learning communities or research-practice partnerships (second area of research), while most studies examined professional learning through PD programs, with the notion of symmetry emerging as a key design principle (third area of research; Reiser et al., 2017; Schneider et al., 2022). A small number of studies examined how organizational and sociocultural contexts interacted with and were shaped by PD, professional learning, and instructional shifts (fourth area of research).

Third, the literature on PD for mainstream teachers of MLs emphasizes the importance of developing teachers' identities as both science and language teachers (Heineke et al., 2019; Rutt & Mumba, 2020; Valdés-Sánchez & Espinet, 2020), guiding teachers to contextualize science as connected to MLs' lived experience in home and community (Lyon et al., 2018; Tolbert & Knox, 2016), and providing PD that addresses teachers' attitudes (Huerta et al., 2019) and instructional practices (Capitelli et al., 2016; Lyon et al., 2018; Molle, 2021). These findings are consistent with the literature highlighting the importance of teachers developing both asset-based orientations *and* instructional practices, with neither orientations nor instructional practices being sufficient on their own (Rutt et al., 2020; Solano-Campos et al., 2020; Viesca et al., 2019).

Overall, the literature review underscores the need for curriculum-based PD that meets the vision of the *Framework* and the NGSS, is symmetrical to student learning, and provides sustained opportunities for teachers to develop the orientations and instructional practices necessary to integrate science and language with MLs in mutually supportive ways. In turn, our conceptual framework for PD programs could contribute to these emerging bodies of literature across science education and language education with MLs.

5 | CONCEPTUAL FRAMEWORK FOR PD PROGRAMS

Key components of PD programs emerge from the science and language instructional shifts (Section 2 of this manuscript), findings from our previous curriculum development project (Section 3), and findings from the three bodies of literature (Section 4). Given that the literature on PD programs that integrate science and language with MLs is in its infancy, in proposing our conceptual framework, we draw heavily from our previous curriculum development project and use our PD program as an example of our conceptual framework.

Our PD program meets the five core features in the consensus model of effective PD (Desimone, 2009), the NASEM (2015) consensus report, and the NRC (2015) consensus report. First, in terms of content focus, our PD program emphasizes science instructional shifts guided by the *Framework* and the NGSS and language instructional shifts guided by contemporary approaches in science and STEM education with MLs. Second, in terms of active learning, our PD program offers opportunities for teachers to experience science and language instructional shifts as learners and to reflect on what these learning experiences mean for their instructional practices with students.

Third, in terms of coherence, our PD program is consistent with the state science standards and assessment at Grade 5 based on the *Framework* and the NGSS. In addition, our PD program leverages teachers' rich knowledge and expertise. Fourth, in terms of duration, our PD program involves a sufficient number of contact hours, specifically, four 2-day PD workshops over a 2-year period. Finally, in terms of collective participation, our PD program involves all fifth-grade teachers from the same schools that share the common feature of having a high percentage of MLs.

Building on these core features of effective PD, our conceptual framework highlights contemporary approaches to integrating science and language with MLs. Our conceptual framework is grounded in our perspective and design principles to guide teacher professional learning.

5.1 | Perspective

As instructional shifts from traditional to contemporary approaches present both opportunities and demands for teacher professional learning, teachers need to experience learning like the students they will teach and learn to adapt their instruction for their students. Mehta and Fine (2019) propose the notion of symmetry in teacher professional learning, which they define as "giving adults opportunities to learn in ways that parallel how students learn" (p. 484). If we expect teachers to meet the vision in the *Framework* and the NGSS, teacher professional learning experiences should be symmetrical to the learning experiences we organize for students (Haas et al., 2021).

With our focus on science and language integration with MLs, we emphasize three aspects of symmetry, which correspond to the three design principles described in the section below. First, teachers bring rich knowledge and expertise from their personal and professional backgrounds (in parallel with how students bring rich knowledge and experiences from their homes and communities). This asset orientation of teachers as collaborators and contributors to PD programs is a shift from teachers as receivers of information from PD programs. Based on this asset orientation, PD programs capitalize on a wide range of knowledge and expertise that teachers bring. For example, teachers bring knowledge of science and engineering disciplines, instructional strategies, students' languages and cultures, and students' homes and communities, among other areas of knowledge.

Second, teachers need to experience science and language instructional shifts at the same time as they learn new ways of communicating about these shifts (in parallel with how students are "doing science, using language"). For example, the NGSS community has developed a specialized register (e.g., "phenomenon," "three-dimensional learning," "storyline") that allows members of the community to communicate precisely about instructional shifts. In PD, teachers begin by experiencing the shifts, for example, what each of the three dimensions (i.e., SEPs, CCCs, DCIs) looks like and how to blend the three dimensions (i.e., three-dimensional learning). As teachers experience the shifts, they develop a more specialized register for communicating about the shifts both within the PD program and beyond it (e.g., with other teacher colleagues, administrators, and parents).

Finally, teachers progress in learning science, learning language, and integrating science and language over time (in parallel with how students build coherent understanding of science and use increasingly specialized language to communicate science ideas over time). Teachers experience how their science understanding develops over the course of the PD program. At the same time, they experience how their language becomes more specialized over the course of the PD program. As teachers participate in PD programs over multiple years, they learn to make adaptations to curriculum materials and instructional practices.

5.2 | Design principles

Grounded in the three aspects of symmetry described above, our conceptual framework consists of three design principles that describe how PD programs can guide teacher professional learning to integrate science and language with MLs. For each design principle, we describe the orientations, knowledge, and instructional practices that we aim for teachers to develop and then how our PD program promotes teachers to develop such orientations, knowledge, and instructional practices.

5.2.1 | Design principle 1: Guide teachers to develop an asset-oriented view of MLs and instructional practices for recognizing and leveraging students' assets

This design principle addresses the importance of developing teachers' orientations toward MLs (prominent in our previous curriculum development project and the literature on learning to teach MLs in content areas) as well as associated instructional practices for putting these orientations into action (which are further built upon in Design Principle 2 below). To engage MLs in science, teachers need to develop both the orientation that MLs bring assets to the science classroom (e.g., meaning-making resources, knowledge, and experiences) and the ability to leverage those assets in instruction.

In our PD program, to develop teachers' asset-oriented view and associated instructional practices, we engage teachers in SEPs to explain phenomena, in parallel with how teachers will engage their students. For example, the first unit in our curriculum is anchored in the phenomenon of what happens to all the garbage in the local school and community (see Lee, 2020, for a detailed description of this PD module). At the beginning of PD for this unit, teachers work collaboratively to make observations (i.e., SEP planning and carrying out investigations) of a pile of garbage materials and then sort the materials into different categories (i.e., CCC patterns). After sorting the garbage, teachers reflect on the meaning-making resources, knowledge, and experiences that *they* deployed as they engaged in the garbage sort. For example, teachers reflect on how they used multiple modalities (e.g., gesture to indicate different materials and which categories these materials belong to), registers (e.g., everyday register, such as "put it over here!" and "this is the same as that one"), and interactions (e.g., one-to-small-group when sorting the materials and one-to-many when sharing observations with the PD group). Teachers also reflect on what knowledge and experiences they brought to the garbage sorting task, such as their knowledge of the different categories used to sort garbage in their local community's garbage system (i.e., CCC systems).

As teachers participate in the garbage sort and reflect on their participation, they come to understand the range of resources that people bring to making sense of and making meaning about phenomena, even without using the specialized register that has been traditionally privileged in science classrooms (e.g., "properties of materials"). Teachers are guided to connect their reflections to the instructional shifts (e.g., gesture as an example of a modality).

Finally, teachers consider ways that they could elicit and recognize the wealth of meaning-making resources, knowledge, and experiences that *students* bring to this task. For example, teachers share and discuss instructional practices for encouraging students to use multiple modalities and everyday registers when beginning to explain a phenomenon, making connections between science ideas and students' knowledge and experiences, and eliciting ideas from students who may be less eager to share.

5.2.2 | Design principle 2: Guide teachers to integrate science and language in mutually supportive ways with MLs

Building on and extending teachers' asset orientation and associated instructional practices (Design Principle 1), this design principle addresses the importance of integrating science and language in mutually supportive ways (a challenge for teachers in our previous curriculum development project and in the literature broadly). Specifically, teachers need to make in-the-moment instructional decisions that capitalize on the mutually supportive nature of science and language learning with all students, especially MLs. This design principle lays the foundation for teachers to develop more sophisticated instructional practices as they enact the curriculum in their classrooms and reflect on this enactment (see Design Principle 3).

In our PD program, teachers engage in modules in which they examine student work related to specific curriculum tasks and develop in-the-moment interpretations of and instructional responses to that work, similar to what they will do in their classrooms. For example, in the second unit of the curriculum, which is anchored in the phenomenon of tiger salamanders disappearing from a local vernal pool ecosystem, teachers examine initial and revised models developed by students to explain the tiger salamanders' disappearance (see Grapin, Haas, et al., 2019 for a detailed description of this PD module). The student models have been strategically selected to capture a range of student ideas as well as a range of ways of communicating those ideas (e.g., multiple modalities and registers to represent relationships among organisms in the ecosystem). As teachers work collaboratively to examine the models, they negotiate different interpretations of students' ideas and clarify the sense-making goals of the task. Examining models developed by MLs specifically helps teachers recognize how MLs can communicate sophisticated science ideas in unanticipated ways that would otherwise be overlooked if a teacher looked only for the “right” answer or representation (Grapin & Llosa, 2022a, 2022b)—what we call *seeing and hearing the science* in MLs' ideas, regardless of how those ideas are communicated (Grapin et al., 2022; Grapin, 2023). Thus, collaborative interpretation of student work further supports teachers to develop an asset-oriented view of MLs (see Design Principle 1).

Next, teachers work collaboratively to discuss in-the-moment instructional decisions they might make based on their interpretations. Specifically, teachers develop probes they could use in conversations with students to build on students' science ideas and their varied ways of communicating those ideas. For example, teachers develop probes for revoicing students' ideas in a more specialized register. Teachers also consider scaffolds they could use to support students' development of language for science at the word, sentence, and discourse levels (WIDA Consortium, 2020) without short-circuiting students' sense-making (e.g., by introducing sentence frames too early in instruction; Grapin et al., 2021). Then, teachers engage in role playing in which they participate in simulated conversations with “students” (i.e., teacher colleagues or PD facilitators) around student work. As teachers hone their instructional practices for integrating science and language, they bring these practices back to their classrooms and reflect on successes and challenges, which they will share in subsequent PD workshops (see Design Principle 3).

5.2.3 | Design principle 3: Guide teachers to develop more sophisticated instructional practices for integrating science and language with MLs over time

Building on teachers' emerging repertoire of instructional practices for integrating science and language with MLs (Design Principle 2), this design principle addresses the importance of teachers continuing to develop their instructional practices over time (a key finding from the literature as well as our curriculum development project that involved both new and returning teachers). Teacher learning progressions occur over a school year as teachers learn to implement different units of a curriculum as well as over multiple years as they teach the same curriculum to new classes of students. Specifically, teacher learning progressions occur in two key ways. First, teachers learn more advanced instructional practices over time that build on the foundation of instructional practices established in earlier PD workshops. Second, teachers learn to reflect on classroom enactment and make contextual adaptations in a supportive community of practice.

In our PD program, we address both aspects of teacher learning progressions. First, we introduce more sophisticated instructional practices over time as teachers develop a firmer grasp of the curriculum specifically and NGSS instruction with MLs broadly. For example, whereas three-dimensional learning is emphasized from the outset of the PD program, CCCs tend to take a backseat to SEPs and DCIs in teachers' instructional practices (Fick & Arias, 2022). Thus, one focus of PD with returning teachers is making CCCs explicit in ways that harness the resources that all students, and MLs in particular, bring to the classroom (Nordine & Lee, 2021). Specifically, teachers recognize how CCCs, such as patterns and systems, are resources students use in their everyday lives that can be harnessed as assets for making sense of phenomena in the science classroom, thus reinforcing an asset-oriented view of MLs (see Design Principle 1). In PD, teachers read classroom snapshots anchored in specific lessons in the curriculum (see Goggins et al., 2019 for an example classroom snapshot anchored in the phenomenon of falling stars). These snapshots offer vivid examples of teachers implementing instructional practices related to CCCs, such as making visible MLs' intuitive ideas and language related to CCCs, providing opportunities for students to apply CCCs across science disciplines, and guiding students in using CCCs intentionally over the course of instruction. Teachers discuss the classroom snapshots, share anticipated challenges in implementing the instructional practices, and develop their own goals for integrating a focus on CCCs as part of three-dimensional learning in the next unit.

Second, we provide opportunities for teachers to reflect on enactment and make adaptations to the curriculum for their classroom contexts. A key affordance of our PD program is that it involves sustained opportunities for teachers to develop their instructional practices (related to duration in Desimone, 2009), with PD workshops interspersed between classroom enactments of curriculum units. This interspersing enables teachers to engage in iterative cycles of enactment in their classrooms and reflection in PD workshops, which supports teacher learning progressions. Moreover, it allows teachers to reflect on how they adapt what they are learning in PD to their classroom contexts.

This emphasis on contextual adaptations is particularly crucial when it comes to teaching MLs, who are a diverse group in terms of their individual characteristics (e.g., language background, English proficiency, literacy skills, prior STEM learning experiences) as well as the contexts in which they are learning science (e.g., English-dominant classrooms, dual language bilingual education classrooms; NASEM, 2018). After implementing each unit, teachers have opportunities to reflect on successes and challenges they encountered in their classrooms (e.g., challenge of strategically grouping "newcomer" MLs who speak different home languages). As teachers engage in PD about the next unit, those who expressed similar successes and challenges work collaboratively to identify possible adaptations that are responsive to their students and contexts. In the second year of PD, we partner new and returning teachers in ways that capitalize on their unique knowledge and expertise. In this way, the PD program creates a supportive community of practice in which each member contributes their unique knowledge and expertise while advancing the community's collective knowledge for teaching MLs in science.

6 | DISCUSSION

As the vision of the *Framework* and the NGSS takes hold in schools and classrooms across the nation, the field of science education has focused on classroom implementation (NASEM, 2015; NRC, 2015). In recent years, high-quality NGSS-designed curriculum materials have been developed for classroom implementation (see the 2021 special issue on the NGSS in the *Journal of Science Teacher Education*). For NGSS-designed curriculum materials to be implemented on a large scale, PD programs to support teacher professional learning are needed. However, research on PD programs using NGSS-designed curriculum materials is just beginning to emerge.

The vision of the *Framework* and the NGSS is expected of *all* students, including the nation's fast-growing population of MLs. Contemporary approaches to science learning and language learning, respectively, indicate key instructional shifts for integration of science and language with MLs (Lee et al., 2019; NASEM, 2018). As NGSS-designed curriculum materials with MLs are beginning to emerge (Haas et al., 2021), there is an urgent need for PD programs that support implementation of these materials in linguistically diverse science classrooms.

Our ongoing work on science and language integration with MLs has been evolving since the release of the *Framework* in 2012 and the NGSS in 2013. Our work, while grounded in the literature, is also contributing to that body of research (NASEM, 2018). In our previous curriculum development project, we proposed our conceptual framework for science and language integration with MLs (Lee et al., 2019) and our conceptual framework for

NGSS-designed curriculum development with MLs (Haas et al., 2021). Building on our previous work and relevant literature, our conceptual framework for PD programs could generate a new research agenda.

In our current work, we are developing our PD program along with our curriculum, which constitute a full intervention to support classroom implementation. Over the course of our current work, our PD program will guide enactment of our PD program through a field trial in a large urban school district with a high percentage of MLs. Through our field trial, our PD program will be further revised and refined. As an extension of our previous curriculum development work, our current work could make important contributions to the field. First, our PD program could serve as a prototype for PD to facilitate uptake of NGSS-designed curriculum materials with MLs. Second, the full intervention consisting of the curriculum and PD program could serve as a prototype for scale-up of an intervention with MLs. Third, our current work involves development of a suite of instruments to measure the impact of the full intervention on teachers and students with a focus on MLs. Finally, the PD program along with curriculum materials, a suite of instruments, and data on the impact of the full intervention on teachers and students with a focus on MLs from our field trial could offer directions for future research, practice, and policy for classroom implementation of the NGSS with all students, and MLs in particular, across the nation.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

ORCID

Okhee Lee http://orcid.org/0000-0003-3551-1583
Scott Grapin http://orcid.org/0000-0002-8982-0771
Alison Haas http://orcid.org/0000-0002-8545-7346

REFERENCES

Allen, C. D., & Heredia, S. C. (2021). Reframing organizational contexts from barriers to levers for teacher learning in science education reform. *Journal of Science Teacher Education*, *32*(2), 148–166. https://doi.org/10.1080/1046560X.2020.1794292

Allen, C. D., & Penuel, W. R. (2015). Studying teachers' sensemaking to investigate teachers' responses to professional development focused on new standards. *Journal of Teacher Education*, *66*(2), 136–149. https://doi.org/10.1177/0022487114560646

Anderson, C. W., de los Santos, E. X., Bodbyl, S., Covitt, B. A., Edwards, K. D., Hancock, II J. B., Lin, Q., Morrison Thomas, C., Penuel, W. R., & Welch, M. M. (2018). Designing educational systems to support enactment of the next generation science standards. *Journal of Research in Science Teaching*, *55*(7), 1026–1052. https://doi.org/10.1002/tea.21484

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher*, *25*(9), 6–14. https://doi.org/10.3102/0013189X025009006

Bang, M., Brown, B., Calabrese Barton, A., Roseberry, A., & Warren, B. (2017). Toward more equitable learning in science: Expanding relationships among students, teachers, and science practices. In C. Schwarz, C. Passmore, & B. J. Reiser (Eds.), *Helping students make sense of the world using Next Generation science and engineering practices* (pp. 33–58). NSTA Press.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, *13*(1), 1–14. https://doi.org/10.1207/s15327809jls1301_1

Biber, D., & Conrad, S. (2009). *Register, genre, and style*. Cambridge University. https://doi.org/10.1017/CBO9780511814358

Bunch, G. C. (2013). Pedagogical language knowledge: Preparing mainstream teachers for English learners in the new standards era. *Review of Research in Education*, *37*, 298–341. https://doi.org/10.3102/0091732X12461772

Bunch, G. C., & Martin, D. (2021). From "academic language" to the "language of ideas": A disciplinary perspective on using language in K-12 settings. *Language and Education*, *35*(6), 539–556.

Buxton, C. A., & Caswell, L. (2020). Next generation sheltered instruction to support multilingual learners in secondary science classrooms. *Science Education*, *104*(3), 555–580. https://onlinelibrary.wiley.com/doi/abs/10.1002/sce.21569

Buxton, C. A., & Lee, O. (2014). English language learners in science education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research in science education* (2nd ed., pp. 204–222). Erlbaum.

Buxton, C. A., & Lee, O. (2023). Section on diversity and equity in science education. In N. G. Lederman, D. Zeidler, & J. Lederman (Eds.), *Handbook of research in science education* (3rd ed.). Routledge.

Campbell, T., & Lee, O. (2021). Instructional materials designed for *A Framework for K-12 Science Education* and the Next Generation Science Standards: An introduction to the special issue. *Journal of Science Teacher Education*, *32*(7), 727–734.

Capitelli, S., Hooper, P., Rankin, L., Austin, M., & Caven, G. (2016). Understanding the development of a hybrid practice of inquiry-based science instruction and language development: A case study of one teacher's journey through reflections on classroom practice. *Journal of Science Teacher Education*, *27*(3), 283–302. https://doi.org/10.1007/s10972-016-9460-9

Castronova, M., & Chernobilsky, E. (2020). Teachers' pedagogical reflections on the Next Generation Science Standards. *Journal of Science Teacher Education*, *31*(4), 401–413. https://doi.org/10.1080/1046560X.2019.1710387

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3–14. https://doi.org/10.3102/0013189X034003003

DeBarger, A. H., Penuel, W. R., Moorthy, S., Beauvineau, Y., Kennedy, C. A., & Boscardin, C. K. (2017). Investigating purposeful science curriculum adaptation as a strategy to improve teaching and learning. *Science Education*, *101*(1), 66–98.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181–199.

Edelson, D. C., Reiser, B. J., McNeill, K. L., Mohan, A., Novak, M., Mohan, L., Affolter, R., McGill, T. A. W., Buck Bracey, Z. E., Deutch Noll, J., Kowalski, S. M., Novak, D., Lo, A. S., Landel, C., Krumm, A., Penuel, W. R., Van Horne, K., González-Howard, M., & Suárez, E. (2021). Developing research-based instructional materials to support large-scale transformation of science teaching and learning: The approach of the OpenSciEd middle school program. *Journal of Science Teacher Education*, *32*(7), 780–804. https://doi.org/10.1080/1046560X.2021.1877457

Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record: The Voice of Scholarship in Education*, *103*(6), 1013–1055. https://doi.org/10.1111/0161-4681.00141

Fick, S. J., & Arias, A. M. (2022). A review of literature that uses the lens of the Next Generation Science crosscutting concepts: 2012-2019. *Journal of Research in Science Teaching*, *59*(6), 883–929. https://doi.org/10.1002/tea.21747

Friedrichsen, P. J., & Barnett, E. (2018). Negotiating the meaning of Next Generation Science Standards in a secondary biology teacher professional learning community. *Journal of Research in Science Teaching*, *55*(7), 999–1025. https://doi.org/10.1002/tea.21472

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*, 915–945. https://doi.org/10.3102/00028312038004915

Goggins, M., Haas, A., Grapin, S., Llosa, L., & Lee, O. (2019). Integrating crosscutting concepts into science instruction. *Science and Children*, *057*(1), 56–61.

Grapin, S. (2019). Multimodality in the new content standards era: Implications for English learners. *TESOL Quarterly*, *53*(1), 30–55. https://doi.org/10.1002/tesq.443

Grapin, S. E. (2023). Assessment of English learners and their peers in the content areas: Expanding what "counts" as evidence of content learning. *Language Assessment Quarterly*, *20*(2), 215–234. https://doi.org/10.1080/15434303.2022.2147072

Grapin, S. E., Haas, A., Goggins, M., Llosa, L., & Lee, O. (2019). Beyond general-purpose talk moves: Using discipline-specific probes with English learners in the science classroom. *Science and Children*, *57*(4), 36–43.

Grapin, S. E., & Lee, O. (2022). WIDA English language development standards framework, 2020 edition: Key shifts and emerging tensions, *TESOL Quarterly*, *56*(2), 827–839. https://onlinelibrary.wiley.com/doi/10.1002/tesq.3092

Grapin, S. E., & Llosa, L. (2022a). Dynamic assessment of English learners in the content areas: An exploratory study in fifth-grade science. *TESOL Quarterly*, *56*(1), 201–229. https://doi.org/10.1002/tesq.3059

Grapin, S. E., & Llosa, L. (2022b). Multimodal tasks to assess English learners and their peers in science. *Educational Assessment*, *27*(1), 46–70. https://doi.org/10.1080/10627197.2022.2028139

Grapin, S. E., Llosa, L., Haas, A., Goggins, M., & Lee, O. (2019). Precision: Toward a meaning-centered view of language use with English learners in the content areas. *Linguistics and Education*, *50*(1), 71–83. https://doi.org/10.1016/j.linged.2019.03.004

Grapin, S. E., Llosa, L., Haas, A., & Lee, O. (2021). Rethinking instructional strategies with English learners in the content areas. *TESOL Journal*, *12*(2), 1–12. https://doi.org/10.1002/tesj.557

Grapin, S. E., Llosa, L., & Lee, O. (2022). Disciplinary practices with English learners in the content areas: Investigating *grasp of practice* in fifth-grade science. *Journal of Language, Identity & Education*. Advance online publication. https://doi.org/10.1080/15348458.2021.2008253

Haas, A., Januszyk, R., Grapin, S. E., Goggins, M., Llosa, L., & Lee, O. (2021). Developing instructional materials aligned to the Next Generation Science Standards for all students, including English learners. *Journal of Science Teacher Education*, *32*(7), 735–756. https://www.tandfonline.com/doi/full/10.1080/1046560X.2020.1827190

Harris, C. J., Krajcik, J. S., Pellegrino, J. W., & DeBarger, A. H. (2019). Designing knowledge-in-use assessments to promote deeper learning. *Educational Measurement: Issues and Practice*, *38*(2), 53–67. https://doi.org/10.1111/emip.12253

Hayes, K. N., Wheaton, M., & Tucker, D. (2019). Understanding teacher instructional change: The case of integrating NGSS and stewardship in professional development. *Environmental Education Research*, *25*(1), 115–134. https://doi.org/10.1080/13504622.2017.1396289

Heineke, A. J., Smetana, L., & Carlson Sanei, J. (2019). A qualitative case study of field-based teacher education: One candidate's evolving expertise of science teaching for emergent bilinguals. *Journal of Science Teacher Education*, *30*(1), 80–100. https://doi.org/10.1080/1046560X.2018.1537058

Hill, H. C., Lynch, K., Gonzalez, K. E., & Pollard, C. (2020). Professional development that improves STEM outcomes. *Phi Delta Kappan*, *101*(5), 50–56. https://doi.org/10.1177/0031721720903829

Huerta, M., Garza, T., Jackson, J. K., & Murukutla, M. (2019). Science teacher attitudes towards English learners. *Teaching and Teacher Education*, *77*, 1–9. https://doi.org/10.1016/j.tate.2018.09.007

Juuti, K., Lavonen, J., Salonen, V., Salmela-Aro, K., Schneider, B., & Krajcik, J. (2021). A teacher-researcher partnership for professional learning: Co-designing project-based learning units to increase student engagement in science classes. *Journal of Science Teacher Education*, *32*(6), 625–641. https://doi.org/10.1080/1046560X.2021.1872207

Kang, E. J. S., McCarthy, M. J., & Donovan, C. (2019). Elementary teachers' enactment of the NGSS science and engineering practices. *Journal of Science Teacher Education*, *30*(7), 788–814. https://doi.org/10.1080/1046560X.2019.1630794

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, *25*(2), 157–175. https://doi.org/10.1007/s10972-014-9383-2

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2014). *Multimodal teaching and learning: The rhetorics of the science classroom* (2nd ed.). Bloomsbury Academic.

Larsen-Freeman, D. (2007). Reflecting on the cognitive-social debate in second language acquisition. *The Modern Language Journal*, *91*(s1), 773–787. https://doi.org/10.1111/j.1540-4781.2007.00668.x

Lee, O. (2020). Making everyday phenomena phenomenal: Using phenomena to promote equity in science instruction. *Science and Children*, *58*(1), 56–61. https://www.nsta.org/

Lee, O. (2021). Asset-orientedframing of science and language learning with multilingual learners. *Journal of Research in Science Teaching*, *58*(7), 1073–1079. https://doi.org/10.1002/tea.21694

Lee, O., & Grapin, S. E. (2022). The role of phenomena and problems in science and STEM education: Traditional, contemporary, and future approaches. *Journal of Research in Science Teaching*, *59*(7), 1301–1309. https://onlinelibrary.wiley.com/doi/10.1002/tea.21776

Lee, O., Llosa, L., Grapin, S., Haas, A., & Goggins, M. (2019). Science and language integration with English learners: A conceptual framework guiding instructional materials development. *Science Education*, *103*(2), 317–337. https://doi.org/10.1002/sce.21498

Lee, O., Llosa, L., Jiang, F., Haas, A., O'Connor, C., & Van Booven, C. D. (2016). Elementary teachers' science knowledge and instructional practices: Impact of an intervention focused on English language learners. *Journal of Research in Science Teaching*, *53*(4), 579–597. https://doi.org/10.1002/tea.21314

Lee, O., Quinn, H., & Valdés, G. (2013). Science and language for English language learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English language arts and mathematics. *Educational Researcher*, *42*(4), 223–233. https://doi.org/10.3102/0013189X13480524

Llosa, L., Lee, O., Jiang, F., Haas, A., O'Connor, C., Van Booven, C. D., & Kieffer, M. J. (2016). Impact of a large-scale science intervention focused on English language learners. *American Educational Research Journal*, *53*(2), 395–424. https://doi.org/10.3102/0002831216637348

Lowell, B. R., & McNeill, K. L. (2022). Changes in teachers' beliefs: A longitudinal study of science teachers engaging in storyline curriculum-based professional development. *Journal of Research in Science Teaching*. Advance online publication. https://doi.org/10.1002/tea.21839

Lucas, T., & Villegas, A. M. (2013). Preparing linguistically responsive teachers: Laying the foundation in preservice teacher education. *Theory Into Practice*, *52*(2), 98–109. https://doi.org/10.1080/00405841.2013.770327

Lyon, E. G., Stoddart, T., Bunch, G. C., Tolbert, S., Salinas, I., & Solis, J. (2018). Improving the preparation of novice secondary science teachers for English learners: A proof of concept study, *Science Education* *102*(6), 1288–1318. https://onlinelibrary.wiley.com/doi/abs/10.1002/sce.21473

Marco-Bujosa, L. M., McNeill, K. L., González-Howard, M., & Loper, S. (2016). An exploration of teacher learning from an educative reform-oriented science curriculum: Case studies of teacher curriculum use. *Journal of Research in Science Teaching*, *54*(2), 141–168. https://doi.org/10.1002/tea.21340

Marshall, S. L., Nazar, C. R., Ibourk, A., & McElhaney, K. W. (2021). The role of collective sensemaking and science curriculum development within a research-practice partnership. *Science Education*, *105*(6), 1202–1228. https://doi.org/10.1002/sce.21676

Mehta, J., & Fine, S. (2019). *In search of deeper learning: The quest to remake the American high school*. Harvard University Press.

Molle, D. (2021). A close look at teacher learning: Why are teachers' journeys so different? *Teaching and Teacher Education*, *100*, 103280. https://doi.org/10.1016/j.tate.2021.103280

National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2018). *English learners in STEM subjects: Transforming classrooms, school, and lives*. National Academies Press.

National Center for Education Statistics. (2021). *The condition of education 2021 (NCES 2021-144)*. U.S. Department of Education. https://nces.ed.gov/programs/coe/indicator/cgf

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

National Research Council. (2015). *Guide to implementing the Next Generation Science Standards*. National Academies Press.

NGSS Lead States. (2013a). *Next generation science standards: For states, by states*. National Academies Press.

NGSS Lead States. (2013b). *Next Generation Science Standards: For states, by states. Appendix D–All standards, all students: Making the NGSS accessible to all students*. https://www.nextgenscience.org/resources/ngss-appendices

Nordine, J., & Lee, O., (Eds.). (2021). *Crosscutting concepts: Strengthening science and engineering learning*. National Science Teaching Association.

Penuel, W. R., Allen, A.-R., Deverel-Rico, C., Singleton, C., & Pazera, C. (2023). How teachers' knowledge of curriculum supports partnering with students in their science learning. *Journal of Science Teacher Education* 1–22. https://doi.org/10.1080/1046560X.2023.2167508

Reiser, B. J., Michaels, S., Moon, J., Bell, T., Dyer, E., Edwards, K. D., McGill, T. A. W., Novak, M., & Park, A. (2017). Scaling up three-dimensional science learning through teacher-led study groups across a state. *Journal of Teacher Education*, *68*(3), 280–298. https://doi.org/10.1177/0022487117699598

Roblin, N. P., Schunn, C., & McKenney, S. (2018). What are critical features of science curriculum materials that impact student and teacher outcomes? *Science Education*, *102*(2), 260–282. https://doi.org/10.1002/sce.21328

Rutt, A., & Mumba, F. (2020). Developing secondary pre-service science teachers' instructional planning abilities for language- and literacy-integrated science instruction in linguistically diverse classrooms. *Journal of Science Teacher Education*, *31*(8), 841–868. https://doi.org/10.1080/1046560X.2020.1760431

Rutt, A., Mumba, F., & Kibler, A. (2020). Preparing preservice teachers to teach science to English learners: A review. *Journal of Research in Science Teaching*, *58*(5), 625–660. https://doi.org/10.1002/tea.21673

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*, *23*(1), 18–36. https://doi.org/10.1080/10508406.2013.778204

Schneider, B., Krajcik, J., Lavonen, J., Salmela-Aro, K., Klager, C., Bradford, L., Chen, I.-C., Baker, Q., Touitou, I., Peek-Brown, D., Dezendorf, R. M., Maestrales, S., & Bartz, K. (2022). Improving science achievement—Is it possible? Evaluating the efficacy of a high school chemistry and physics project-based learning intervention. *Educational Researcher*, *51*(2), 109–121.

Sherwood, C.-A. (2020). The goals remain elusive": Using drawings to examine shifts in teachers' mental models before and after an NGSS professional learning experience. *Journal of Science Teacher Education*, *31*(5), 578–600. https://doi.org/10.1080/1046560X.2020.1729479

Short, J., & Hirsh, S. (2020). *The elements: Transforming teaching through curriculum-based professional learning*. Carnegie Corporation of New York.

Solano-Campos, A., Hopkins, M., & Quaynor, L. (2020). Linguistically responsive teaching in preservice teacher education: A review of the literature through the lens of cultural-historical activity theory. *Journal of Teacher Education*, *71*(2), 203–217. https://doi.org/10.1177/0022487118808785

Thompson, J. J., Hagenah, S., McDonald, S., & Barchenger, C. (2019). Toward a practice-based theory for how professional learning communities engage in the improvement of tools and practices for scientific modeling. *Science Education*, *103*(6), 1423–1455. https://doi.org/10.1002/sce.21547

Tolbert, S., & Knox, C. (2016). They might know a lot of things that I don't know": Investigating differences in preservice teachers' ideas about contextualizing science instruction in multilingual classrooms. *International Journal of Science Education*, *38*(7), 1133–1149. https://doi.org/10.1080/09500693.2016.1183266

Valdés, G. (2015). Latin@s and the intergenerational continuity of Spanish: The challenges of curricularizing language. *International Multilingual Research Journal*, *9*(4), 253–273. https://doi.org/10.1080/19313152.2015.1086625

Valdés-Sánchez, L., & Espinet, M. (2020). Coteaching in a science-CLIL classroom: Changes in discursive interaction as evidence of an English teacher's science-CLIL professional identity development. *International Journal of Science Education*, *42*(14), 2426–2452. https://doi.org/10.1080/09500693.2019.1710873

Viesca, K. M., Strom, K., Hammer, S., Masterson, J., Linzell, C. H., Mitchell-McCollough, J., & Flynn, N. (2019). Developing a complex portrait of content teaching for multilingual learners via nonlinear theoretical understandings. *Review of Research in Education*, *43*(1), 304–335. https://doi.org/10.3102/0091732X18820910

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching*, *38*(5), 529–552.

WIDA Consortium. (2020). *WIDA English language development standards framework, 2020 edition*. Board of Regents of the University of Wisconsin System. https://wida.wisc.edu/sites/default/files/resource/WIDA-ELD-Standards-Framework-2020

Zuengler, J., & Miller, E. R. (2006). Cognitive and sociocultural perspectives: Two parallel SLA worlds? *TESOL Quarterly*, *40*(1), 35–58. https://doi.org/10.2307/40264510

How to cite this article: Lee, O., Grapin, S., & Haas, A. (2023). Teacher professional development programs integrating science and language with multilingual learners: A conceptual framework. *Science Education*, 1–22. https://doi.org/10.1002/sce.21807