Invited Article

"DOING" SCIENCE, USING LANGUAGE

Professional Development to Promote Science and Language Integration with a Focus on Multilingual Learners

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This article describes the design and implementation of a series of four professional development workshops to engage middle school science teachers and English as a New Language teachers in "doing" science and using language. The workshops were guided by three design principles: (a) identify local phenomena that are compelling for students, (b) engage multilingual learners in doing science and using language, and (c) leverage multilingual learners' linguistic and semiotic resources. The results indicate that after participating in the workshops, teachers expressed having a better understanding of how science learning and language learning are mutually supportive of each other with all students, especially multilingual learners. In addition, they emphasized that engagement in science and engineering practices provided opportunities for rich language use, which was an instructional shift from frontloading of vocabulary and concepts. As the workshops took place during the COVID-19 pandemic, we acknowledge the role of digital technologies to support remote instruction and professional development.

Keywords: COVID-19, digital technologies, language, professional development, science

In science education, *A Framework for K-12 Science Education* (National Research Council, 2012; shortened to the *Framework* hereafter) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013b) were developed with the vision of "all standards, all students" (NGSS Lead States, 2013a). To date, 21 states and the District of Columbia have adopted the NGSS and 24 additional states, including New York, have developed their own standards based on the *Framework* and the NGSS (https://ngss.nsta.org/About.aspx). The New York State P-12 Science Learning Standards (NYS P-12 SLS) were adopted in December 2016.

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A research base exists on how to promote contemporary approaches to science and language learning with multilingual learners (Lee et al., 2013, 2019; National Academies of Sciences, Engineering, and Medicine [NASEM], 2018; New York State Education Department [NYSED], 2021). However, the literature on teacher professional development (PD) focused on contemporary approaches to instruction with science and language teachers is limited and only beginning to emerge (Buxton & Lee, in press; NASEM, 2018). Integration of science and language grounded in contemporary approaches requires PD facilitators to understand contemporary approaches to science learning and language learning and the mutually supportive nature of science and language learning. This shift to contemporary approaches has resulted in the need to build a knowledge base related to the design and implementation of PD with science and language teachers of multilingual learners.

The purpose of this article is to describe our process in designing and implementing a series of four PD workshops to engage middle school science teachers and English as a New Language teachers in the New York City Department of Education (NYC DOE). To engage teachers and, in turn, their students in "doing" science and using language, we developed the workshops using three design principles: (a) identify local phenomena that are compelling for multilingual learners to figure out, (b) engage multilingual learners in doing science and using language, and (c) leverage multilingual learners' linguistic and semiotic resources. As the workshops took place during the COVID-19 pandemic, we describe the role of digital technologies in supporting remote PD, which is reflective of remote instruction.

In this article, we first describe our conceptual framework grounded in the emerging literature on PD and the more established literature on design principles to promote science and language integration with multilingual learners. Second, we describe the setting in which our PD workshop series took place. Third, we describe our PD workshop series on science and language integration with multilingual learners. Fourth, we describe teacher reflections over the four-session workshop series. Finally, we discuss implications for PD programs grounded in contemporary approaches to integrating science and language with multilingual learners.

Conceptual Framework

The conceptual framework we developed to guide our work consists of (a) PD to promote science and language integration with science and language teachers and (b) instructional design principles to promote science and language integration with multilingual learners.

PD to Promote Science and Language Integration

As the vision of science teaching and learning expressed in the *Framework*, the NGSS, and, subsequently, the NYS P-12 SLS involves instructional shifts, the emerging literature on PD to promote classroom implementation of the standards indicates three key findings. The first finding is that teacher learning requires both educative curriculum materials and professional learning opportunities (NASEM, 2015; Short & Hirsh, 2020). The second finding is an emphasis on professional learning communities and teacher-researcher partnerships (Juuti et al., 2021; Thompson et al., 2019). The focus is on communities of practice among PD facilitators and teachers rather than on teachers receiving PD. The third finding is increased attention to the contexts for teacher learning, including organizational resources (Allen & Penuel, 2015; Anderson et al., 2017) and online or video-based professional learning opportunities (Reiser et al., 2017; Tekkumru-Kisa & Stein, 2017).

Only a small number of studies have combined contemporary approaches to science with contemporary approaches to language to support preservice and practicing science teachers of multilingual learners. The limited research in this area may be due to multiple factors: (a) the NGSS were released in 2013 and are still relatively new; (b) state adoption of the new science standards takes time; (c) classroom implementation requires development of new science curriculum materials and teacher PD; and

(d) integration of science and language from contemporary views requires conceptualization, operationalization, and implementation over time to produce generalizable research findings. Based on their comprehensive review of the literature since 2014 (after the release of the *Framework* in 2012 and the NGSS in 2013), Buxton and Lee (in press) identified two themes for teacher learning.

The first theme for teacher learning involves developing teachers' identity as a science teacher and language teacher simultaneously. Heineke et al. (2019) argued for the need to prepare secondary science preservice teachers with an integrated view of science and language learning despite the separation that typically exists between these topics in teacher preparation programs. Rutt and Mumba (2020) examined how secondary science preservice teachers who engaged in a model of language-and-literacy-integrated science instruction grounded in science and engineering practices changed their instructional planning over time. Capitelli et al. (2016) examined how one elementary teacher came to integrate her PD experiences in an NGSS-designed teacher learning project with her classroom experience and, over time, created a hybrid model of instruction for integrating science and language. Valdés-Sánchez and Espinet (2020) examined how one elementary teacher's professional identity as a teacher of science and language evolved through engaging in co-teaching experiences with science teachers.

The second theme for teacher learning involves contextualizing science topics in real-world phenomena and problems, compelling students to communicate their science ideas in an additional language they are learning. Tolbert and Knox (2016) examined the ideas that preservice teachers developed for contextualizing science instruction with multilingual learners, primarily using two categories of contexts: local ecological contexts and multicultural contexts. Lyon (2017) created contextualized spaces for language and literacy development with preservice teachers by connecting science to multilingual learners' lived experiences (e.g., local ecologies, home activities, community events, global contexts, socioscientific issues).

Instructional Design Principles to Promote Science and Language

Grounded in contemporary approaches to science and language integration with multilingual learners (Lee et al., 2013, 2019; NASEM, 2018), we used three design principles to promote rigorous science learning and rich language use.

Design Principle 1: Identify local phenomena. Phenomena and problems should be compelling and motivating for all students to figure out, 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, 2020). As local phenomena and problems involve everyday experience and language in home and community contexts, they promote both equity and science. From an equity perspective, through place-based learning, students apply science and engineering to their daily lives in local contexts of home and community. Multilingual learners bring with them cultural and community funds of knowledge (Moll et al., 1992) that help them make sense of phenomena and design solutions to problems. From a science perspective, through project-based learning, students integrate science disciplines as they investigate a driving question to explain a phenomenon and use engineering to design solutions to a problem (Krajcik & Czerniak, 2013; Miller et al., 2021).

Design Principle 2: Engage multilingual learners in doing science and using language. In science learning, traditional views have focused on individual learners' mastery of discrete elements of science content, whereas contemporary views emphasize that students make sense of phenomena and design solutions to problems as scientists and engineers do in their professional work (National Research Council, 2012). Because the contemporary approach involves using and applying knowledge for a particular purpose, it has been referred to as *knowledge-in-use* (Harris et al., 2016). In short, traditional approaches focused on "what science is" or "a body of knowledge," whereas contemporary approaches focus on "what science does" or "knowledge-in-use."

In language learning, traditional views have focused on discrete elements of vocabulary (lexicon) and grammar (syntax) to be internalized by learners, whereas contemporary views 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 particular purpose in context, they have been referred to as *language-in-use* (Lee et al., 2013). In short, traditional approaches focused on "what language is" or "a system of language," whereas contemporary approaches focus on "what language does" or "language-in-use."

In recent years, parallel shifts in science learning and language learning have occurred. In the science classroom, multilingual learners make sense of phenomena and use whole linguistic repertoires to communicate science ideas (NASEM, 2018). The emphasis on using language to learn science in contemporary views differs from the emphasis on vocabulary (lexicon) and grammar (syntax) as a precursor or prerequisite to learn science in traditional views.

Design Principle 3: Leverage multilingual learners' linguistic and semiotic resources. All students engage in science and engineering and communicate science ideas using multiple meaning-making resources, including gestures, symbols, equations, images, drawings, diagrams, and computational models. Teachers suspend their preconceived assumptions and beliefs about what language use should look and sound like in academic settings and, instead, listen to students' ideas and create spaces for meaning making. We highlight two linguistic and semiotic resources: multiple modalities and translanguaging.

Modalities refer to the multiple and varied channels through which communication occurs (Kress et al., 2014) and include visual modalities (e.g., gestures, pictures, symbols, graphs, tables, equations) and linguistic modalities across the continuum of oral and written modes of communication. In science and engineering, multiple modalities, especially the visual variety, are essential meaning-making resources. In language education, while traditional views privileged language and took nonlinguistic modalities as scaffolds for language development with multilingual learners, contemporary views recognize multiple modalities as essential to engaging in disciplinary practices (Grapin, 2019). For example, the science and engineering practice of developing models involves conceptual models beyond physical representations, and multilingual learners develop models to argue from evidence and construct explanations. Thus, multiple modalities, especially the nonlinguistic variety, are essential to engagement in science and engineering practices and particularly beneficial to multilingual learners (Ascenzi-Moreno et al., 2020; Grapin, 2019; Lee et al., 2019).

The translanguaging perspective legitimizes multilingual learners' use of linguistic and semiotic resources to make meaning while they add new features of science discourse into their existing repertoires (García & Wei, 2014; Karlsson et al., 2019; Seltzer & de los Ríos, 2021). In linguistically diverse science classrooms, where the teacher and students might not share the same minority language (e.g., Spanish), a translanguaging pedagogy helps multilingual learners to construe relations between everyday language and language use in science (Ünsal et al., 2018). In bilingual science classrooms, translanguaging helps multilingual learners tap into their prior experiences and knowledge when presented with new science concepts (Kang et al., 2017), engage in talk and text to share and negotiate science ideas with peers (Ciechanowski, 2014), and learn new content and linguistic forms (Poza, 2018). In adopting a translanguaging perspective, science and language educators are invited to naturalize multilingualism, validating the complex, fluid, and creative essence of doing language (García, 2020).

Setting of Our PD Workshop Series

Science and Language Education in the New York City Department of Education

The NYC DOE is the largest school district in the nation. As of the 2020-2021 school year, the ethnic makeup of the 1,094,138 students was 40.8% Hispanic, 24.7% Black, 16.5% Asian, and 14.8% White non-

Hispanic; 73% of students were considered economically disadvantaged; 20.8% of students had disabilities; and 13.3% were designated as English Language Learners, the term used by NYC DOE (2021). There are over 500 middle schools in NYC, and close to 20% of middle school students have been designated as English Language Learners.

Since the adoption of the NYS P-12 SLS in December 2016, implementation of the new science standards has been underway. To make these new science standards accessible to multilingual learners, who account for nearly 9% or almost a quarter million of New York's pre-K-12 student population, science and language teachers need PD to make key shifts in their instruction and assessment. In the NYC DOE, PD programs for science and language teachers of multilingual learners have been guided by the Instructional Leadership Framework (WeTeachNYC, 2019), a system-wide approach aimed at accelerating learning for every student. Combining the instructional practices of advanced literacies (WeTeachNYC, 2019) with the *Culturally Responsive-Sustaining Education Framework* (NYSED, 2019), PD programs for NYC DOE science and language teachers focus on creating inclusive environments that engage multilingual learners in rigorous, relevant, grade-level content learning.

Participants

During our four-session PD workshop series Doing Science, Using Language, 33 participants attended at least one of the workshops. Most participants attended multiple workshops: January 2021 workshop (27 participants), February 2021 workshop (24 participants), March 2021 workshop (25 participants), and April 2021 workshop (18 participants). The participants consisted of 30 middle school science teachers, two English as a New Language teachers, and one principal (who attended the first workshop only) from 30 schools across all five boroughs of NYC. The group was linguistically diverse with participants speaking Italian, Mandarin, and Spanish.

Remote PD and Classroom Instruction During the COVID-19 Pandemic

During the COVID-19 pandemic, there has been an even greater need to utilize multilingual learners' assets to create a welcoming and affirming environment while addressing disparities in access to high-quality science instruction particular to remote learning environments. As a result, the NYC DOE provided access and ongoing PD related to digital platforms (e.g., Google Suite, Microsoft), tools (e.g., Nearpod, Pear Deck), and curricula (e.g., CK-12) to support teachers in leveraging and implementing technology to ensure continued student learning. The PD related to these digital technologies (e.g., Flipgrid, Google Slides, Jamboard, Padlet, Pear Deck) addressed how to use these tools in remote learning environments. For example, for science instruction, as teachers were not able to conduct in-person investigations, computer simulations were recommended to conduct science investigations and construct explanations. Furthermore, to increase accessibility for all students and multilingual learners in particular, digital tools were recommended for translation, text-to-speech conversion, and screen recording, which contribute to creating inclusive virtual classrooms.

As such, our PD workshops used digital technologies provided by the NYC DOE to engage teachers in PD sessions and to support remote instruction with their students. For example, we used Pear Deck to create interactive slides for teachers to draw or develop diagrams, answer multiple-choice polling questions, and click on accessible content. We used Jamboard as a digital board tool for teachers to display and share ideas and Flipgrid as a video-mediated discussion tool for teachers to record and transcribe their explanations. Overall, we employed specific technology to model for teachers how digital technologies could be used in their remote and physical classrooms to integrate science and language, promote student-centered pedagogies, and build a classroom learning community.

PD Workshop Series

We designed a PD series of four 1-hour virtual workshops for middle school science teachers and English as a New Language teachers to promote science and language integration with multilingual learners. Our aim was to create a PD series focusing on (a) an overview of instructional shifts in the new science standards that were being rolled out in NY; (b) a conceptual framework for integrating science and language with multilingual learners; and (c) classroom examples using phenomena across physical, life, and Earth science as well as engineering design. To present an overview of the new science standards, we highlighted three-dimensional learning by blending science and engineering practices, crosscutting concepts, and disciplinary core ideas (National Research Council, 2012; NGSS Lead States, 2013b). Then, we highlighted what a language-supported three-dimensional science lesson looked like (Lee et al., 2019; NASEM, 2018). To illustrate classroom examples, we provided engaging and hands-on opportunities and facilitated conversations around ways language use mediated science learning across science and engineering disciplines. At the completion of each workshop, we asked teachers for their reflections on science and language integration with multilingual learners and used these reflections to refine plans for the subsequent workshops (to be described in the next section).

Across the four-session workshop series, we presented local and relevant phenomena connected to specific middle school performance expectations (i.e., standards) across science and engineering disciplines–life science (Workshop 1), physical science and engineering (Workshops 2 and 3), and Earth science (Workshop 4). In Workshop 1, teachers learned about the central role of a phenomenon in guiding science instruction. They collected evidence to explain why the Arctic woolly bear caterpillar lives for 7 years, whereas the local painted lady caterpillar only lives for 4 weeks. In Workshops 2 and 3, teachers engaged in an engineering task around designing fast sailboats to improve upon the miniature sailboats one finds in Central Park, a local phenomenon that teachers living in NYC could be expected to connect to their lives and experiences. In Workshop 4, teachers practiced identifying the role of density in Earth's convecting mantle to explain plate tectonics.

In this article, we focus on the second and third workshops as teachers engaged with the phenomenon of sailboats in Central Park. Over these two workshops, teachers engaged in a learning progression—starting with the phenomenon of sailboats in Central Park, moving to designing boats, advancing to collecting evidence, and ending by constructing and editing their explanations for what caused their boats to move (see Figure 1). By explaining this phenomenon, they were expected to meet MS-PS2-2 (see Figure 1).

MS-PS2-2. Plan and conduct an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system (including simple machines), qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.]

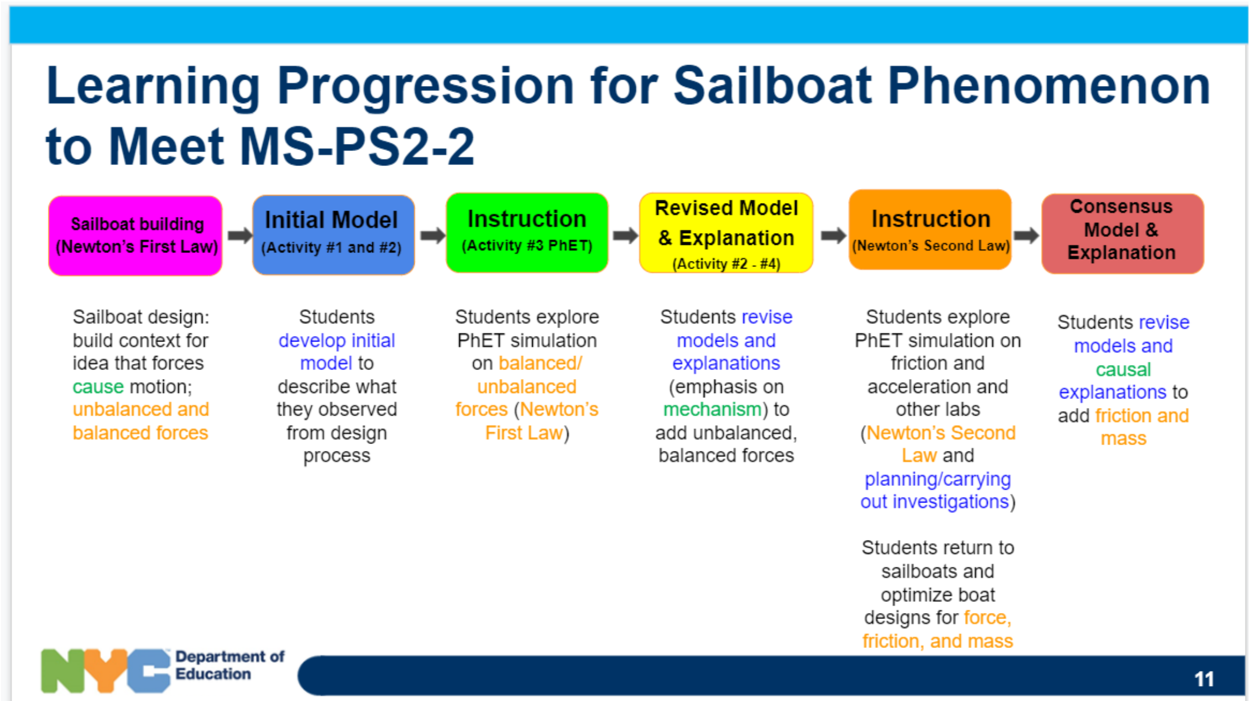

Figure 1. *Learning Progression for Sailboat Phenomenon*

Design Principle 1: Identify Local Phenomena

We provided a brief video of model sailboats racing in a pond in Central Park. Teachers watched the video and then engaged in an activity in which they shared their ideas in speech bubbles presented via shared Google Slides about what they observed and what they thought was happening (see Figure 2). Many of the teachers' responses highlighted their prior knowledge about the movement of sailboats on the water.

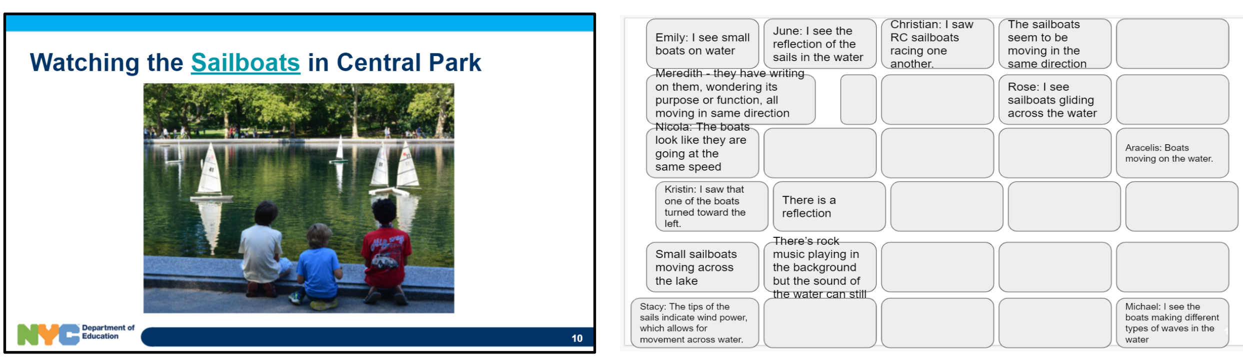

Figure 2. *What Do You See? The Phenomenon of Sailboats in Central Park*

Design Principle 2: Engage Multilingual Learners in Doing Science and Using Language

After teachers were introduced to the sailboat phenomenon, the following problem was presented: *The boat is too slow! How can we build a faster boat?* In the remote PD environment, teachers were tasked with constructing a boat that could move along a tabletop at the highest speed possible using a fan or blow dryer as a wind source. Teachers were asked to use common household materials to construct their boats (e.g., plastic takeout containers, straws, paper, tape, fan/blow dryer). We intentionally chose a task that would use readily available materials so that all teachers could engage in the task.

As teachers continued to engage in the process of developing their models, they constructed more sophisticated explanations and used more precise language. For example, teachers initially used everyday language (e.g., "small sailboats moving across the lake," "going at the same speed," "moving in the same direction"; see Figure 2). As teachers revised their initial models (see Figure 3) and continued constructing their boats, they started using more science vocabulary (e.g., force, catch air, push, friction). Finally, when teachers constructed explanations for the movement of their sailboats, they used specialized language (e.g., force, friction, mass, balanced and unbalanced forces) to communicate precise ideas in science.

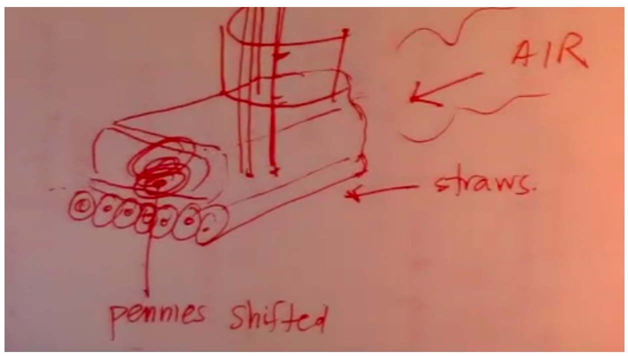

Figure 3. *A Teacher's Initial Model of a Sailboat*

Design Principle 3: Leveraging Multilingual Learners' Linguistic and Semiotic Repertoires

In Workshop 3, we engaged teachers in using multiple modalities and translanguaging to construct oral explanations via the use of Flipgrid, a video-mediated collaborative digital tool. Being a multimodal tool, Flipgrid enabled teachers to record and share their explanations, which they used as a springboard for revising and refining their own explanations. Specifically, the immersive reader feature on Flipgrid allowed for an aural and written transcript to be produced from the recordings. Figure 4 shows an example of dynamic text created using the immersive reader. The transcript became dynamic text that teachers could manipulate by adding, removing, and changing additional linguistic features. Across Workshops 2 and 3, teachers drew upon both their emerging understanding of science and their linguistic and semiotic resources, which included home language practices, use of digital tools, and experiences with scientific sense- making. It is important to note that translanguaging involved not only more traditional uses of "named" languages (e.g., Spanish, English) but also the leveraging of diverse varieties of Englishes and everyday language. Over time, teachers revised and refined their explanations and expanded their science discourse features.

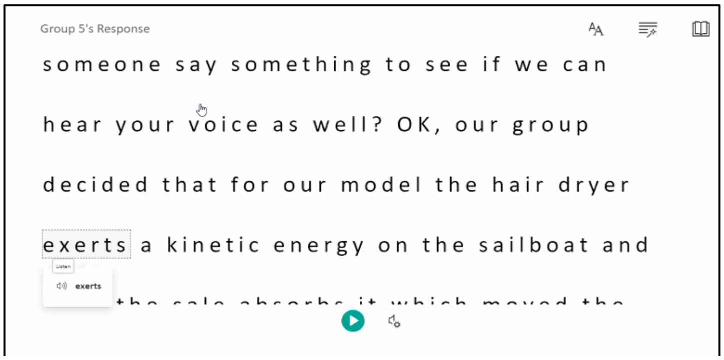

Figure 4. *Using the Flipgrid Immersive Reader to Revise an Explanation*

Teacher Reflections

After each workshop, we asked teachers to complete an online exit questionnaire to assess the following: (a) teachers' evaluations of the effectiveness of each workshop, (b) whether teachers gained an understanding of the content, and (c) teachers' feedback so that subsequent workshops could better address their needs and capitalize on their strengths. To protect the anonymity of individual teachers, the feedback was anonymous. Overall, most of the teachers reported that the content was relevant to promoting science and language learning with multilingual learners.

Design Principle 1: Identify local phenomena. As teachers reflected on what they found most useful, two themes emerged. One theme involved the role of phenomena to generate student engagement: "allowing students to experience phenomenon prior to supplying them with the knowledge," "start with a phenomenon and let students come up with questions," "using phenomena to have students create their questions and come up with ideas," and "the idea of starting with a phenomena or problem that students have to address." The other theme involved the role of phenomena to promote language use: "really using the phenomena approach to get students talking and engaged" and "finding really engaging phenomena that excite students and weaving in language throughout."

Design Principle 2: Engage multilingual learners in doing science and using language. Teachers seemed to understand the importance of doing science to promote science learning and language learning: "The engineering activity can be brought to my class"; "The materials should be easy enough for students to get if this activity is done remotely"; and "Incorporating engineering design [can] help students learn content vocabulary."

Teachers expressed how to start from everyday language and progress toward specialized language in science: "I learned that giving the students the opportunity to discuss the science in everyday language first and then giving them the scientific vocabulary allowed for better understanding and will likely promote usage" and "Build[ing] explanatory language start[s] with a diagram, then common language, then science specific content language in order to understand motion & Newton's laws."

Design Principle 3: Leveraging multilingual learners' linguistic and semiotic repertoires. Teachers recognized the value in having students present their ideas using multiple modalities, that is, extending students' linguistic and semiotic resources beyond more traditional verbal and written language (Kress & van Leeuwen, 2002). They identified modeling as a key tool for helping students develop science understanding: "Drawing models is still a valid way to develop understanding, not just writing text," and "Modeling for the kids doesn't have to necessarily present a perfect example–sometimes a 'faulty' one can give a lot of ideas to the students." Another teacher added, "You should engage students through multiple modalities, not just one. Engage students through exploration before introducing vocabulary. This way they observe the concepts prior and can connect the vocabulary to what they observed."

Teachers' reflections on multiple modalities also included digital technologies, including collaborative word processors and presentation tools, such as Google Docs and Google Slides, as well as video-mediated online forum discussions, such as Flipgrid: "Use different modalities to engage students (Google Slides that students can write, showing videos, creating an experiment)" and "Using Flipgrid is a great tool to allow the students to build on their explanation skills."

Some teachers used their home language of Spanish or Italian to explain phenomena. Others described how the use of their home language could help develop science ideas and, thus, promote learning science in English.

Discussion

As implementation of NYS P-12 SLS is underway, PD with science and language teachers of multilingual learners needs to be part of the statewide implementation. Building upon and extending the NYSED initiative, we present PD with middle school science and language teachers in the NYC DOE. Over the course of our four-session workshop series spanning 4 months, teachers expressed their increasing understanding of the mutually supportive nature of science learning and language learning with multilingual learners. They identified the importance of providing multilingual learners with local phenomena relevant to their daily lives (Design Principle 1). They also emphasized that engagement in science and engineering practices provided opportunities for rich language use; hence, "doing" science and using language as students progress from everyday language to specialized language in science (Design Principle 2). In addition, they recognized that multiple modalities, especially nonlinguistic modalities, and translanguaging are essential in engaging with science and engineering disciplines and particularly beneficial for multilingual learners in communicating science ideas (Design Principle 3).

Our PD is at the exploratory stage of design and implementation. Considering that our PD workshop series involved four 1-hour sessions over the course of 4 months, it could be more fully implemented for a more sufficient duration in terms of both the numer of contact hours and span over time. It could also be more fully developed around the design principles guiding our PD program. In addition, it could be designed to more fully support a professional learning community. Finally, the PD could be extended to measure its impact on classroom practices, teacher change, and learning outcomes.

Despite the exploratory stage of our PD described above, the results indicate its promise grounded in contemporary approaches to integrating science and language with multilingual learners (Lee at al., 2019; NASEM, 2018). The results also contribute to the limited but emerging literature on PD for science and language integration with multilingual learners (Buxton & Lee, in press; NASEM, 2018). It is noted that our PD involved primarily science teachers (i.e., 30 middle school science teachers and two English as a New Language teachers). Our future PD efforts will include implementation with greater numbers of language teachers and with teams of science and language teachers.

As our PD took place during the COVID-19 pandemic, we acknowledge the role of digital technologies in the design and implementation of remote PD programs, which, in turn, reflect remote instruction with multilingual learners. While digital technologies were essential during the pandemic, these technologies will continue to be used to complement in-person PD and instruction after the pandemic. Our PD program was designed and implemented to capitalize on the affordances of digital technologies to promote science and language integration with multilingual learners. The preliminary results of our PD program offer insights into the potential of digital technologies.

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