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Learning in motion: Examining in-process teacher development of inquiry-based science pedagogies for multilingual learners

RESEARCH ARTICLE OPEN ACCESS

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- Case showed teacher learning is a non-linear, relational process shaped by context
- Participant hybridized PD learning and her long-standing practices
- Multilingual learners' responses catalyzed shifts in teacher practice and beliefs

Abstract

Despite recent investments in science education professional development (PD), inequities persist for multilingual learners (MLLs) in elementary classrooms. This may be due in part to the ways teachers interpret, negotiate, and translate their PD learning into practice. To provide insight into this process, this case study investigates the "learning-in-motion" of a veteran fifth-grade teacher, Heidi, from a multi-year, inquiry-based science PD initiative. Drawing on video observations, interviews, and artifacts, we examined how Heidi engaged in the complex, moment-to-moment processes of implementing new pedagogies with her MLL students. Findings demonstrate that Heidi's learning trajectory was co-constructed by context and shaped by both her classroom challenges and her students' responses. Although she initially interpreted inquiry and agency rigidly, through iterative questioning, reflection, and multiple enactments of lessons, she began to hybridize PD learning with her longstanding practices, ultimately shifting her beliefs about MLLs' science capabilities. This case highlights the importance of understanding teacher learning as a non-linear, situated, relational process, rather than as a fixed outcome of PD. It offers valuable insights for PD facilitators and other stakeholders to support teachers in improving their practices to support MLLs.

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INTRODUCTION

Despite multifaceted science reform efforts, inequities persist for multilingual learners (MLLs) in elementary science classrooms, affecting MLL access to and participation in meaningful science learning (Calabrese-Barton & Tan, 2020). Part of these reforms has included investments in science teacher professional development (PD), aiming to address these equity issues. However, the way teachers interpret and enact learning from such PD initiatives is not thoroughly understood (Shanahan & Shea, 2012; Whitworth & Chiu, 2015), especially how they sense-make with their new ideas "in the moment" during teaching (Walkoe & Luna, 2020). To gain a more nuanced understanding of how teachers of MLLs in elementary science are taking up PD, we argue that we need to focus on the moment-to-moment interactions that comprise teaching. It is within these micro-level interactions that teachers negotiate their emerging learning with their own beliefs, their students, and contextual variables (Strom & Martin, 2017/2022; Vossoughi et al., 2020), all of which shape the practices that are eventually enacted (Hayes et al., 2019; Strom, 2015). Such studies can give us an in-depth look at what teacher learning looks like in process, in its mobile form, and at how learning and practice develop relationally and situationally across classrooms (Strom & Viesca, 2021).

In this paper, we present an in-depth case study examining how one teacher negotiated her learning from an equity-focused, inquiry-based professional development initiative, The Science Learning Project (SLP), in a diverse urban district on the US West Coast that serves predominantly MLL students. SLP is a multi-year inquiry-based science PD initiative emphasizing discourse and modeling, in which elementary teachers engage in a combination of hands-on science content learning and pedagogical learning throughout the school year. This PD provides an ideal context for examining teacher learning-in-motion, given its focus on equity for MLLs. In this case study, we address the research question: How does a veteran elementary teacher negotiate inquiry-based science PD learning with her beliefs, MLL students, and classroom context across two years of implementation? We begin with a review of the literature on the impact of professional development that integrates language and science content on MLLS teaching practice. We then discuss our conceptual framework, a systems-informed version of critical sociocultural theory, followed by an overview of the research design. We then move to the case itself, which offers a rich example of what teacher learning might look like as it is "in motion," and which we argue can provide valuable insights for improving teaching practices to support MLLs. We conclude with a discussion of the process of teacher learning for supporting MLLs in science and offer implications for teacher development.

LITERATURE REVIEW

For a variety of pedagogical and political reasons, MLLs are often excluded from meaningfully participating in science education (Calabrese-Barton & Tan, 2020; Kayumova & Buxton, 2021), contributing to entrenched patterns of educational exclusion in science for students of color (Philip & Azevedo, 2017). Disrupting these inequities requires ongoing professional development for teachers that emphasizes discourse and student-driven inquiry, while legitimizing students' multiplicities of knowing and being (Calabrese-Barton & Tan, 2018/2020).

Studies have shown that professional development for science teachers focused on student inquiry and discourse has positive benefits for both teachers and students (Alvarez et al., 2023; Shanahan & Shea, 2012; Shim & Thompson, 2022; Thomas & Drew, 2022). For example, Shanahan & Shea (2012), with a specific focus on teachers implementing "student-talk" strategies to support ML students in developing language and science content, also found increased student talk in classes of teachers who attended more than 75 percent of the workshops. Teachers also reported seeing the benefits of using student-talk strategies and inquiry-based science for language development, and felt more efficacious as a result of the PD. Lee and colleagues (2016), in their study seeking to improve fifth grade teachers' science content and pedagogy while supporting MLL language learning, demonstrated impressive teacher growth: Using a randomized trial design with 33 schools each in the treatment and control groups, researchers found a significant increase in both teachers' science content knowledge and all four practices studied (instructional practices for understanding, teaching practices for inquiry, language development strategies, and home language use). Moreover, at least one study has shown the possibility of increasing student achievement when inquiry-based science learning integrates language, culture, and experiential knowledge: Lambert & Ariza's (2008) mixed-method study of twenty-three teachers in 5 elementary schools, who engaged in science-focused, inquiry-based professional development on student learning that emphasized integrating student resources with content, showed significant positive gains in student outcomes on standardized tests.

However, other literature regarding the effectiveness of science PD for teachers of MLL students often reports disappointing results (Adamson et al., 2013; Buxton et al., 2013; Kayumova & Buxton, 2021; Lee &

Maerten-Rivera, 2012; Maerten-Rivera et al., 2016). Effectively teaching grade level science content while also supporting second language acquisition is extremely challenging (Heineke et al., 2019): not only do most teachers come without any previous preparation for doing so (Lee & Maerten-Rivera, 2012; NASEM, 2015; Stoddart et al., 2002), but this type of instruction requires to move away from transmission-based patterns of teaching and rethink deeply held beliefs–all within school systems whose structures typically do not support either (Hayes, 2016; Opfer & Pedder, 2011; Strom & Martin, 2017). Such belief and pedagogical change is difficult, particularly in the face of entrenched deficit thinking toward MLLs (Suarez & Lee, 2021). This challenge is illustrated by Buxton and colleagues (2013), whose participants engaged in PD aimed to improve pedagogical reasoning, targeting teachers' ability to recognize and leverage students' cultural and linguistic assets in relation to science content. The teachers showed no change in their pedagogical reasoning when analyzing student science task videos, which researchers explained in part by pointing to rigidly held deficit perspectives of their students.

Adding to the complexity, contextual and political factors such as teacher mobility, accountability policies, and district/school-based leadership agendas also affect teachers' pedagogical learning. For instance, Lee and Maerten-Rivera (2012) reported that, from a three-year PD that combined curriculum and workshops with teachers in 6 elementary schools, science content knowledge and the use of ELD strategies increased after the first year of the study, but not after years two and three of the intervention. The researchers suggested external factors, such as teacher attrition and pressure from standardized testing, impacted the results. Kayumova and Buxton (2021) provide another striking example of the complex systems of elements that shape teachers' ability to translate learning into classroom practice. In their study of two eighth-grade science teachers who participated in a multi-year PD focused on "language-rich inquiry science" (p. 6), the teachers were highly engaged in the learning activities, but they faced testing pressures and school improvement initiatives that contradicted the PD. Combined with the teachers' deeply embedded deficit perspectives of their MLL students, these factors hindered meaningful changes in instructional practice.

Despite the promise of research investigating professional development that increases teachers' ability to support MLLs in science instruction, the studies overwhelmingly focus on the inputs (i.e., the features and design of the professional development intervention) and outcomes (i.e., increases in teachers' science content knowledge and pedagogical strategies, as well as student scores on high-stakes tests). What these studies do not report is what the process of teacher learning and enactment looks like as it is under development, which may help to shed light on the multiple elements (e.g., teacher beliefs, context, policy, and so on) that situationally influence those outcomes. This study examines teacher learning from a professional development initiative in motion, or in the process of development, to begin to address that gap.

THEORETICAL FRAMEWORK

In this study, we employ a critical sociocultural perspective (Vossoughi & Gutierrez, 2016), which combines an explicitly political perspective on teaching (Freire, 1970) with sociocultural views of learning (Vygotsky, 1978). From a sociocultural perspective (Vygotsky, 1978), learning is a social process that is culturally, historically, and materially mediated. In other words, a learner makes meaning through interactions with others (both experts and peers) within a particular cultural context. Learning is influenced by the participant's past experiences and current knowledge, and is mediated by material artifacts (such as curricula and technology) and symbolic artifacts (such as language). These social, historical, cultural, and material interactions take place in what Vygotsky refers to as the "Zone of Proximal Development" (ZPD), the space between what learners currently know/can do on their own and what they cannot do, even with assistance. This space represents what students are on the cusp of learning, and are capable of learning with a "just-in-time" support, or "scaffolds" (Walqui & van Lier, 2012).

Applied to the current study, then, multiple factors at multiple systems levels shape the way teachers interpret and make meaning of PD offerings in their ZPD: their past experiences and knowledge; their interactions with PD facilitators and PD peer participants; their interactions with students (whose learning is also shaped by their experiences and understandings); their PD, classroom, and school contexts; the PD materials, facilitators, discourses, and ideas; and so on. This interactional lens, allowing analysis of learning at micro and macro levels, makes sociocultural theory an excellent frame for examining the phenomenon of learning-in-motion.

However, none of these systems is neutral–they are shaped by particular systems and power relations, as is the larger issue of ELD instruction. A critical pedagogical perspective (Freire, 1970) is essential to understand the ways that the power relations mediate teacher learning and practice–and offer possibilities for liberatory transformation (Teemant et al., 2014), which is why we combine sociocultural theory with a critical lens

(Vossoughi & Gutierrez, 2016). Dialogue-rich, inquiry-based teaching disrupts status quo "banking" pedagogies in which teachers use transmission methods to make "deposits" of knowledge in students. This traditional model perpetuates hierarchical power relations that position students as passive receivers of knowledge, molding them into obedient consumers of information (Freire, 1970). The banking model has particular significance for MLLs: the one-way transmission of information denies them the opportunity to practice and gain language skills (Martin & Strom, 2015). This lack of access ultimately limits college and career prospects and contributes to the perpetuation of poverty in immigrant communities (Mancilla-Martinez, 2020). In contrast, inquiry-based, dialogic pedagogies blur the binary between teacher and student, creating the potential of disrupting entrenched inequities through the collaborative process of teaching and learning (Vossoughi & Gutierrez, 2016).

Our understanding of critical sociocultural theory is also viewed through a complex systems perspective on teacher learning (Strom et al., 2018; Opfer & Pedder, 2011). This perspective, which sees teaching as complex phenomena that are collectively produced by an entire system (such as the teacher, students, material and discursive elements, and sociohistorical, cultural, and political contexts), helps in understanding teacher learning "on the move." As mentioned earlier, professional development literature focusing on MLLs often adopts a linear approach, analyzing the input (professional development activities) and the outcomes (student test scores) (Viesca et al., 2019). However, between that input and output, there are collective and recursive negotiation processes that happen as teachers participate in learning activities, interpret practices, and implement them in the classroom alongside their students and contexts (Strom & Martin, 2017/2022). Using a complex systems framework directs our analysis to how teachers' learning, enacted during instructional moments, is relationally influenced by system elements–and becomes hybridized (Strom et al., 2018). Therefore, a systems-informed critical sociocultural perspective helps shed light on the moment-to-moment processes of teacher development-in-motion that we examine in this paper.

METHOD

The data in this qualitative case study were drawn from a larger 3-year study that investigated the ways teachers participating in 3-Dimensional, inquiry-based science PD (The Science Learning Partnership; SLP) interpreted and enacted their learning in their classrooms, with a focus on supporting MLLs. We selected a case study as a research design (Merriam, 1998) because it allowed us to investigate the complex, micro-level processes involved in teacher translation of learning into practice. Although we acknowledge that school and district-level factors also shape teacher practices, in this paper, we focus mainly on classroom influences.

The Science Learning Partnership

SLP is a three-year partnership between a university and a county office of education focused on professional development. The initiative offered 3D, inquiry-based professional learning for 3rd to 5th-grade teachers and supported administrators in implementing standards-aligned science instruction, with the goal of providing high-quality science education to historically underserved students. Key teaching practices included encouraging student sensemaking through science and engineering practices—especially scientific modeling—emphasizing student discourse. Each year, participating educators attended two weeks of summer professional development and three Saturday workshops during the school year. The PD team included university science faculty, COE staff, and Teachers on Special Assignment (TOSAs) from the local district. The sessions aligned with SLP goals and focused on student sensemaking through discourse about science phenomena and creating and using models to explain thinking with evidence. Teachers participated as both learners and practitioners, engaging in phenomenon-based science lessons during content sessions and leading reflections on videos, written vignettes, and their own practices to deepen their understanding as science educators. Teachers also participated in annual Lesson Study, working in grade-level groups to collaboratively design lessons based on content PD experiences, observe peers teaching, analyze student artifacts for patterns of learning, and plan next steps. Additionally, teachers could join a book club, participate in monthly technology sessions, and share ideas on interactive platforms.

Context and Participants

The focal teacher in this study, pseudonym Heidi, taught in the Easton Unified School District (EUSD), one of eight local school districts involved in SLP. EUSD, located in a large metropolitan area on the West Coast of the United States, has 75% of students qualifying for free or reduced lunch, a standard indicator of poverty. The district is highly diverse: 63% of the nearly 20,000 students enrolled are MLL students, and over 6,000 students are officially designated as "English Learners," roughly 30% of the student body (California Department

of Education, 2020; California School Dashboard, 2020). While students spoke more than 43 different home languages, Spanish was by far the most prevalent, making up 60%.

For this case study, we used purposive sampling. Since the focus was on understanding change, we first selected all teachers who primarily served MLL students from the 100 teachers participating in SLP PD over four years. To observe the micro-processes of change, we chose a teacher who attended all available PD sessions and took part in all data collection, yet initially relied more on teacher-centered approaches. We aimed to explore teachers' experiences as they went through the process of change. Heidi was a white, monolingual veteran teacher with 22 years of classroom experience, of which 21 were at Buena Vista Elementary School (BV). She taught fifth grade but had also taught fourth and sixth grades prior to this study. Although she valued the relationships with her colleagues and received support from teacher leaders at her school, she felt largely unsupported by the district. At the start of the project, Heidi's teaching was rooted in direct instruction, and she confirmed that this approach had characterized her teaching throughout her career.

Data Sources

Focal data included two recorded classroom lessons, three post-lesson interviews with Heidi, and post-observation researcher memos that combined impressions of the lesson and interviews. These primary data sources were supplemented by documents and interviews from SLP, including student artifacts, lesson study recordings, additional interviews, and surveys, to better understand Heidi's application of PD learning in practice. These supplementary data provided triangulation for our interpretations of Heidi's enacted practice and evolving understanding. Additional interviews offered a longitudinal view of her belief changes. For the classroom observations, teachers were asked to select a lesson in which they applied focal pedagogical areas of SLP, specifically student sensemaking discourse and modeling. In other words, the lessons were chosen to exemplify the teachers' best implementation efforts. In year one, these lessons were video-recorded, and an audio recording was made of a focal student group in each class to capture their interactions during the lesson. Each focal student group included at least one student identified as an MLL. In year two, the lessons were recorded using two video cameras—one focused on the teacher and the other on the focal student group. All recordings from these lessons and student focal groups were transcribed. After the observed lessons, we conducted semi-structured interviews to gain insight into Heidi's goals for the lesson, her impressions of how the lesson went, and how it related to her experience in SLP. These interviews lasted an average of 45 minutes, were audio-recorded, and transcribed.

Data Analysis

To analyze the data, we started by conducting open coding across all sources and identified initial codes while memoing throughout this stage (Leavy, 2017; Merriam, 1998). We first coded and analyzed the primary data (lesson recordings, post-lesson interviews, and memos) from the case using an inductive coding approach, applying a constant comparative method (Leavy, 2017; Merriam, 1998). We began with Heidi's first-year lesson, then moved to year two. We used Google Sheets for the initial coding phase, segmenting the verbatim transcripts by talk turn (Hogan et al., 1999; Murphy et al., 2018). Each exchange was entered into a separate cell, with an adjacent cell available for coding. After this initial round, we analyzed supplementary data such as lesson study artifacts and recordings to find information that supported or challenged our initial understanding, memoing and noting significant quotes or details. Examining these lessons through multiple data sources and at the micro-interactional level provides the rigor needed to understand learning-in-motion as a situated process.

One of the most compelling was "in-process learning enactments," or instances where we identified that the participant was enacting, or attempting to enact, an idea or practice associated with the PD. Recognizing that this was an area that is understudied in the literature, we developed specific memos for each of these instances and analyzed them using key ideas from the PD, our theoretical framework, and extant literature on teacher learning from complex perspectives. Because Heidi's case provided the clearest exemplars, we chose to develop her "in-process learning enactments" into a case study, which we share next.

Limitations

While this in-depth case study design allowed micro-level analysis of learning-in-motion, it focused intensively on one teacher's experience. The findings illuminate processes rather than generalizable outcomes. Additionally, while we drew on supplementary data sources (lesson study recordings, additional interviews, student artifacts) to contextualize Heidi's practice, the primary focus remained on observed lessons and post-lesson reflections as sites of learning-in-motion.

FINDINGS

In the case description below, we discuss how Heidi made sense of the SLP professional development in conjunction with her own beliefs about students and instruction, her socio-historical-political and material contexts, and her students. This sense-making unfolded as a dynamic and situated process. While at first her interpretations of student-centered pedagogy and student agency were relatively rigid and "all-or-nothing," over time her enactments evolved into a hybrid approach that blended direct supports with student-centered sensemaking, particularly as repeated teaching opportunities allowed her to refine lessons. In so doing, we illuminate an example of the non-linear development of teacher learning "in motion" at the micro-level.

Heidi's First Year

Overview

In Heidi's first year of the professional development initiative, the emphasis on student agency conflicted with her strong belief in direct instruction. Her lesson implementation demonstrated her sense-making that "student-centered" meant she could provide no information, instructions, or typical scaffolds she would provide to support her students, particularly MLLs. At the same time, she embraced the PD's emphasis on student questioning, leveraging her in-the-moment learning from student interactions to refine her questions as she moved from group to group. As she reflected on the outcomes of the lesson, she used her observations to re-evaluate and complexify her understanding of supporting student agency and MLL language support.

Iterations produce teacher learning in context: group by group

Heidi, who had long believed in the effectiveness of direct instruction and front-loading, particularly for her MLLs, found SLP's phenomenon-based, student-centered approach a drastic change from the methods she previously used. However, in the first year of the PD, Heidi gamely moved toward a situated interpretation of a student-centered approach. A close look at her implementation showed that in her early meaning-making, she had interpreted "student centered" to mean that she should not "give anything away" so as not to interfere with student-led sense-making. In the first-year interview, Heidi explained that she believed "student-centered" meant that the teacher should be totally absent from their learning process: "Well, the kids would be doing it. The teacher would not be involved in that at all."

This aligned with our observation of Heidi's lesson on states of matter (focused on condensation) during her first year of PD. At the start of the lesson, she intentionally did not explain to students what the lesson was about or have students make predictions before beginning the hands-on activity, as she would have before joining SLP. When introducing the lesson and explaining the lab sheet, she was careful not to reveal what they would be investigating, even choosing not to include a title on the lab sheet that guided students through the experiment and on which they recorded their observations. She told the class, "I didn't want to give away what it was, so I didn't put a title for you" (Lesson, Y1). Heidi removed the scaffolds and supports she normally would have provided, although she was not yet convinced her students, many of whom were MLLs, could succeed without them.

These practices, along with her reflections in the first-year interviews, showed an "all or nothing" view of student-centered learning. She explained in the lesson debrief that she made these pedagogical choices to maximize student agency in their learning. However, she also described her struggle to avoid front-loading, saying, "It was so hard to not front-[load], you know what I mean. They're not gonna get anything out of [the lesson] because they don't know what any of it is" (Interview, Y1). Believing her students, especially her MLLs, wouldn't succeed without pre-teaching vocabulary and concepts, Heidi experienced a deep internal conflict between her desire to follow her SLP approach and her fear that not doing so would set her students up for failure.

Nevertheless, Heidi's learning was "in motion": While she struggled with scaffolds, she worked on asking questions to guide students' thinking and discussion, which was emphasized in the PD. Unsure of what to expect from her students in this new situation, Heidi engaged them with questions to help her understand their learning process and facilitate their understanding. Her questioning during the lesson also showed how her pedagogical understanding evolved through practice. As she moved from group to group, engaging students in discussions about condensation, their responses gave her opportunities to evaluate how well her questions worked. For example, in the first group, students mistakenly believed the water on the outside of the cup was coming from the inside. In response, Heidi asked, "How could we test that, what could we do, like what further test could we do to see if it was coming from inside or outside of the cup?" (Lesson, Y1). Building on their suggestion to take out the ice to see if the outside water remained, the teacher suggested:

> If we wanted to test if this water was coming from inside the cup, what can I do to that water in the cup to see, cuz, right? So, if I did something to that, and it was truly coming from inside the cup, then it would be like that when it came outside, right? If this liquid was coming from inside, so, what if I did something like dying that green? Right, or if I made the ice green, right? If I dyed that first, then what would happen to this liquid on the outside? (Lesson, Y1)

Heidi left the students discussing that question and moved to the next group. Recognizing the question's effectiveness in helping students relate the phenomenon under study to their lived experiences, she refined the question for the next group with whom she spoke. The second time she articulated this question, she made it even more relatable to students by drawing upon their experiences with the condensation that formed on the outside of their cups while drinking soda:

> So, since you said ice, if I made ice out of Pepsi, and put it in, then this stuff on the outside would be...Pepsi, right? Because I made the ice cubes out of Pepsi... Does that happen? Think about when you go to a restaurant. Does that happen? (Lesson, Y1)

Through each of the subsequent iterations of her question-asking in the groups, she made the question more relevant to the students' lived experiences, refining her practice of question-asking as a tool to support students' learning in the new learning context, from moment to moment. Through her interactions with students and reflections in the seconds she took moving between tables, Heidi's question-asking evolved as she tailored her questions to support students' thinking, utilizing their prior knowledge and experiences.

Heidi's approach positioned her as a learner alongside her students, and Heidi actively observed her students' physical and verbal interactions during the lesson to understand how they were making sense of the phenomenon of condensation. As she was learning how to support students in the shifted context, her engagement with students was very attuned to what each group was experiencing and understanding, with her choice of questions authentically inspired by the students' responses.

Heidi's learning through engaging in the implementation of the lesson with her students the first year of SLP was evident. In reflecting on both the successes and challenges her students faced during the hands-on lessons, she reconsidered how some of the supports she would use in the past, such as student discourse scaffolds, like sentence stems and turn-taking protocols, could have supported her students' participation during the lessons. During the post-lesson interview, she explained:

> I had thought about putting up sentence frames to narrow what I wanted them to look at, which I think I would do the next time because some of them got off on the temperature and the rising levels of the water. More narrowly focused what's happening on the outside of the cup maybe? … Maybe it's the sentence fragment or ask the question directly to focus that better. (Interview, Y1)

As her statement demonstrates, through interacting with her students during the lessons and reflecting afterward, her learning continued to develop as she began to negotiate how to provide support for students within a student-centered context, beginning to ease away from her all-or-nothing understanding of student-centered learning.

Heidi's Second Year

Overview

During her second year in SLP, Heidi continued to intentionally shift her practice away from direct instruction to a student-centered approach in line with her PD learning. Although she still found it challenging, she began to find more ways to blend her new learning and past practices, including grounding lessons in students' experiences and supporting collaboration through written instructions and scaffolds. Additionally, both Heidi's participation in Lesson Study and her new arrangement with a partner teacher to teach science to both groups of students allowed her multiple opportunities to teach the same lesson, adding a new layer of learning through enactment in the second year.

Iterations produce teacher learning in context: class by class

In her second year of the program, Heidi made more nuanced movements in her practice as she negotiated how to scaffold the lessons for her students while allowing for their agency in sensemaking. We observed these movements through analyzing the Lesson Study documents used to plan the lesson, and during the lesson, where students explored air pressure using syringes and plastic tubing with the goal of developing an understanding that, although air is not visible, it is still a form of matter. In preparing for the lesson, Heidi's

written document stated, "Prior to activity, students will make a prediction of what they think will happen [with the syringes]" (Lesson Study Planning Tool, Y2). This approach added a student prediction back into her lesson. She had incorporated such scaffolds as a routine prior to the PD, but abandoned the approach in the first year, believing it to be contradictory to the SLP teachings. She also planned to "allow students to play with the syringes and materials (they will anyways)" (Lesson Study Planning Tool, Y2). When implementing, Heidi taught the lesson to several classes, and she subtly adjusted each iteration of the lesson based upon her observation of her students' responses to her instruction, as she "learned in motion." During the first implementation of the lesson, Heidi realized that the students were unsure of what was expected of them and were not clear on how to approach the task with the syringes. In the next lesson, still adhering to her intentional shift away from "frontloading", she hybridized her new commitment to student sensemaking with her existing pedagogies, adding more specific instructions to the lab sheet (Student Artifact, Y2). She described, "[I tried] to be more specific in what we wanted in the model, because they had no clue even where to-... specifically we put 'label'" (Interview, Y2).

These moves indicate Heidi's successful negotiation of the conflict that had caused contradictions for her in her first year of the PD between scaffolds and student agency. Specifically, she was able to hybridize her practice by still planning student supports/structure (i.e., providing instructions and sentence stems), which she believed to be vital for supporting MLLs while also fostering student agency by modifying her lab sheet to include explicit written instructions. The latter allowed her to avoid providing the up-front verbal instructions she believed were not aligned with a student-centered approach.

Heidi also spent a bit more time at the beginning of the lesson preparing the students for participation and engagement with the materials by drawing out students' personal experiences with the primary materials for the lesson—syringes—and sharing her own experiences with them. Heidi also posed a series of questions to guide the students' investigations with the materials, with questions such as "What's going on with these? What's happening with these syringes? What things that you can see, hear, smell?" (Lesson, Y1). utilizing gesture and realia to support her communication with her students. These are examples of bringing her past pedagogical understandings and approaches into dialogue with what she was learning in the PD. As these dialogues progressed over the course of the day, she began to demonstrate more fluidity in her teaching approach.

Contextual Influences on Learning

A very prominent contextual factor that influenced Heidi's practice was her perception of her students and their needs. In her first year participating in SLP, Heidi had what she described as a "really nice class" without highly differentiated academic needs, which made Heidi feel more courageous in trying new ways of teaching science. In contrast, in the second year of SLP, she faced more challenges with the group of students, which greatly affected her approach to teaching in general and, more specifically, to implementing her learning from PD. Heidi was exhausted, both physically and emotionally. As Heidi strove to meet her students' needs, her energy for new instructional practices waned. She reverted to more traditional practices, less willing to turn over control to the students by engaging them in student-centered learning activities. This shift highlights the non-linear, context-dependent nature of teacher learning.

In leaning more heavily on her prior practices, yet wanting to implement her PD learning, she struggled with the tension between allowing for students to engage in more active, student-centered practices, knowing that it was what they needed, but reluctant to provide them the opportunity, as she wanted to maintain a calm, controlled learning environment. She explained her concerns:

> *I find that a lot of things that I used to do, like… a stand-up activity where they would share with each other…I don't do it as much because when they get up and walk around that's when stuff happens. People get knocked over...That's when the chaos happens, and so find myself much more keeping them bound to their chairs, …. Which is probably not what I should do with that group, because they probably need to get up more than other groups. (Interview, Y2)*

Heidi recognized that providing students with the opportunity to engage in discourse with their peers and physically move around the classroom were likely what was best for her students, yet she often kept her students "bound to their chairs" and relied more on traditional, teacher-centered practices to maintain a controlled environment. As Heidi experienced more challenges as a teacher in trying to support students' socio-emotional needs at the same time as their academic development, she was more comfortable maintaining control in the classroom, though she also recognized that her approach was likely not best for her students, and did not align with her learning in SLP.

After participating in SLP for two years and working to enact her learning in the classroom, Heidi reflected on her interactions and the students' responses to the shifts in her practice, finding that students largely exceeded her expectations in how they engaged in discourse. They also had surprised her with their enthusiasm

and willingness to engage in the new learning experiences, and she observed that her ML students actively participated in science more than in other subjects. She explained, "With science, they're just excited… 'We have this stuff in front of us. We get to play with it, and then we have to tell people. Okay, we can do that.'... It draws them in more and it's almost like a safer environment that way to share and participate" (Interview, Y3). The successes she saw in her students' responses on a day-to-day basis increased her belief in the new practices that she was learning in PD and reinforced her willingness to implement and continue to refine them. As she continued to recognize her ML students' success in the science lessons she was working to implement, her belief in her students as capable meaning-makers, even as they developed their English proficiency, also increased. Additionally, as a learner herself, Heidi continued to grow as she reflected on ways she would alter her lessons, and brought in her years of experience as an educator to improve upon the lessons in response to how the students engaged, finding that she did not have to abandon all of her past practices to make room for those she was learning in PD.

DISCUSSION

Given increased investment in teacher professional development (PD) supporting inquiry-based science, as well as the inequities faced by MLL students in science education, gaining a better understanding of what teachers do with that PD is essential. While a significant body of literature explores professional learning for teachers of MLL students (e.g., Viesca et al. 2019; Kalinowski, Gronostaj & Vock, 2019), our understanding of the specific, micro-level processes through which teachers' learning from PD translates into practice remains limited—especially how these practices create environments that support both science content learning and language development (Lambert & Ariza, 2008; Shanahan & Shea, 2012). This paper aims to address this gap by shedding light on how teachers interpret their ongoing science professional development and how they translate that understanding into action, working collaboratively with their MLL students within their social-historical-political contexts.

Heidi's learning journey was significant. The shifts she made to implement her new understanding differed markedly from her decades of direct instruction. Specifically, she began creating opportunities for students to construct knowledge through hands-on experiences and discourse with peers. Her learning process continued over the years in SLP through iterative cycles, as she moved her learning from PD into her classroom and reflected again. Heidi engaged as a teacher-learner (Freire, 1970) with the new pedagogical approaches, initially through instruction promoted by SLP, and subsequently through her interactions with students as she experimented with new science teaching strategies.

Initially, Heidi participated in hands-on experiences during PD sessions, oscillating between a student and teacher perspective. During workshops, she experienced the lessons from a learner's standpoint—engaging in activities, then analyzing and discussing the science content and pedagogical approaches from both learner and instructor roles. In these settings, facilitators and colleagues acted as "more capable peers" (Vygotsky, 1978), supporting her in scaffolding her learning of both science content and pedagogical practices within her ZPD (Kuusisaari, 2014). Such rigorous, iterative, collaborative, scaffolded sense-making opportunities are crucial for shifting teachers' understanding and practices (Thomas & Drew, 2022).

Secondly, Heidi applied her PD learning in her classroom context, where she continued her journey of learning as both teacher and learner. In other words, Heidi kept progressing through her ZPD as she worked with her students in hands-on science lessons. Her students and their feedback served as scaffolding, supporting her development as a "less capable peer" (van Lier, 1996). She also supported their learning with her knowledge and experiences–what Vygotsky (1978) describes as self-talk—as she interacted with her students. Observing her students, especially her MLLs, respond to lessons provided her with feedback—generating insights and ideas for modification (Hayes et al., 2019). As Heidi moved away from her previous lecture-based practices to provide more student-centered learning experiences, she noted her students' successful participation, particularly her MLLs', in complex sense-making activities with peers. These observations acted as positive feedback, encouraging her to continue enacting the practice shifts she was developing—and challenging her initial perceptions of her MLL students' capabilities.

Her students' struggles also served as an inflection point: for example, Heidi's initial binary understanding of needed conditions for agency led her to completely withhold instructions at the beginning of a lesson, and she observed students' resulting difficulty. In her reflections afterward, she considered how she might reintroduce some of the scaffolds she usually provides in her instruction, indicating a more nuanced understanding of agency-fostering science pedagogy. Ultimately, her learning from how the students responded during the lessons reinforced many of the shifts she was making in her practices and led to further modifications of the lessons to

better meet her students' observed needs. These examples contribute to an emerging body of work illustrating the productivity of student sense-making as a powerful learning site for teachers (Hayes et al. 2019; Heredia et al., 2022)–and which we argue is a form of scaffolding within teachers' ZPDs. However, these teacher-student interactions also worked in tandem with an entire system, or systems, of other human and nonhuman elements that simultaneously shaped Heidi's learning and how it translated into practice (Strom, 2015; Opfer & Pedder, 2011; Von Esch et al., 2025)—for example, Heidi's prior knowledge, beliefs, and past practices; the PD activities, ideas, pedagogical structures, facilitators, and teacher peers; contextual factors specific to her school site/district; and even larger societal narratives about what specific student groups are capable of (Kayumova & Buxton, 2021), all contributing to the situated process of Heidi's ongoing learning.

Implications

The documentation and analysis of Heidi's moment-to-moment enactments of learning provide valuable insight into where and how shifts in teachers' practices occur, as well as the role of experiential learning in supporting the learning process. Since teachers' professional development (PD) continues even after the formal sessions—when teachers grapple with their new knowledge in relation to their students and context (Kayumova & Buxton, 2021; Osman & Warner, 2020; Von Esch et al., 2025)—these insights from teachers' complex learning processes are also promising for understanding the nonlinear, situated practice shifts that enhance ML students' learning experiences. In this study, hands-on learning opportunities—both during PD activities and in classrooms as teachers begin negotiating their learning within their contexts—were found to support teachers' growth within their ZPD and facilitate the enactment of their new knowledge (Hayes et al., 2019; Mutch-Jones et al., 2022). PD facilitators need to create conditions that enable teachers to engage as both instructors and learners in the practices and content they are expected to teach their students. Throughout the process, facilitators should foster opportunities for teachers to reflect both as teachers and students (Thomas & Drew, 2022), often in community with their peers (Kuusisaari, 2014), as they co-construct meaning. Ongoing PD should also allow teachers to share their experiences of enacting their learning—highlighting successes, challenges, and adaptations made in collaboration with their students—to support continuous growth in partnership with fellow teachers and PD facilitators (Opfer & Pedder, 2011).

Two specific aspects of teacher learning emerged in this study as needing support through ongoing, reflective PD opportunities. First, teachers need to understand what student success looks like with new pedagogies they learn and how to assess it. Traditional assessment views treat students as passive recipients of static information, while student-centered learning positions students as meaning-makers and active knowledge-constructors. Teachers implementing discourse-rich, inquiry-based pedagogies, especially with MLLs, must learn to recognize and appreciate different forms of student learning (Grapin, 2023), including productive struggle with understanding and explaining phenomena, collaborative knowledge-building through discourse, and sense-making that draws on a variety of linguistic and non-linguistic resources (Alvarez et al., 2023). Second, teachers need support in managing the tension between fostering student agency and providing necessary scaffolding and structure, particularly for MLLs. Student-centered learning contrasts with many traditional teaching practices and calls for not only new strategies but also a reconceptualization of the teacher's role. As Heidi's case shows, teachers may initially interpret "student-centered" as an either/or choice—either providing direct support or stepping back entirely. As they explore and enact lessons with their students, ongoing PD can help them develop responsive, context-specific scaffolds that support MLLs and other students in building agency within inquiry-based processes.

Conclusion

Teachers' classrooms and practices are a powerful environment for ongoing learning, as teachers engage in experiential learning with their students. Through further research that explores learning in action for both teachers and students, like in this study, we can develop a better understanding of teacher learning to improve future professional development for educators. As ML students continue to be underserved in our schools and are often excluded from science education, it is essential to ground research efforts in a solid understanding of the theoretical and ideological foundations that shape the understanding of teaching and learning for ML students. Additionally, we must prioritize the experiences of ML students in research, viewing their language practices and ways of knowing as assets to their learning and to the classroom environment overall.

Statement of Researchers

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