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Why does teacher learning vary in professional development? Accounting for organisational conditions

Kathryn N. Hayes ^a, Linda Preminger  ^a and Christine L. Bae  ^b

^aDepartment of Educational Leadership, California State University East Bay, Hayward, CA, USA; ^bDepartment of Foundations of Education, Virginia Commonwealth University, Richmond, VA, USA

ABSTRACT

Professional development providers often struggle with how some teachers take up and internalise new instructional practices while others have difficulty implementing new ideas and strategies. Teacher personal characteristics account for only part of this differentiation in learning, and there are unanswered questions regarding how organisational conditions shape teacher learning in professional development (PD). To address these questions, we examined U.S. elementary teachers' learning and change in a science professional development project. We expected to find that, in addition to personal characteristics, teacher change would be differentiated by the type and number of constraints within the organisational environment. Instead, we found that teacher change was differentiated by teachers' ability to draw on areas of alignment and iterative learning as resources to resist anti-science and teacher-centred aspects of the organisational environment. These resources were generated through coherence between the PD, teacher pedagogical beliefs, and existing instructional routines, as well as observing student learning while trying out PD strategies.

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Professional development; teacher change; organizational environment; science education

Introduction and literature

Although professional development (PD) is generally considered essential for teacher learning and implementation of reform-based instructional practices, it often results in variable outcomes, with some teachers enthusiastically taking up new practices, and others incorporating surface level features (Sandholtz *et al.* 2019, Longhurst *et al.* 2021, Molle 2021, Shi 2022). Some of the differences are clearly due to the design of PD itself, and much of the literature focuses on these differences, including the strategies within PD (e.g. active learning, collaboration, coaching) (Desimone 2009, Darling-Hammond *et al.* 2017). Yet, reviews of the literature in this area note that the variable success of PD is still not fully explained, and may be due to interactions between professional learning and the complex context in which such learning takes place (Opfer and Pedder 2011, Kennedy 2016, Darling-Hammond *et al.* 2017). In these reviews, context is broadly defined as including teachers' immediate professional world (classrooms and students), teacher social and organisational context (e.g. norms, collaboration opportunities, policies), and the external milieu (e.g. social trends).

Emerging research examining the situated, complex nature of teacher learning in context has produced intriguing findings across international contexts (Kayumova and Buxton 2021 [United

CONTACT Kathryn N. Hayes  kathryn.hayes@csueastbay.edu  Department of Educational Leadership, California State University East Bay, 25800 Carlos Bee Blvd, Hayward, CA 94542, USA

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States], McChesney and Aldridge 2021 [Abu Dhabi], Shi 2022 [China]; Taylor 2023 [United Kingdom]). However, conceptual frameworks that explain teachers' learning and change within context have yet to be taken up in much of the literature examining specific PD efforts (Opfer and Pedder 2011). In short, understanding the instructional change that might (or might not) result from PD has been difficult because research in education tends to separately examine PD and the contexts in which teacher learning and instructional change occur (Kennedy 2016) (for exceptions, see Longhurst *et al.* 2017; McChesney and Aldridge, 2021).

Our view of the importance of context positions our work alongside studies of PD that take an organisational or socio-cultural lens (e.g. Kayumova and Buxton 2021, Longhurst *et al.* 2021, McChesney *et al.* 2019, Pringle *et al.* 2020, Shi 2020). These scholars argue that conceptualising teacher learning as an iterative process that incorporates teachers' context will help us understand how teachers differentially respond to PD. To contribute to this understanding, we examined how elementary teachers in the western region of the United States differentially understood and implemented reform-based science instructional practice after approximately a year of participation in science PD. We define reform-based instructional practice as an inquiry-based and discourse-rich approach to science education, undergirded by centering of students' languages and lived experience (NRC 2012, Stroupe 2014, Odden and Russ 2019). We used a theoretical framework called the Interconnected Model of Professional Growth in an Organisational Context (based on Clarke and Hollingsworth 2002, Hayes *et al.* 2019, 2020) (Figure 1) to understand how *the interactions* between a) teacher personal characteristics, b) their immediate professional world (classrooms and students), and c) their organisational and external context shaped teacher learning and change across levels of implementation. In the following section, we summarise the research on

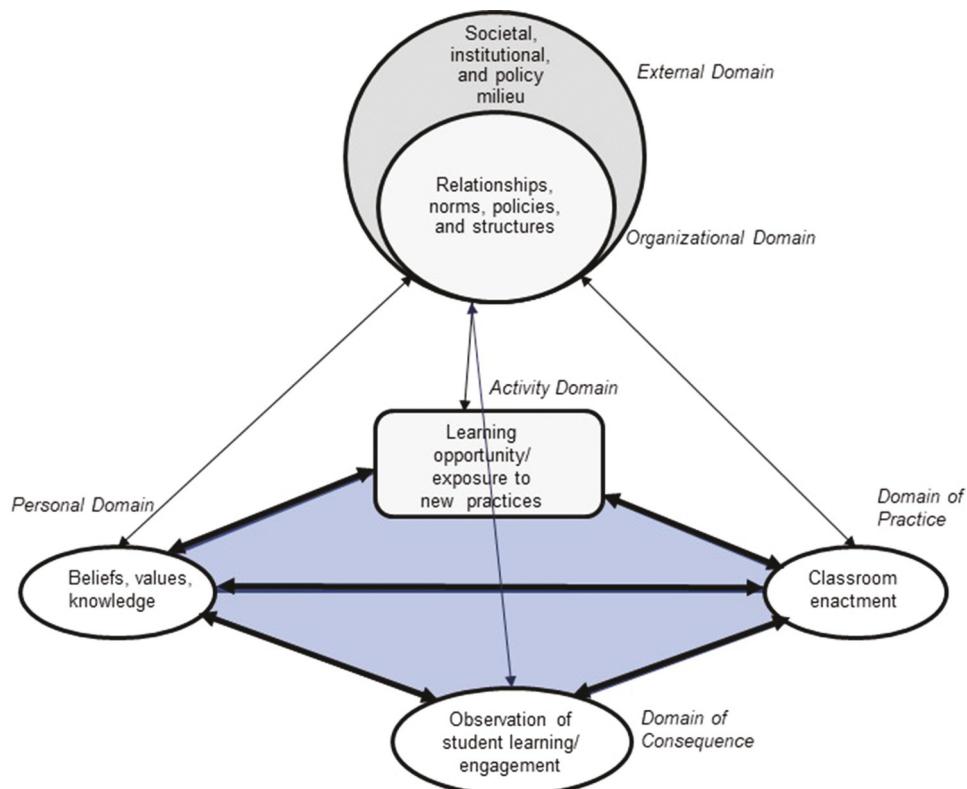


Figure 1. Interconnected model of professional growth in an organisational context (Hayes *et al.* 2019; Clarke and Hollingsworth (2002).

each of these areas particular to science education, followed by examples of the few studies that examine interactions across them.

Personal characteristics

In science education, teachers' lack of content knowledge and confidence with science can make implementation of reform-based instructional practices difficult in the elementary grade bands (Lee and Maerten-Rivera 2012, NAS 2015). Additionally, teachers' beliefs about pedagogy can range broadly. Many teachers report alignment between their pedagogical beliefs and reform-based instructional practices (Banilower *et al.* 2018), and may even resist norms towards teacher-centred instruction in order to teach science in accordance with student-centred beliefs (Carlone and Kimmel 2010). Yet, traditional teacher-centric beliefs and practices persist, such as front-loading academic vocabulary in advance of exploring phenomena (McNeill 2011, Banilower *et al.* 2018). These beliefs, and other personal factors such as knowledge and self-efficacy, can mediate the ways PD is translated into instructional practice (Hayes *et al.* 2019, Whitworth and Chiu 2015).

Classrooms and students

As teachers shift away from 'telling' the science and move towards students producing their own science knowledge, they learn that students are capable of complex thinking about science ideas. Such understanding of student learning can reinforce shifts in instructional practice driving teacher learning and change (Franke *et al.* 2001, Lee *et al.* 2009, McNeill 2011, Taylor 2023). Changes in teachers' beliefs and practices more often result when teachers notice what students say and do, interpret their ideas, and respond to advance student thinking (Preminger *et al.* *under review*).

Organisational and external environment

Although research on the role of organisational and external environments in teacher learning is still developing, especially in science education, research on PD occasionally notes specific barriers and supports. This literature shows that in most elementary schools in the United States, science is largely on the 'back burner,' (i.e. assigned a lower priority than maths and English language arts (ELA) (Dorph *et al.* 2011, Sandholtz *et al.* 2019). Outdated textbooks and strict pacing guides can reinforce teacher-centred approaches to instruction and result in piecemeal adoption of new strategies from PD (Sandholtz *et al.* 2019, Stollman *et al.* 2020). Even more significant than these constraints, teacher perceptions of accountability pressures in maths and ELA have a negative impact on their learning in science PD, leading to teacher-centred pedagogies to cover the required material (Fore *et al.* 2015, Kayumova and Buxton 2021). These issues are more pronounced in schools serving historically marginalised children, where absence of regular and robust science instruction is the norm and its impact is cumulative (NAS 2015, Hayes and Trexler 2016). Yet, a few studies have shown ways that organisational context can support the translation of PD into reformed instructional practice, including administrator support for PD (Sandholtz *et al.* 2019, Pringle *et al.* 2020) and opportunities for teacher leadership (Gallucci 2008).

Holistic context

In order to support teacher learning in PD, a few scholars have argued that there is a need to understand the interactions between teachers' personal characteristics, their students and classroom context, and their organisational and external environments (Opfer and Pedder 2011, Whitworth and Chiu 2015, Boylan *et al.* 2018). Based on foundational work in the 1990s (e.g. Grossman *et al.* 1999), recent research has emerged regarding how dilemmas in the organisation interact with other aspects of teacher learning to shape teacher

implementation during PD (e.g. Fore *et al.* 2015, Longhurst *et al.* 2017, Sandholtz *et al.* 2019). For example, Fore *et al.* (2015) examined the professional learning of 13 secondary teachers in a nanotechnology PD using subjectivity as a framework. They found that a complex interaction between teachers' existing understandings of their students (classroom context), along with lack of materials, strict pacing guides, and standardised tests (organisational environment), resulted in teachers implementing the new content primarily through lectures rather than problem-based learning. The research in this area also demonstrates that teachers in PD are continuously sensemaking regarding factors external to their immediate professional world and are particularly attentive to incoherence across their personal beliefs, learning in PD, and organisational norms and policies (Allen and Penuel 2015, Heredia 2020, Marshall *et al.* 2021).

Conceptual Framework

We situate our work within this important and growing area of literature by using the Interconnected Model of Professional Growth in an Organisational Context (Figure 1) to examine the system in which teacher learning and change takes place. This model represents an extension of Clarke and Hollingsworth's (2002) model, which proposes that teacher change rests on an iterative and reflective process between four domains in teachers' immediate professional world: the activity domain (which they call the external domain; sources of information or support such as PD), the personal domain (e.g. teachers' knowledge and beliefs), the domain of practice (e.g. classroom experimentation), and the domain of consequence (e.g. teachers' perception of student learning). The framework has been applied in a number of studies, primarily to document the ways in which teacher PD influences changes in the personal domain and domain of practice (Justi and van Driel 2006, Witterholt *et al.* 2012).

However, although Clarke and Hollingsworth incorporated a 'change environment' as part of the model, its components are not delineated. A few articles using the framework in the Netherlands (e.g. Voogt *et al.* 2011) note the change environment as an important factor influencing teacher change, but do not define it clearly. One exception, Schipper *et al.* (2017) designated an additional domain they call the domain of school context. We build on this work by adding two domains that explicate features of the organisational and external environments. The organisational domain includes two major areas: 1) teachers' professional relationships, organisational norms, and instructional culture (Gallucci 2008, Schipper *et al.* 2017), and 2) the structures and policies that both constrain and facilitate instructional change (e.g. collaboration time; accountability) (Allen and Penuel 2015, 2016). The external domain consists of the societal, institutional, and policy milieus that exists outside of the organisation, yet exert influence on teacher learning (Opfer and Pedder 2011). Because it accounts for the system of teacher learning, the model has the potential to illuminate the interactions and feedback loops across multiple domains that lead to differential learning from PD. Hereafter, we use the acronym PGOC (Professional Growth in an Organisational Context) to refer to the present version of Clarke and Hollingsworth's model.

Clarke and Hollingsworth (2002) argue that change across domains is mediated through processes of reflection and enactment. In order to understand the teacher change process within a holistic context that explicitly includes the organisation, we add sensemaking to processes that mediate change (Weick 1995). Sensemaking recognises the recursive relationship between reflection and enactment, but also takes into account the role of dilemmas and inconsistencies in the teacher's environment (Allen and Penuel 2015, Marshall *et al.* 2021). Prior work based on the PGOC model shows the explanatory capability of a model that brings an organisational domain into an iterative model of teacher growth (Hayes *et al.* 2019, 2020). Grounded in the existing literature and conceptual framework presented here, we examined the following questions:

- (a) How do interactions across domains in teachers' immediate professional world (personal domain, domains of practice and consequence) create the conditions for differential teacher learning in science PD?
- (b) What deeper understandings of teacher differential learning are afforded by the inclusion of the organisational and external domains in interaction with other domains in the teacher change process?

Methods

Setting

Professional development

This study examines teacher learning after 9–15 months of participation in a PD project called the Science Learning Partnership (SLP; a pseudonym). Hereafter, all references to the SLP PD project are referred to as SLP for specificity. General references to other professional development are referred to simply as PD. Participants were 3rd through 5th grade teachers from eight partner districts (local educational agencies) in an urban area (Table 1). The professional development approach was predicated on existing research that calls for active learning, integration of content and pedagogy, sustained duration, and teacher collaboration (Desimone 2009). In addition to these, SLP was informed by seven years of research practice partnership that established the importance of relationships, teacher leadership, and communities of practice (Bae *et al.* 2016, Hayes *et al.* 2020). The SLP model consisted of a five-day summer institute and three Saturday workshops in the academic year. The SLP facilitation team for each grade level included a science faculty, a pedagogical expert, and a teacher leader. In SLP sessions, teachers learned science content in the role of a student (through a set of model lessons), followed by 1) adult level content discussion and 2) teacher discussion of how to adapt lessons to their instructional context. Most teachers also participated in lesson study (Lewis *et al.* 2006), in which a small group of same-grade teachers planned a lesson together, took turns trying it out, observed one teacher, then analysed student work before making additional revisions. In year one, 63 teachers joined the project; in year two, 26 joined. SLP also partnered with teacher leaders and administrators to develop school and district science education capacity.

SLP supported teachers in learning about three-dimensional Next Generation Science Standards (NGSS) with an emphasis on equitable sensemaking discourse (National Research Council 2012, Odden and Russ 2019). A three-dimensional approach supports students' learning of fundamental science content around a phenomenon; participation in exploring, modelling, and explaining natural phenomena; and investigation of crosscutting concepts that govern all science disciplines (National Research Council 2012). In addition to such phenomena-based instruction, for students to engage deeply in science learning, they must come to believe their voices are pertinent to solving real-world problems that matter to them (Bang and Medin 2010, Stroupe 2014). This requires engaging students in sensemaking discourse that incorporates students' home, cultural, and out-of-school languages and experiences (Bae *et al.* 2021, NAS 2015, Lee and Maerten-Rivera 2012). We refer to these approaches as reform-based instructional practices.

Table 1. Sample district demographics.

District Name	Enrollment	% English Learners	Largest Ethnic Group	% FRL
Helmwood	21,900	35	Hispanic	73
Mt. Danworth	32,000	25	Hispanic	55
San Loredo	8,700	34	Hispanic	65
San Isabela	12,300	28	Hispanic	69
Natchez	12,600	24	Hispanic	50
Jersey	6,300	25	Hispanic	54

Organisational context

For the teachers in this study, the organisational context corresponded fairly closely with literature on elementary science teaching described above. Nearly all interviewed teachers spoke of science being underemphasised, 'on the back burner,' or simply discouraged. Maths and ELA were emphasised because of accountability, particularly in third and fourth grades (Dorph *et al.* 2011). Yet, because California tests student achievement in science during fifth grade, fifth grade teachers felt a great sense of responsibility to prepare students for the test. None of the SLP partner districts had engaged in a science curriculum adoption for the new elementary science standards (despite the standards being ratified 12 years earlier), thus textbooks and other curriculum were quite outdated. Some teachers had older science kits, and many had access to Mystery Science curriculum in which students watched videos about science concepts, then conducted confirmatory labs. That said, teachers perceived organisational barriers differently, and these differences in perception (and related actions) shaped their change process. This is described in the results.

Sample and data collection

This study is part of a larger multi-year grant-funded science PD project. The present study primarily draws on interview data collected as part of classroom implementation observations in the first two years. Teachers were asked to select a science lesson that incorporated reform-based instructional practices for researchers to observe and record. The researcher took notes during the observation and completed a memo summarising their perceptions of the teacher's understanding and implementation of these practices. For this study we selected all teachers who were willing to be observed and had participated in SLP at least nine months ($M = 95$ hrs) ($N = 21$; [Table 2](#)). The pandemic precluded collection of video data from four of these teachers; they were interviewed just after schools moved to remote instruction.

Following the lesson, teachers were interviewed (40–60 minutes) using a semi-structured protocol (audio recorded and transcribed) (see [Appendix A](#)). The first set of questions addressed the classroom observation, the teachers' perceptions of student learning, and how the lesson fit into a larger unit. The second part of the interview focused on eliciting teachers' understanding and beliefs regarding the nature of three-dimensional instruction and equitable sensemaking discourse, and their perceptions of how they implemented each in practice. For example, for the focal outcome of sensemaking discourse they were asked to describe the sensemaking they sought, how the lesson turned out, and the pedagogies (current and past) by which they supported sensemaking discourse. They were then asked to describe an ideal moment of sensemaking discourse as if to another teacher. Finally, researchers asked teachers how they had changed their practice for each of the pedagogical outcomes over the course of SLP, and what supported or discouraged these changes. This latter aspect of the interview is known as attributional, in that we ask the teachers to 'attribute' their instructional changes to particular processes (Miles *et al.* 2019).

Table 2. Sample teacher demographics.

Gender		Ethnicity		Grade Level	
Female	19	White	10	Grade 3	8
Male	2	African-American	2	Grade 4	6
		LatinX	5	Grade 5	7
		Asian	3		
		Other	1		

Analysis

Categorising teacher change

In order to understand how interactions across domains influenced differential teacher change, we first needed to categorise the degree of teacher change. Thus, as part of the larger study, we analysed teacher interviews, post-lesson memos, and video observational notes for evidence of the following (drawing on Grossman *et al.* 1999 appropriation schema): 1) Understanding: teachers' expressed understanding of SLP pedagogical principles and practices (conceptual tools; Longhurst *et al.* 2021); 2) Implementation: congruence between pedagogical outcomes and teacher instructional practice (practical tools); and 3) Perceived Change: how teachers described having changed their understanding and implementation over their involvement with SLP (Table 3) (Franke *et al.* 2001). If their described change differed from what was seen in the observation, we noted the discrepancy in the memo. Using this evidence, we placed teachers in one of four categories of change: Static, Initiating, Advancing, and Nuanced (Table 4). Two authors analysed the data for each teacher, placing each in a change category based on the boundaries described in Table 3, and documenting the placement with evidence from the data. The authors then met to resolve discrepancies with the goal of consensus. For example, the authors' initial disagreement as to whether teacher Gil better met the criteria of the Nuanced or Advancing category turned on evidence that, prior to participation in SLP, Gil's science instruction had been limited to reading expository text. While both

Table 3. Ordinal change categories and descriptions.

Change Category	Teachers in this category ...
Static Change	<ul style="list-style-type: none"> Exhibit misalignment in their understanding of pedagogical principles and practices. Describe teacher-centred, transmission approach to teaching. Discuss trying to implement student centred practices, but when challenged, default to a teacher-centred approach.
Initiating Change	<ul style="list-style-type: none"> Discuss struggling with surface level instructional practices; do not reflect on their degree of change. Understand surface-level features of pedagogical practices and strategies. Experiment with tools, strategies, and formats mechanistically Express anxiety about skill level with new practices. May embrace a pedagogical concept, but are stymied when students become stuck. Implement SLP strategies on top of existing, non-aligned curricula. Describe tentative use of new student-centred discourse strategies or science-specific pedagogies, such as modelling.
Advancing Change	<ul style="list-style-type: none"> Generally, describe a student-centred approach to teaching. Actively apply pedagogical strategies from PD. Willingly experiment with conceptual underpinnings and adapt them to current context Actively support student sensemaking discourse. Describe making purposeful instructional shifts, sometimes structural in nature Discuss moving away from directing student conversations, and towards facilitating a flow of ideas.
Nuanced Change	<ul style="list-style-type: none"> Show deep understanding of pedagogical principles, and quickly develop understanding of new strategies. Adapt pedagogical principles from PD to their classroom context. Adjust existing routines to better facilitate student equitable sensemaking discourse. Use SLP content and strategies as the backbone of the curriculum Describe changing their approach to classroom culture, integrating students' productive struggle to make meaning of phenomena. Are sometimes explicit about strategies not yet implemented; perceive their shifts as works in progress.

Table 4. Ordinal change categories and teacher data.

Change Category	Number of teachers	Average hrs SLP PD	Average hrs other science PD	Average years' experience
Static teachers	4	89.5	9.3	15.0
Initiating teachers	7	120.6	6.9	18.9
Advancing teachers	5	91.5	8.4	12.4
Nuanced teachers	5	119.9	28.4	18.4
<i>N</i> = 21				

authors acknowledged Gil's challenges with reform-based instruction, they eventually agreed that the distance he had come from merely reading about science to implementing discourse-rich, inquiry-based science were within the boundaries for Nuanced change, and the discrepancy was resolved. This analysis process is described in greater detail in Preminger et al. (*under review*). We would like to note here that we do not believe teachers in Static and Initiating categories are deficient. However, these teachers experienced organisational issues that, if understood better, would help PD providers better target their professional learning.

Coding for the domains in the PGOC model

To understand how interactions across the domains created the conditions for the differential change seen in the categories, two authors coded interviews for reference to each of the six domains of the PGOC model (personal, practice, activity, consequence, organisational, external) (Clarke and Hollingsworth 2002, Hayes *et al.* 2020). We used the domains as a priori categories, and allowed elements of each domain and interactions between domains to emerge from the data as subcodes (Saldana 2013). For example, 'testing pressure' emerged as a subcode under 'organisational domain.' Both researchers coded one transcript, then discussed and compared their analysis with the goal of achieving precise code definitions. The process was repeated until researchers reached 70% similarity in code application, after which all transcripts were coded using Dedoose software by one author. After coding all interviews, both authors memo'd each teacher's change process individually and mapped interactions onto a copy of the PGOC model (Figure 2). The research questions focus on interactions, thus the maps were a key secondary analysis process because they

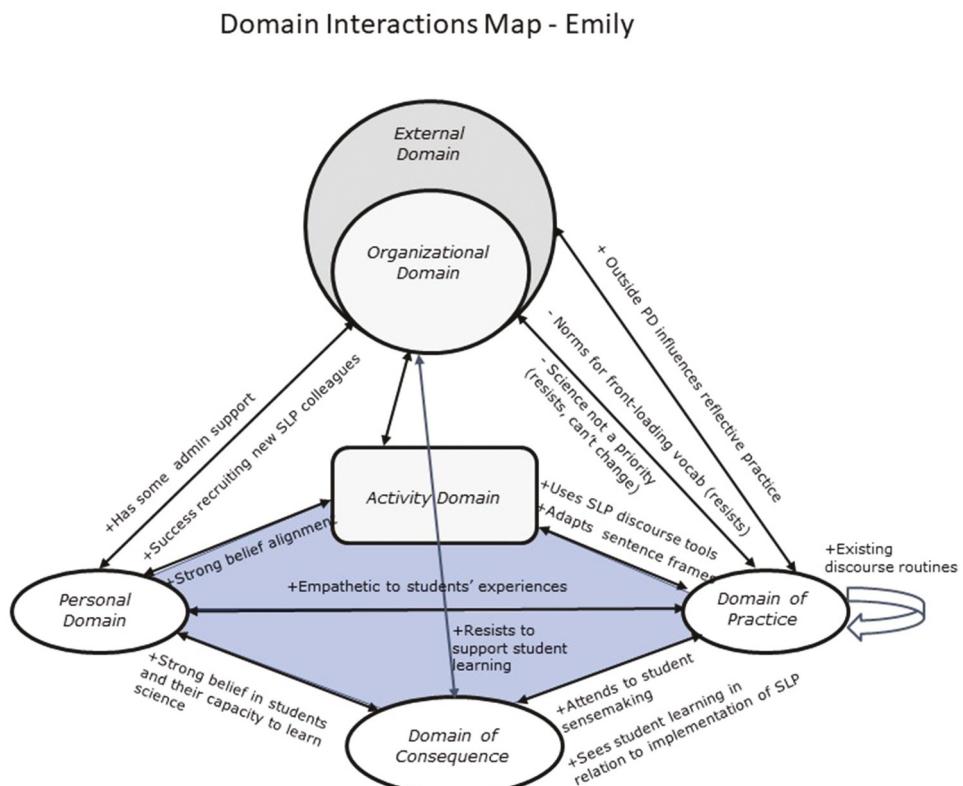


Figure 2. Example of interactions map for one teacher created in the analysis process.

indicated how each domain interacted with other domains to support or stymie the change process. The memos and maps were compiled to serve as the foundation of subsequent themes.

Generating themes regarding the holistic context of teacher learning

Based on the results of the coding and the maps of each teacher's change process, we systematically identified the most salient interactions among the teachers' immediate professional domains in the PGOC model: personal, consequence, and practice, as well as SLP PD (activity domain). We found two prominent themes among these domains: I) alignment between personal and activity domains facilitates change; and II) close observation of student learning (domain of consequence) reinforced SLP pedagogies (activity domain). For the 2nd research question, we then examined the evidence for interactions among the domains of teachers' immediate professional world and the organisational and external domains. We wrote memos documenting both one-to-one relationships (e.g. lack of materials [organisational domain] discouraged science teaching) and relationships among multiple domains. As an example of the latter, for one teacher, we documented how her teacher-centred beliefs (personal domain) interacted with legacy science curriculum kits (pre-NGSS) (organisational domain) to stymie change, while simultaneously she was excited about trying out instructional practices from SLP (activity domain). A secondary coding of the memos revealed that these processes involving the organisational and external domains amplified the interactions documented in Themes I and II. These 'amplifications' are described below as Theme I and II in context.

Results

In the following section, we present two themes that showcase how key interactions between domains in the teachers' immediate professional world create the conditions for differential teacher learning. We then expand each theme to show how including the organisational and external domains further informs our understanding of differential learning in SLP. Each Theme is represented by a figure, with the interactions between domains noted in text and figure by a letter.

Theme I: alignment between personal and activity domains facilitates change

Teachers tended to change more when there was alignment between teacher pedagogical beliefs (personal domain) and the pedagogical principles underlying SLP strategies (activity domain). Static teachers were committed to transforming their teaching, but they had difficulty implementing reform-based science instruction, often due to their existing pedagogical beliefs (Figure 3; process b). For example, all four were uncomfortable with aspects of equitable sensemaking discourse strategies. Two of the teachers professed to have an affinity for science, yet their enthusiasm for science education tended to undermine a reform-based approach to teaching as they focused on direct instruction (Figure 3; a). Margaret, a fifth grade teacher who had been a dedicated science lead for years, described of students, 'You are an empty slate! Let me fill it up for you.'

Although Initiating teachers often exhibited alignment to aspects of SLP pedagogies, they tended to remain committed to teacher-centred approaches in other areas. They often tried out the forms and formats of SLP pedagogies mechanistically without fully understanding the pedagogical principles underlying the strategies. Advancing teachers exhibited more well-developed pedagogical beliefs and incorporated SLP strategies that already fit their understanding of how to move students towards sensemaking (Figure 3; e). For teachers in the Nuanced category, the sensemaking discourse strategies proposed by SLP (activity domain) resonated strongly with their existing beliefs (personal domain) even if it went against organisational norms (organisational domain) (Figure 3; c). Here Emily discusses how she felt about SLP strategies, implementing them despite organisational expectations (Figure 3; c, d, e), 'We're trained ... [with] all of that upfront vocabulary, [but]

Theme I: Personal-Activity Domain Alignment

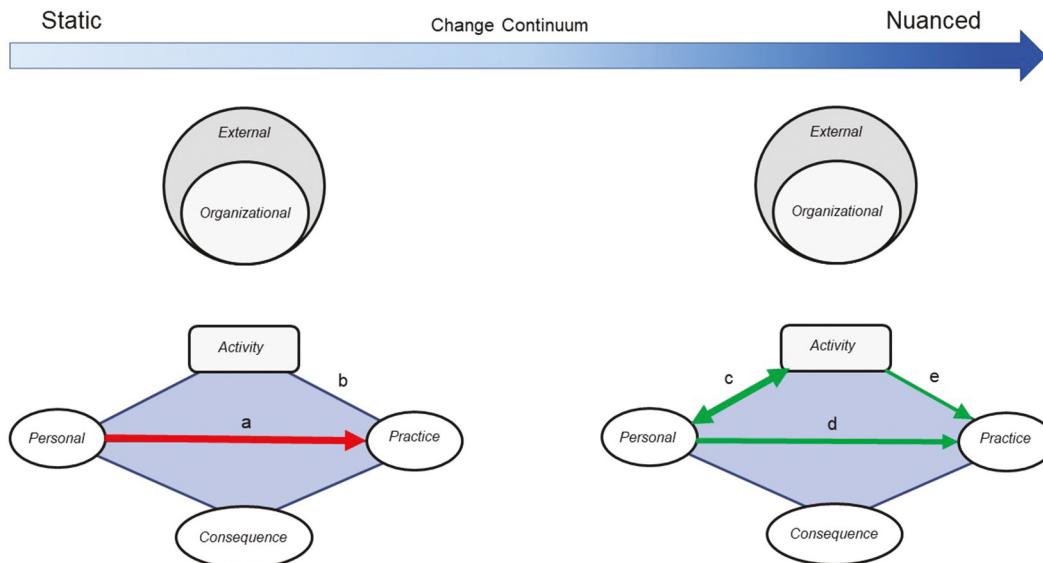


Figure 3. Illustration of interactions between domains of the PGOC model for Theme I. in all figures red and green arrows indicate interactions that hinder and support reform-based science instruction, respectively. Lower case letters label interactions referenced in the results. The weight of the line is a rough approximation of the prevalence of the interaction. Absent or very weak interactions may be indicated by a letter with no arrow.

I really like this backloading. It's so much better.' She continued, 'To me that's that aspect of really good discourse, is when . . . they're like, "I don't know if that fits yet and I need to talk to you more about it." I'm just in love with that concept . . .' Due to resonance with their existing pedagogical principles, Nuanced teachers readily adopted SLP equity and discourse strategies, then, over the course of the SLP PD, increased their understanding and implementation of science-specific pedagogies.

Theme 1 in context

In Theme I, teachers who had pedagogical beliefs closely aligned with SLP principles more easily adapted SLP strategies into their instructional practices (Franke *et al.* 2001, Rivera Maulucci *et al.* 2015). Yet, analysing the teachers' context more holistically revealed additional processes occurring in interaction with Theme I that influenced teacher learning. For teachers at the lower end of the change continuum, anti-science and teacher-centred organisational norms reinforced their existing pedagogical beliefs, and because of mechanistic implementation of SLP practices, they were unable to draw on SLP principles as a source of resistance. For teachers at higher ends of the change continuum, alignment between the personal and activity domains (i.e. between their beliefs and SLP principles), along with other professional learning opportunities, served as a resource for teachers to navigate organisational barriers. Thus, alignment indirectly facilitated change through pathways of resistance.

For teachers on the Static and Initiating side of the change continuum, the organisational environment interacted with their teacher-centred pedagogical beliefs to stymie change (Figure 4; f, g, a). For example, their interpretation of state testing pressure (organisational/external domain) reinforced their proclivity towards vocabulary and direct instruction (domain of practice). In addition, although teachers in all categories mentioned outdated textbooks and science kits (organisational domain), there was a clear progression across change categories in how teachers *used* legacy curricula. Those who struggled to change

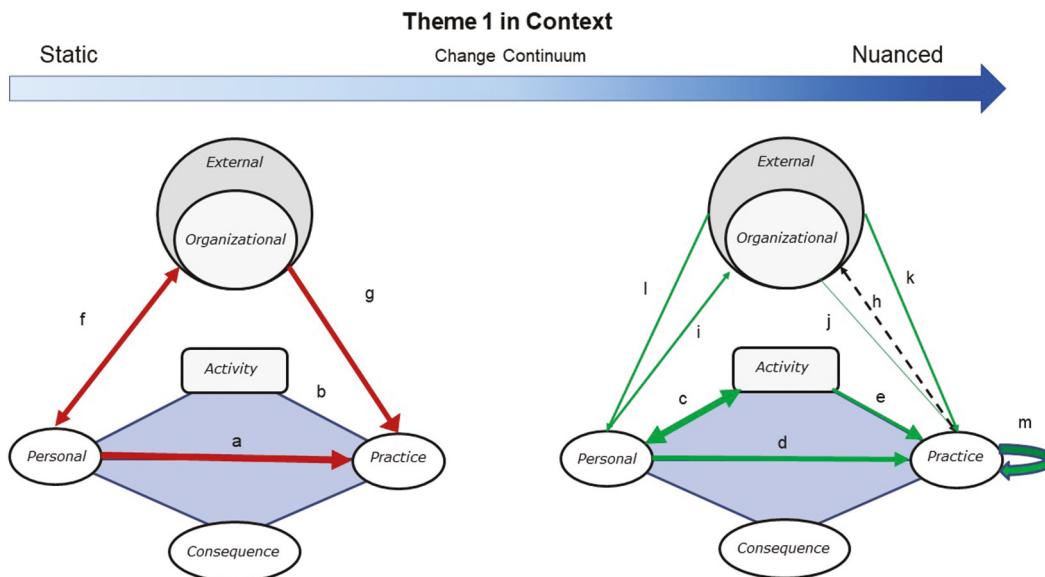


Figure 4. Interactions between domains of the PGOC model for Theme I in context. Dotted black lines indicate teacher resistance towards the organisational context.

tended to rely on outdated materials without modification (Figure 4; g), which reinforced existing teacher-centred beliefs and instruction (personal domain, domain of practice; f). For example, Initiating teachers spoke of layering SLP pedagogical strategies on top of non-aligned curriculum.

Even when there was potential alignment between reform-based instructional practices and organisation initiatives, Static teachers felt conflicted by competing priorities (Figure 4; f, g). When asked about incorporating SLP curriculum into her school's major initiative, Margaret said, 'We have to teach [in the style of the initiative], which is NGSS, which is you guys' way.' But, she went on, 'That [SLP science lesson] I was able to put in for an [initiative] unit, I kind of forced it. They [other teachers] weren't too happy.' Margaret could have drawn on alignment between SLP and the school initiative to reinforce reform-based pedagogies (activity domain). Instead, she allowed resistance among her colleagues (organisational domain) (Figure 4; g) to constrain her implementation of reformed instructional practices (domain of practice; a, f).

In contrast, Advancing and Nuanced teachers' belief alignment with SLP (personal and activity domain) (Figure 4; c) supported resistance to anti-science organisational incentives (h), facilitating implementation of SLP pedagogies (e). Lesley (Nuanced) stated,

So when you add in the [English], the math . . . I've used up more than the minutes I have . . . So I have to figure out and be smarter about how can I connect . . . Or you shut the door and you ignore, and then the chances whether someone walks in or not . . . I *am* going to do science, and I'm *going* to do social studies. [emphasis is the teacher's]

Similar to teachers at the lower end of the change continuum, Lesley experienced constraints regarding organisational preference for ELA instruction over science. She navigated this issue through more deft content integration or ignoring the organisational environment (Figure 4; i, h), professing a commitment to teach science despite organisational opposition (d).

Likewise, teachers who changed to a greater extent tended to ignore legacy curricular structures or use them judiciously, instead favouring SLP approaches, which aligned with their student-centred beliefs (Figure 4; c, e, h). They discussed strategies such as excerpting short textbook passages, or incorporating videos from district-purchased programmes into SLP lessons. David

(Advancing) described how he has changed over time from Mystery Science to SLP lessons as his foundational curriculum (e, h):

Last year was more Mystery Science and the SLP stuff as my backup ... But this year, I kind of reversed it where the stuff from the SLP website was what I focused on, and then I would take some of the lessons from Mystery Science.

Finally, unlike other teachers, every Nuanced teacher talked about how additional (non-SLP) PD, usually with pedagogical foundations similar to SLP (e.g. engaging students in sensemaking discourse), supported their understanding and uptake of reform-based pedagogies (Figure 4; k, l, m). Kathleen (Nuanced) provides an example. 'Well, there was a program I was trained in called Math Studio. The kids would explain their thinking about how they tried to solve a problem [like SLP].' For Kathleen, foundational pedagogies from the prior PD (external domain) influenced her pedagogical beliefs (personal domain; k), and became routine in her classroom (domain of practice; k, m), making SLP reform-based pedagogies for science more accessible (activity domain; e).

Theme II: close observation of student learning reinforced SLP pedagogies, facilitating change

The second prominent theme that emerged from analysis of domains in the teachers' immediate professional world was how observation of student learning informed teacher change. Teachers who changed less readily championed fact accumulation rather than student sensemaking, and thus had difficulty connecting student learning to their instructional practice (domain of practice, consequence) (Figure 5; a, c). These challenges undermined their ability to adapt SLP instructional practices (activity domain) to their classrooms (b). Ann typified Static teachers when she described how she taught a particular lesson:

And you know that the clouds, most of the clouds are forming there near the equator where the water is real warm. And then we talked about why the water's real warm there, and the intensity of the Sun ... I brought out the globe and showed with a flashlight.

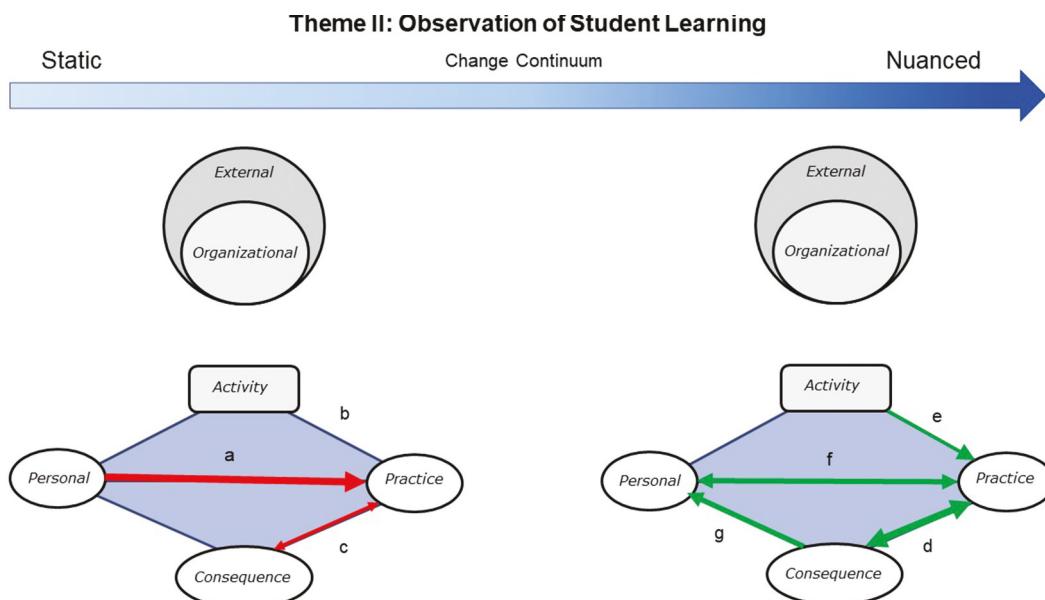


Figure 5. Illustration of interactions between domains of the PGOC model for Theme II.

Although Ann was trying science activities from SLP (activity domain), her proclivity towards information transmission (personal domain; domain of practice) (Figure 5; a, b) prevented her from fostering and noticing student sensemaking (domain of consequence; c).

Initiating teachers more often discussed their observations of students, but tended to emphasise student affect, describing how hands-on science ‘blew their minds,’ or how students were ‘very curious.’ In contrast, Advancing and Nuanced teachers conceptualised student learning and their teaching practice as integral to each other, rarely reflecting on one without the other (Figure 5; d). They also described instances of student productive struggle when they implemented SLP strategies, and their own responses (e, d, f). For example, Tess (Advancing) described:

One of the [SLP] strategies that I really feel is successful is when we're all in productive struggle, when we see a group that is getting a hook in something, that we fishbowl or do a gallery walk [SPL strategies] . . . it's really effective at keeping the teacher out of it.

As Tess reflected on trying out SLP strategies (activity domain) (Figure 5; e) she celebrated student sensemaking (personal domain, domain of consequence) in relation to the learning process (domain of practice; f, d, g).

Theme II in context

In Theme II, teachers' reflections on student learning played a pivotal role in encouraging uptake and implementation of SLP strategies (Preminger *et al.* *under review*) (Figure 5). As shown in the section above, feedback loops between the domain of consequence, the domain of practice, the personal domain, and the activity domain directly facilitated change. Once again taking the broader view, our analysis showcases how interactions between these domains and the organisational domain indirectly facilitated teacher implementation of reform-based instructional practices (Figure 6), often through resistance or other forms of navigation.

Reflecting on student learning provides inspiration to overcome organisational barriers. In addition to supporting changes in beliefs and practice, teachers' reflection on students' learning helped them navigate barriers to science education in the organisational environment (Figure 6; g). Advancing and Nuanced teachers spoke of resisting, ignoring, or transforming organisational

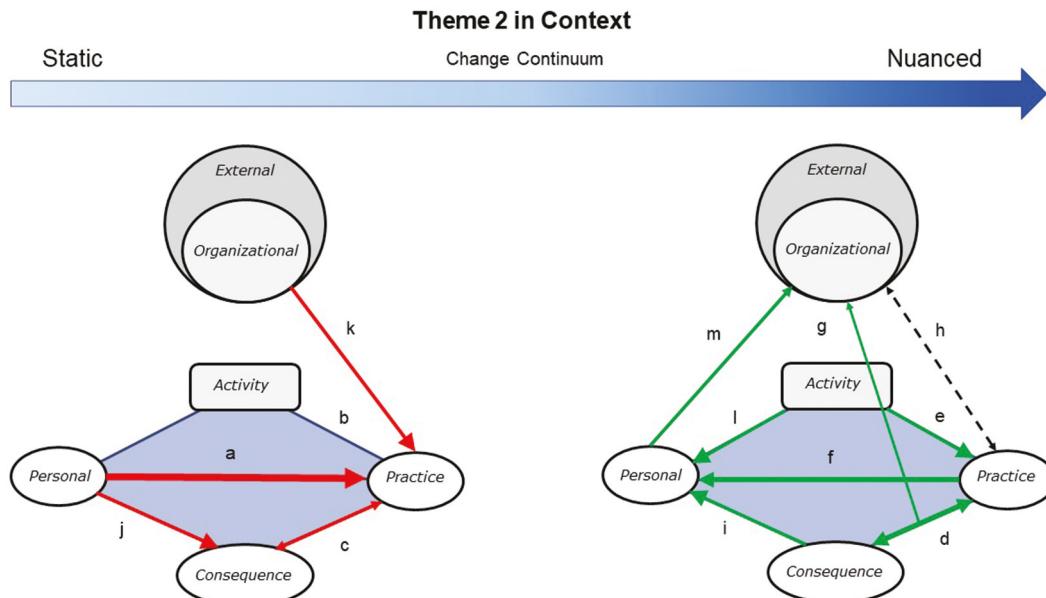


Figure 6. Illustration of interactions between domains of the PGOC model for Theme II in context

barriers to reform-based science education because they saw the student learning engendered by such teaching (h). For example, Lesley said,

Being in the program last year I taught the complete life cycle unit, which was me, 'Closing my door and I'm just going to do it.' And it ate up time from other things... but it's good for the students.

Kathleen (Nuanced) reflected on how her observations of students allowed her to dismiss organisational barriers.

I don't have a curriculum. I don't know how it's all going to come together. But when we actually looked at student work, it was amazing to see how much more they had picked up than I thought... maybe in the absence of a curriculum I had more freedom to play around with this, with my students... It's exciting.

Kathleen once believed a lack of aligned curriculum (organisational domain) inhibited science planning, but ongoing participation in SLP (activity domain) and seeing the student learning (domain of consequence; d) shifted her perception of curriculum as a barrier (personal and organisational domains; g, m, h) and gave her freedom to try new pedagogical strategies (domain of practice; f).

Although Initiating and Advancing teachers often focused on student affect rather than learning, observing student excitement when they implemented lessons from SLP still inspired them to teach science in the face of barriers. For example, Helena's (Initiating) students' insistence (Figure 6; d) led her to embed science as part of the schedule, overcoming organisational norms that de-emphasised science (h).

Since I started SLP one of the big changes is that science is part of our schedule. . . . in all honesty, we don't highlight science at our school . . . [but now] it's on our schedule. They know when you try to skip it. once you put something in a schedule, it's there. . . . Every Wednesday is science and they look forward to it.

In contrast, Static teachers were unable to draw inspiration from their students to navigate organisational barriers. Margaret described compound organisational difficulties in the following excerpt:

[Science] takes a while. Then you get the ones goofing around. Meanwhile, the principal's going through the room . . . I get kind of stuck [at my desk]. . . you have to circle like a shark, how am I going to do that? And do the computer? . . . my seven-year-old computer.

Margaret felt overwhelmed by interacting aspects of her organisational environment, including an older computer and the principal's judgement (k). But importantly, her perception of students was not one of learning, but of mischief (domain of consequence) (j, c). Student reaction to the lesson had become a burden rather than a resource. Teachers at lower ends of the change continuum had difficulty implementing productive discourse (activity domain), resulting in expressions of frustration with students rather than inspiration (Figure 6; c, j, k). This frustration, combined with a constellation of barriers in the organisational environment, reinforced teacher-centred pedagogies (b).

SLP provided tools and resources essential for noticing student learning. Most of the teachers acknowledged that the reason they were able to see student engagement and learning was because SLP PD encouraged implementation and provided resources (Figure 6; e). Gil (Nuanced teacher) had not been teaching inquiry science at all; he started because of SLP requirements.

Before, it was all just the book. . . . In the past I would have done all individual [learning] because it's quieter . . . You walk into another class and they're just like, 'Shh.' And I always feel like I'm failing somewhere because my classes aren't that quiet. But, through SLP . . . they always promote students having conversations . . . because if they're talking it's part of them thinking.

Insights on student learning (domain of consequence), resulting from implementation encouraged by SLP (domain of practice, activity domain), helped Gil push back on organisational norms about a quiet classroom (organisational domain). Lesley (Nuanced) reflected on how

pedagogies she learned in SLP were ‘the opposite’ of what ‘we’re told’ in other subject area programmes (Figure 6; e, h). But observing student learning through SLP supported her resistance (d).

It was something that I learned in [SLP] which is the opposite of what we’re told in our math program [where] they tell you to load upfront the vocabulary ... But having gone through the pedagogy I [saw] that actually second language students learn better if you allow them to mostly use their own language and give them a little bit of words.

SLP PD also provided resources that directly helped teachers overcome organisational barriers. Erin (Advancing) noted that she didn’t have the resources to implement science lessons that required uncommon materials (organisational domain) (Figure 6; h), but the lesson she learned in SLP used easily available resources (pennies) (e). Such ease enabled her to teach the lesson, and the student reaction encouraged her implementation (d), reinforcing changes in her beliefs about appropriate pedagogies (i, f). She said, ‘any activity that’s hands-on that I have access to is very beneficial because ... if they can experience it, they’re going to have a deeper, more active understanding.’

Discussion

Past PD literature often treated the organisational context as external to the professional learning process itself, which reduced our ability to understand the conditions under which instructional change occurs and respond with more effective PD. This study contributes to a growing body of literature examining the role of context in teacher professional learning (e.g. Heredia 2020, Stollman *et al.* 2020; Shi, 2020). An understanding of how holistic context shapes teacher learning is particularly important in elementary science education in the United States, because of the consistent de-emphasis on science, and persistent issues with equity (e.g. Dorph *et al.* 2011, Hayes *et al.* 2016, Sandholtz *et al.* 2019). Yet, it may also inform understanding of PD wherever the organisational context provides a set of understudied yet persistent barriers to teacher learning (e.g. Opfer and Pedder 2011, Stollman *et al.* 2020).

In our study, teachers’ organisational environments were relatively similar and largely discouraging of science education. However, although almost all sampled teachers discussed organisational barriers, their perceptions and navigation of these barriers differed. We expected to find that teacher change would be differentiated by the type and number of constraints within the organisational environment. Instead, we found that teacher change was more often differentiated by teachers’ ability to experience and draw on motivational resources to navigate anti-science and teacher-centred aspects of the organisational environment. These resources were generated through rich interactions between learning in SLP (activity domain), trying out student-centred instruction (domain of practice), observing student learning (domain of consequence), and coherence with well-developed pedagogical beliefs (personal domain). Clarke and Hollingsworth (2002) suggest that more consistent and ongoing interactions between the domains may result in more long-lasting teacher growth, a conjecture reflected in our analysis.

In theme I, alignment between teachers’ existing pedagogical beliefs (personal domain) and the pedagogical principles underlying SLP PD (activity domain) directly facilitated internalisation and implementation of new science instructional strategies (domain of practice) (Justi and van Driel 2006, Witterholt *et al.* 2012). Yet when the holistic context was taken into account, additional patterns emerged. For teachers who struggled to change, their perception of the organisational environment (e.g. legacy curriculum, testing pressure) reinforced teacher-centred beliefs, or proved overwhelming (Fore *et al.* 2015). In contrast, among teachers at higher ends of the change continuum, resonance between existing pedagogical beliefs and SLP principles, as well as prior PD (external domain) and related instructional routines (domain of practice), reinforced SLP pedagogies (activity domain). This alignment in turn served as a resource for teachers to resist or otherwise navigate organisational barriers, an additional, indirect support for instructional change.

In theme II, teachers who changed to a greater degree noticed and reflected on student learning in relation to their implementation of SLP instructional practices, a finding strongly supported in the literature (Fore *et al.* 2015, Schipper *et al.* 2017, Preminger *et al.* *under review*). Yet when examined more holistically, it became apparent that noticing student learning resonated beyond teachers' immediate professional world. When they tried out SLP practices (activity domain), those that closely noticed students' learning (domain of consequence) found inspiration (personal domain) to resist or ignore anti-science and teacher-centred aspects of the organisational environment. This feedback loop thus both directly (i.e. teachers who noticed student learning continued implementing reform-based instruction) and indirectly (i.e. through resistance to organisational barriers) facilitated instructional change. The SLP PD itself acted as a catalyst and resource for these teachers. Lower change teachers tended to focus on what they taught rather than what students learned, and thus were unable to draw on student learning as a source of motivation for resistance.

Implications for research

In science education in the United States, a few studies have noted organisational barriers and supports to teacher learning, such as leadership (Fischer *et al.* 2018, Sandholtz *et al.* 2019), trust (Marshall *et al.* 2021), availability of materials (Fore *et al.* 2015), and, above all, accountability policies (Hayes *et al.* 2016). Although enumerating the organisational barriers is an important step, frameworks that model the systems that influence teacher learning afford a more systematic understanding (Longhurst *et al.* 2021). Because the PGOC model attends to the domains in teachers' immediate professional world as well as organisational and external contexts, it models such systems, shedding light on why teachers in PD change differentially. Inclusion of organisational and external domains in the analysis illuminated feedback loops that amplified or stymied teacher change (Allen and Penuel 2015, Schipper *et al.* 2017). Some research using complexity and activity theory explores how such feedback loops and interactions shape teacher learning (e.g. Fore *et al.* 2015, Kayumova and Buxton 2021), but additional research is needed in this area.

The aspects of the learning process that acted as the greatest resources for resistance to anti-science aspects of the organisation were alignment (across teacher beliefs, SLP, and other areas of experience) and noticing student learning (while trying out SLP instructional practices). A few studies on teacher sensemaking in PD also demonstrate the importance of teacher perceptions of alignment or coherence (e.g. Allen and Penuel 2015, Stollman *et al.* 2020, Marshall *et al.* 2021). The present study adds to this literature, showing that alignment across multiple domains can be a self-reinforcing system that amplifies teacher learning recursively through positive feedback loops. Likewise, a large body of research demonstrates the importance of reflection on student learning for teacher change (Franke *et al.* 2001, Fore *et al.* 2015, Schipper *et al.* 2017). We inform this body of literature through showing how such reflection can provide motivation, even inspiration, to teach science in the face of constraints.

Finally, this study contributes to a body of literature examining teacher resistance to inequitable or otherwise misaligned areas of organisational practice (Caralone and Kimmel 2010, Gutiérrez 2016, Rivera Maulucci *et al.* 2015, Shi 2020). These studies have found that teachers who learn more student-centred, equitable ways of teaching sometimes need to find ways to navigate or resist organisational norms, often with the support of PD providers. Similar findings in the current study indicate that teacher acts of 'creative insubordination' (Gutiérrez 2016) are a fruitful area of future research, especially in elementary science education (Caralone and Kimmel 2010).

Altogether the findings beg the question: if organisational barriers were removed (thus removing the need to resist), would teachers change their instructional practice to a greater degree? Although we cannot directly answer this question without an experimental design, we note the following: Our findings demonstrate that differentiation in teacher change is related to both interactions among domains in the teachers' professional world (Theme I and II) and the ways teachers draw on these interactions as a resource for resistance to organisational barriers (Themes I and II in context). It's

possible that if these organisational barriers were removed (that is, if science was a priority and reform-based instruction was the norm), our low change teachers would have a greater growth trajectory because they would not have an organisational environment reinforcing their traditional beliefs (Theme I). Likewise (from Theme II), without organisational barriers to inquiry based science, opportunities to notice the student learning that emerged from reform based instruction may have accelerated teacher change. However, we suspect differentiation happens in intersection across: a) the interactions among domains in teachers' professional world, b) the presence of organisational barriers, and c) teachers' motivation to resist. The ability to discern the role of each is beyond the scope of this paper, but may provide fruitful lines for future research.

Implications for practice

Changing instructional practice can be difficult, especially within organisations that generate barriers to change. Our findings also demonstrate that teachers may be more likely to take up and implement reform-based instructional practices if PD providers create opportunities to identify and amplify areas of alignment with their organisational environment (e.g. initiatives in maths or ELA), or to discuss ways to resist misaligned incentives (Brown and Weber 2016). For example, PD providers may allocate time for teachers to discuss curricular time constraints and how to navigate them, such as integrating school language and literacy requirements into science units. Such discussions should also include how to use legacy curriculum judiciously, as some teachers' reliance on existing kits and textbooks forestalled their ability to incorporate sensemaking discourse and other reform-based approaches advocated in SLP. Finally, teachers need time to problem-solve how to use resources available in the PD (e.g. lessons that use commonly available materials) to overcome organisational barriers. This study confirms calls by Heredia (2020), Allen and Penuel (2015), and others to intentionally build time into PD for sensemaking around organisational policies and examination of the relationships between reforms and current practices. Altogether, such sensemaking can shift teachers' perception of organisational barriers, such that they feel less overwhelmed, see greater areas of alignment, or obtain motivational or conceptual resources for resistance.

Our examination also showcases the need for differentiated PD in two areas (Stollman *et al.* 2020). First, teachers need support to examine their existing pedagogical beliefs and how these manifest in classroom culture and instructional routines across content areas. PD can provide opportunities for teachers to identify existing aligned routines, amplifying the learning and uptake of strategies within the PD. Second, teachers may benefit from PD differentiation in regard to noticing student assets and student learning, using it as inspiration to shift instructional practices in the face of organisational barriers (Franke *et al.* 2001; Preminger *et al.* *under review*). Such PD has the potential to support teachers' growth away from teacher-centred distribution of facts and towards opportunities for learning science that undergird democratic participation in solving the complex problems facing our world.

Limitations

This study has several limitations, enumerated here. First, the study is based primarily on interview data, and thus the claims supported by the data are derived from teachers' conceptualisation of their change process and what influenced them. Second, the data presented are from one time point and the findings represent teacher conceptualisations of a change process in its nascent stage. Third, in this paper, we did not specify how the organisational environment itself differed between teachers, but instead report on how they perceived, reacted to, and interacted with the organisational environment. Fourth, although the authors did not facilitate SLP PD, they worked with the facilitators in regards to the broad planning of the PD. Thus there is potential for bias in interpretation. We worked to reduce

bias through engaging in a systematic data collection and analysis process, including: a) using memos and observations to confirm interview analysis; b) establishing reliability across two coders; and c) involving a third author who did not participate in PD planning. Finally, due to policies and cultural approaches, organisational context can operate quite differently across international and local contexts. Because this study takes place in California, it may not be generalisable to all PD efforts. However, as this area of research grows, the research community may be able to establish common, or at least transferable, processes that occur for teachers as they learn in context.

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ORCID

Kathryn N. Hayes  <http://orcid.org/0000-0003-2121-1053>
 Linda Preminger  <http://orcid.org/0000-0003-4860-3049>
 Christine L. Bae  <http://orcid.org/0000-0002-3492-7598>

References

Allen, C.D. and 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. doi: [10.1177/0022487114560646](https://doi.org/10.1177/0022487114560646)

Bae, C. L., Hayes, K. N., Seitz, J. C., O'Connor, D., & DiStefano, R. 2016. A coding tool for examining the substance of teacher professional learning with example cases from middle school science lesson study. *Teaching & teacher education*, 60, 164–178. [10.1016/j.tate.2016.08.016](https://doi.org/10.1016/j.tate.2016.08.016)

Bae, C. L., Mills, D. C., Zhang, F., Sealy, M., Cabreria, L., & Sea, M. 2021. A systematic review of science discourse in K-12 urban classrooms in the United States: accounting for individual, collective, and contextual factors. *Review of educational research*, 91(6), 831–877. [10.3102/00346543211042415](https://doi.org/10.3102/00346543211042415).

Bang, M. and Medin, D., 2010. Cultural processes in science education: supporting the navigation of multiple epistemologies. *Science education*, 94 (6), 1008–1026. doi: [10.1002/sce.20392](https://doi.org/10.1002/sce.20392)

Banilower, E.R., et al., 2018. Report of the 2018 NSSME+. Chapel Hill, NC: Horizon Research, Inc.

Boylan, et al., 2018. Rethinking models of professional learning as tools: a conceptual analysis to inform research and practice. *Professional development in education*, 44 (1), 120–139. doi: [10.1080/19415257.2017.1306789](https://doi.org/10.1080/19415257.2017.1306789)

Brown and Weber, N.B., 2016. Struggling to overcome the state's prescription for practice: a study of a Sample of early educators' professional development and Action research Projects in a high-stakes teaching context. *Journal of teacher education*, 67 (3), 183–202. doi: [10.1177/0022487116636452](https://doi.org/10.1177/0022487116636452)

Carlone, H.-F.J. and Kimmel, S.C., 2010. Tempered radicals: elementary teachers' narratives of teaching science within and against prevailing meanings of schooling. *Cultural studies of science education*, 5 (4), 941–965. doi: [10.1007/s11422-010-9282-6](https://doi.org/10.1007/s11422-010-9282-6)

Clarke, D. and Hollingsworth, H., 2002. Elaborating a model of teacher professional growth. *Teaching & teacher education*, 18 (8), 947–967. doi: [10.1016/S0742-051X\(02\)00053-7](https://doi.org/10.1016/S0742-051X(02)00053-7).

Darling-Hammond, L., Hyler, M.E., and Gardner, M., 2017. *Effective teacher professional development*. Palo Alto, CA: Learning Policy Institute.

Desimone, L.M., 2009. Improving impact studies of teachers' professional development: toward better conceptualizations and measures. *Educational researcher*, 38 (3), 181–199. doi: [10.3102/0013189X08331140](https://doi.org/10.3102/0013189X08331140)

Dorph, R., et al., 2011. *High hopes- few opportunities: the status of elementary science education in California*. Sacramento, CA: The Center for the Future of Teaching and Learning at WestEd.

Fischer, et al., 2018. Investigating relationships between school context, teacher professional development, teaching practices, and student achievement in response to a nationwide science reform. *Teaching & teacher education*, 72, 107–121. doi: [10.1016/j.tate.2018.02.011](https://doi.org/10.1016/j.tate.2018.02.011)

Fore, G.A., *et al.*, 2015. Learning at the nano-level: accounting for complexity in the internalization of secondary STEM teacher professional development. *Teaching and teacher education*, 51, 101–112. doi:[10.1016/j.tate.2015.06.008](https://doi.org/10.1016/j.tate.2015.06.008)

Franke, M.L., *et al.*, 2001. Capturing teachers' generative change: a follow-up study of professional development in mathematics. *American educational research journal*, 38 (3), 653–689. doi:[10.3102/00028312038003653](https://doi.org/10.3102/00028312038003653).

Gallucci, C., 2008. Districtwide instructional reform: using sociocultural theory to link professional learning to organisational support. *American journal of education*, 114 (4), 541–581. doi:[10.1086/589314](https://doi.org/10.1086/589314).

Grossman, P.L., Smagorinsky, P., and Valencia, S., 1999. Appropriating tools for teaching English: a theoretical framework for research on learning to teach. *American journal of education*, 108 (1), 1–29. doi: [10.1086/444230](https://doi.org/10.1086/444230)

Gutiérrez, R., 2016. Strategies for creative insubordination in mathematics teaching. *Special issue mathematics education: Through the Lens of social Justice*, 7 (1), 52–62.

Hayes, K. N., Inouye, C., Bae, C. L., & Toven-Lindsey, B., 2020. Reciprocal learning in K-12 professional development: how do faculty change their instructional practices? *Science education*, 105(1), 95–106.

Hayes, K. N., & Trexler, C. J. 2016. Testing predictors of instructional practice in elementary science education: the significant role of accountability. *Science education*, 100(2), 266–289. doi:[10.1002/sce.21206](https://doi.org/10.1002/sce.21206).

Hayes, K.N. and Trexler, C.J. 2016. Testing predictors of instructional practice in elementary science education: the significant role of accountability. *Science education*, 100 (2), 266–289.

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. doi: [10.1080/13504622.2017.1396289](https://doi.org/10.1080/13504622.2017.1396289).

Heredia, S.C., 2020. Exploring the role of coherence in science teachers' sensemaking of science-specific formative assessment in professional development. *Science education*, 104 (3), 581–604. doi: [10.1002/sce.21561](https://doi.org/10.1002/sce.21561)

Justi, R. and van Driel, J., 2006. The use of the Interconnected model of teacher professional growth for understanding the development of science teachers' knowledge on models and modelling. *Teaching and teacher education*, 22 (4), 437–450. doi: [10.1016/j.tate.2005.11.011](https://doi.org/10.1016/j.tate.2005.11.011)

Kayumova, S. and Buxton, C., 2021. Teacher subjectivities and multiplicities of enactment: agential realism and the case of science teacher learning and practice with multilingual latinx students. *Professional development in education*, 47 (2–3), 463–477. doi:[10.1080/19415257.2021.1879225](https://doi.org/10.1080/19415257.2021.1879225).

Kennedy, M.M., 2016. How does professional development improve teaching? *Review of educational research*, 86 (4), 945–980. doi: [10.3102/0034654315626800](https://doi.org/10.3102/0034654315626800)

Lee, *et al.*, 2009. Urban elementary teachers' perspectives on teaching science to English language learners. *Journal of science teacher education*, 20 (3), 263–286. doi:[10.1007/s10972-009-9133-z](https://doi.org/10.1007/s10972-009-9133-z).

Lee and Maerten-Rivera, J., 2012. Teacher change in elementary science instruction with English language learners: results of a multiyear professional development intervention across multiple grades. *Teachers college record*, 14 (8), 1–42. doi: [10.1177/016146811211400805](https://doi.org/10.1177/016146811211400805)

Lewis, C., Perry, R., and Murata, A., 2006. How should research contribute to instructional improvement? The case of lesson study. *Educational researcher*, 35 (3), 3–14. doi: [10.3102/0013189X035003003](https://doi.org/10.3102/0013189X035003003)

Longhurst, M.L., Jones, S.H., and Campbell, T., 2017. Factors influencing teacher appropriation of professional learning focused on the use of technology in science classrooms. *Teacher development*, 21 (3), 365–387. doi: [10.1080/13664530.2016.1273848](https://doi.org/10.1080/13664530.2016.1273848)

Longhurst, M.L., Jones, S.H., and Campbell, T., 2021. Mediating influences in professional learning: factors that lead to appropriation & principled adaptation. *Professional development in education*, 48 (3), 506–522. doi: [10.1080/19415257.2021.1879220](https://doi.org/10.1080/19415257.2021.1879220)

Marshall, *et al.*, 2021. The role of collective sensemaking and science curriculum development within a research-practice partnership. *Science education*, 105 (6), 1202–1228. doi: [10.1002/sce.21676](https://doi.org/10.1002/sce.21676)

McChesney, K. and Aldridge, J.M., 2021. What gets in the way? A new conceptual model for the trajectory from teacher professional development to impact. *Professional development in education*, 47 (5), 834–852. doi: [10.1080/19415257.2019.1667412](https://doi.org/10.1080/19415257.2019.1667412)

McNeill, K., 2011. Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. *Journal of research in science teaching*, 48 (7), 793–823. doi: [10.1002/tea.20430](https://doi.org/10.1002/tea.20430)

Miles, M.B., Huberman, A.M., and Saldana, J., 2019. *Qualitative data analysis: a methods sourcebook*. 4th ed. Los Angeles: Sage.

Molle, D., 2021. A close look at teacher learning: why are teachers' journeys so different? *Teaching and teacher education*, 100, 103280. doi:[10.1016/j.tate.2021.103280](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*. Washington, DC: The National Academies Press. doi:[10.17226/21836](https://doi.org/10.17226/21836)

National Research Council. 2012. *A framework for K-12 science education: practices, crosscutting concepts, and core ideas*. Washington, DC: National Academy Press.

Odden, T.O.B. and Russ, R.S., 2019. Defining sensemaking: bringing clarity to a fragmented theoretical construct. *Science education*, 103 (1), 187–205. doi:[10.1002/sce.21452](https://doi.org/10.1002/sce.21452).

Opfer, V.D. and Pedder, D., 2011. Conceptualizing teacher professional learning. *Review of educational research*, 81 (3), 376–407. doi: [10.3102/0034654311413609](https://doi.org/10.3102/0034654311413609)

Preminger, L., Hayes, K., Bae, C. L., & O'Connor, D. *under review*. Why do teachers vary in their instructional change during science PD? The role of noticing students in an iterative change process. *Science education*.

Pringle, Mesa, J., and Hayes, L., 2020. Meeting the demands of science reforms: a Comprehensive professional development for Practicing middle school teachers. *Research in science education*, 50 (2), 709–737. doi: [10.1007/s11165-018-9708-9](https://doi.org/10.1007/s11165-018-9708-9)

Rivera Maulucci, M.S., Brotman, J.S., and Fain, S.S., 2015. Fostering structurally transformative teacher agency through science professional development. *Journal of research in science teaching*, 52 (4), 545–559. doi: [10.1002/tea.21222](https://doi.org/10.1002/tea.21222)

Saldana, J., 2013. *The coding manual for qualitative researchers*. 2nd ed. London: Sage.

Sandholtz, J., Ringstaff, C., and Matlen, B., 2019. Coping with constraints: longitudinal case studies of early elementary science instruction after professional development. *Journal of educational change*, 20 (2), 221–248. doi: [10.1007/s10833-019-09338-2](https://doi.org/10.1007/s10833-019-09338-2)

Schipper, *et al.*, 2017. Professional growth in adaptive teaching competence as a result of lesson study. *Teaching & teacher education*, 68, 289–303. doi: [10.1016/j.tate.2017.09.015](https://doi.org/10.1016/j.tate.2017.09.015)

Shi, L., 2022. Professional learning, positioning, and institutional power. *Professional development in education*, 48 (2), 330–342. doi: [10.1080/19415257.2020.1725595](https://doi.org/10.1080/19415257.2020.1725595).

Stollman, *et al.*, 2020. Teachers' learning and sense-making processes in the context of an innovation: a two year follow-up study. *Professional development in education*, 48 (5), 718–733. doi: [10.1080/19415257.2020.1744683](https://doi.org/10.1080/19415257.2020.1744683)

Stroupe, D., 2014. Examining classroom science practice communities: how teachers and students negotiate epistemic agency and learn science-as-practice. *Science education*, 98 (3), 487–516. doi: [10.1002/sce.21112](https://doi.org/10.1002/sce.21112)

Taylor, P., 2023. The complexity of teacher professional growth—unravelling threads of purpose, opportunity and response. *Professional development in education*, 49 (1), 16–29. doi: [10.1080/19415257.2020.1747106](https://doi.org/10.1080/19415257.2020.1747106).

Voogt, J., *et al.*, 2011. Teacher learning in collaborative curriculum design. *Teaching and teacher education*, 27 (8), 1235–1244. doi: [10.1016/j.tate.2011.07.003](https://doi.org/10.1016/j.tate.2011.07.003).

Weick, K., 1995. *Sensemaking in organizations*. Thousand Oaks: Sage Publications.

Whitworth and Chiu, J.L., 2015. Professional development and teacher change: the missing leadership link. *Journal of science teacher education*, 26 (2), 121–137. doi: [10.1007/s10972-014-9411-2](https://doi.org/10.1007/s10972-014-9411-2)

Witterholt, M., *et al.*, 2012. The Interconnected model of professional growth as a means to assess the development of a mathematics teacher. *Teaching and teacher education*, 28 (5), 661–674. doi: [10.1016/j.tate.2012.01.003](https://doi.org/10.1016/j.tate.2012.01.003).

Appendix A

Post lesson/Explanatory Interview Protocol

- (1) Let's start by talking about the lesson you and your students just completed. How did you think the lesson went?
 - What were some of the successes or challenges?
- (2) Where did you get the ideas and resources for this lesson? If SLP, probe what aspects, what influenced.
- (3) What did you do leading up to this lesson to support students in their conceptualisation of the science ideas? How will you follow it? In other words, what is the unit in which this lesson is embedded?
- (4) Let's talk about student discourse for a few minutes – how students are talking about the science they are doing and seeing. Can you tell me what kind of discourse were you hoping students would engage in to support their sensemaking of science concepts? How did their participation in discourse turn out?
 - When students are talking to one another about science ideas, how do you try to support their sensemaking?
 - How do you try to ensure all of the students get an opportunity to share their ideas? How do you support ELLs in their participation in science discourse? [If they have no ELLs, ask about other diverse learners]
 - What kinds of activities have you been doing to support your students in being ready to participate in scientific discourse and sensemaking?
 - How would you describe to a colleague an ideal moment of student to student discourse around science ideas? Are there advantages to engaging students in peer-to-peer discourse around science?
 - Have you changed your instructional practice around student discourse over the last year or two? What resources did you draw on – SLP or other? What were the barriers to changing? If they mention SLP, what aspects of SLP?
 - **Probes:** What about that aspect resonates with you? What influenced you to adopt that lesson/activity etc. versus others?
- (5) In this research project, we're paying particular attention to two of the NGSS Science and Engineering Practices. These two are: Constructing Explanations and Developing and Using Models. I'm now going to ask several questions that could relate to either of these practices. How did you incorporate modelling or scientific explanations? How did it turn out?
 - In addition to the lesson, what are the way you have been creating opportunities for students to engage in modelling and scientific explanations throughout the year?
 - How would you describe engaging student in the scientific practice of modelling to a colleague? How about engaging students in scientific explanations? Are there advantages to engaging students in these practices?
 - We are specifically interested in EL students. How do you engage EL students or other specific group of students in modelling/explanation?
 - Have you changed your instructional practice around modelling or explanation over the last year or two? If so, what supported that change? What were the barriers to changing? If they mention SLP, what aspects of SLP?
 - **Probes:** What influenced you to adopt that lesson/activity etc. versus others?
- (6) Have you been able to find ways to connect science to your student's lived experiences? Are students responding with lived experiences/prior knowledge in connection to the lesson?
 - **Probe:** What strengths do students bring that you can make use of in your science instruction?
 - **Probe:** Particularly, what strengths do English language learners bring?
- (7) Have you seen any other changes in your teaching since you started going to SLP? If so, what aspects of SLP influenced your teaching? What aspects of SLP?
- (8) What motivated you to start SLP? What motivates you to stay?
- (9) Has your science time increased or decreased since last year? What has contributed to the change?
- (10) What do you see as the barriers and supports to teaching science in the way that you believe in? (Self? Classroom? Site? District?)