The Role of Productive Ambiguity in Shaping Teachers' Sensemaking and Implementation of Science Education Reform

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Abstract: Attending to teachers' instructional contexts is integral for understanding the implementation of education reform. However, there is still much to be learned about the interplay between teachers' contexts, their perceptions of reform, and their instructional decision-making within science education. This paper utilizes conceptual tools from organizational theory to understand this interplay for two teachers working within the same middle school, adopting instructional practices associated with the *Framework for K-12 Science Education*. While on the surface, both teachers had similar personal, social, and organizational resources for their sensemaking and a shared commitment to integrating reform, only one implemented *Framework* practices, while the other maintained more traditional approaches. This analysis demonstrates ambiguity as a key differentiator in teachers' sensemaking and enactment of reform. Ambiguity close to practice served as a catalyst for noticing and enacting instructional change.

Introduction

Like other reforms in education, the *Framework for K-12 Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) place demands on teachers to actualize the goals of ambitious improvement efforts in their daily practice. Recent literature recognizes the integral role schooling environments have in shaping teachers' perceptions of teaching, learning, and content and teachers' decision-making about what aspects of reform to integrate into their instruction (Carlone, Haun-Frank, & Kimmel, 2010). These studies have pointed to the challenging task teachers face when being asked to engage with ideas of reform while simultaneously navigating the numerous institutional practices that manage and monitor their instruction. Further, these studies demonstrate the multitude of often conflicting messages from colleagues, school and district leaders, and prior reform efforts about what constitutes best practice that teachers must contend with in their decision-making processes.

When educators work in contexts supportive of reform adoption – like those with consistent leadership (McLaughlin & Mitra, 2001), collaborative colleagues (Coburn, 2001), and adequate professional learning opportunities and material resources (Davis & Krajcik, 2005) – this can lead to deeper understandings of reform goals and sustained changes to instructional practice. However, it is ultimately teachers' perceptions and ideas of how (or if) reform fits into existing schooling practices that shape what aspects of reform get implemented and in what ways (Spillane, Reiser, & Gomez, 2006). Thus, understanding the process through which teachers come to certain views of reform is paramount in our efforts to best support teachers in accomplishing lasting instructional changes in science education.

The analysis described in this article began as an attempt to document the relationships among teachers' interpretations of the *Framework* and NGSS, their uptake of these ideas, and the ways schooling practices shaped these interpretations and uptake. While, I started with certain assumptions from prior literature about which aspects were likely to matter for teachers' perceptions and implementation of *Framework* instruction - such as teachers' backgrounds (Hill, Blazar, & Lynch, 2015), material resources (Davis & Krajcik, 2005), and instructional contexts (McLaughlin & Mitra, 2001), another factor surfaced as most salient in shaping teachers' perceptions and uptake of practices: *ambiguity*. In what follows, I demonstrate the integral role that ambiguity played in catalyzing and shaping teachers' sensemaking by contrasting the sensemaking and enactment of two 6th grade science teachers working within the same school. Specifically, I show how ambiguity centered on instruction led to more noticing of what was different about reform and, when paired with appropriate resources for sensemaking, led to greater instructional shifts. However, ambiguity that focused outside of the classroom (e.g. state accountability practices) left educators with a confluence of conflicting guidance for instruction, an absence of needed resources, and a reliance on traditional approaches to teaching.

Teacher learning as an act of organizational sensemaking

In order to understand the relationship between teachers' interpretations of reform, their implementation of these ideas, and the role of their organizational contexts in this process, I utilize conceptual tools from organizational theory about the *process of sensemaking* (Weick, 1995). *Sensemaking* from this perspective is a way of describing how actors make meaning of and respond to change within their environment; it is the process through which

actors within an organization – both individually and collectively - "structure the unknown" (Waterman, 1990, p. 4). Although sensemaking is an ongoing process, it is occasioned when change is introduced to an environment from an external agent (such as policy makers or PD providers). The introduction of change is often experienced as "shocks" to those within the organization, as they disrupt the practices and routines. When what is new or what "does not fit" (Weick, 1995, p. 4) is noticed, this can cause uncertainty and ambiguity for those within the organization. Through sensemaking, actors work to reduce ambiguity and uncertainty and to resolve the disruption caused by the introduced change. Sources of ambiguity can include the presence of conflicting goals, contradictions or paradoxes, limited resources available to perform actions demanded of external change agents, lack of clarity with respect to roles and responsibilities, or the absence of measures for judging the success of action (Weick, 1995). Uncertainty that occasions sensemaking arises when people lack understanding of how different aspects of the system are changing, the potential impact of change on the system, or the response options that are open to them.

With the introduction of the *Framework* or NGSS into districts and schools, teachers are likely to experience these ideas as "shocks" that interrupt the day-to-day routines, practices, and shared ideas regarding science education of the school, district, or state. As teachers engage with the new reform, they may encounter ambiguity from conflicting goals for instruction, such as competing district initiatives; limited resources to support instruction that aligns with the standards (e.g. time to plan new lessons/units); a lack of clarity with respect to roles and responsibilities with the new standards; and the absence of measures (e.g. assessments) for judging how successfully they have accomplished goals of reform. Additionally, teachers are likely to experience uncertainty around what reform means for how and in what ways the different aspects of the system are changing as a result of the new standards (Allen & Penuel, 2015).

One substantial outcome of teachers' sensemaking of reform is their interpretations of how reform fits into their existing institutional practices. These interpretations have a direct impact on teachers' decisions about what of reform to implement into their instruction. Prior research suggests that teachers' perceptions of reform (Spillane, et al., 2006) and their perceptions of the ways reform coheres with existing institutional practices (Penuel et al., 2009) are most influential in mediating teachers' implementation. Teachers' sensemaking processes – what forms of ambiguity or uncertainty they experience, what resources are utilized during sensemaking, and to what degree teachers have time and opportunity to engage in sensemaking – will look different depending on the teacher and the organizational context (Penuel et al., 2009; Coburn, 2001). Further, the nature of sensemaking processes can get short circuited and lead to surface-level engagement with ideas of reform (Coburn, 2001).

As teachers engage with the new standards and the *Framework*, they are likely to experience the changes suggested in these documents as shocks and experience varying forms of ambiguity and uncertainty with regard to how these changes fit into their existing ideas about science, teaching, and learning and into their existing instructional context. In this analysis. I focused on following questions to surface this process of sensemaking for teachers and understand the interplay between these processes, their organizational contexts, emerging conceptions of NGSS and the *Framework*, and teachers' enactment decisions: (1) What are the sensemaking processes regarding ideas and practices of the NGSS and the *Framework* for two teachers within the same school? (2) What are the relationships among teachers' sensemaking, their ideas of NGSS and the *Framework*, and their instructional practice?

Methods

To examine the relationship among teachers' organizational sensemaking, their perceptions of the *Framework* and NGSS, and their implementation of these reform ideas, I employed an embedded case study methodology (Yin, 2013) of two teachers within the same school. I draw on multiple forms of teacher data from a two-year period, including teacher classroom video, interviews, and classroom artifact data (e.g. lesson examples, assessments).

Research context

This study takes place in the context of a larger project that intended to evaluate the impact of curriculum materials in supporting *Framework*-oriented instruction, when combined with PD (Harris et al., 2015). The research team worked with 6th grade science teachers in a large, urban school district, Georgetown School District (all names are pseudonyms), in the Southeast. At the time of the study, Georgetown served more than 140,000 students, and the district's demographics resembled many urban districts in the United States with a student composition of 42 percent African American, 32 percent White, 18 percent Hispanic, and 5 percent Asian. Fifty-four percent of the students in the district were eligible for free or reduced-price lunch, and the
district had a growing ELL population. Georgetown was in a state that was one of the lead states that provided guidance for the writing of the NGSS; however, at the time of the study, this state had not yet adopted the

standards. This is important to note, as current standards play a critical role in guiding teachers' sensemaking (see Coburn, 2001; Heredia, 2015).

Participants and school site

The participants for this study were selected through a multi-stage process aimed at reflecting teachers' sensemaking and implementation patterns within the context of the current science education reform. First, I created a data display of all teachers who had (1) participated in the treatment condition of the larger study (and, thus, using the curriculum materials) and (2) had participated in an interview (described in more detail below). The display included teachers' years teaching, years in current assignment, years teaching science, highest degree achieved, science background (e.g., degrees earned), and their participation in PD. From this display, I removed any teachers who had not attended all PD sessions, as I wanted the PD and curricular resources provided through the study to be consistent given its likely role in teachers' sensemaking processes. This participant list included 8 teachers across 4 middle schools.

Table 1: Participant characteristics.

Teacher	School	Years teaching	Degree	Science background
Alice	Columbus	6	Master's	None
Joe	Greenfield	7	Bachelor's	AS Integrated sciences BA Secondary science
Abby	Norman	4	Master's	BS Secondary science
Alexis	Norman	2	Bachelor's	None
Joan	Norman	10	Master's	BS Biology MA Secondary science
Marcus	Norman	17	Master's	None
Kate	Robinson	3	Bachelor's	BS Biology
Richard	Robinson	42	Master's	None

Data collection and sources

Data for this analysis was collected over the two-year period (2012-2013 & 2013-2014) during which teachers were participating in PD and were implementing aspects of the curriculum and PD in their classrooms. Data included classroom video, teacher assignments, and teacher interviews. Focal teachers were interviewed during fall 2013 and spring of 2014. The interview protocol was developed using a construct-centered approach to assessment design. Fall interview topics included instructional management practices at teachers' schools sites and teachers' perceptions of coherence between the *Framework*, their current instructional approaches, and state and district goals. The spring interview focused on particular lessons in which teachers engaged students in science practices, the objectives of these lessons, any modifications teachers made, what type of student the reform seemed most effective for, and what materials teachers used in the planning and implementing of these lessons. The interviews were conducted over Skype, phone, or in person, lasted roughly 30 minutes, and were audio recorded and transcribed. Teachers were asked to record video of the same six lessons across two curricular units within PBIS and during both years of the study. The lessons were chosen because of their focus on the practice of either modeling or explanation. Included in this analysis are two of these six lessons – one from each focal unit. I made this decision based on teacher participation and lesson content. In addition to recording lessons, the teachers were asked to submit in-depth descriptions of lessons they taught during both years. I selected five assignments total for each teacher, choosing assignments that could represent the range of topics covered by the 6th grade standards.

Analysis

Given that I was interested in the relationship between teachers' sensemaking and their implementation of *Framework*-oriented instructional practices, I analyzed the data for both teachers' instructional patterns and their sensemaking processes. I defined *Framework*-oriented practices as those that (1) engaged students in science practices, (2) pressed students to reason about phenomena, and (3) positioned students as active participants in their learning. While there are a number of *Framework*-oriented practices I could have focused my analysis on, I chose these practices because of their centrality in the PD provided to teachers and in the PBIS materials, and because they represent some of the more significant shifts called for in the *Framework*.

Opportunities to engage students in science practices included activities and lessons explicitly organized around the use and development of models and explanations. These activities were coded with "practices" codes,

which included *prompting for explanation* or *prompting for reasoning*. The video codes were developed and iterated on over the course of the 5-year project by members of the research team (author included). Additionally, teacher assignment data were scored for their incorporation of modeling and explanation practices. Similar to the video data, the scoring rubric was developed and iterated on by research team members over the course of the 5-year project. Instruction that pressed students to reason involved teacher questioning patterns that required students to do the "heavy intellectual lifting" and engage more deeply in science. These include questions that elicited students' ideas or those that pushed students to discuss an idea further or support a claim. The video data were coded for teachers' patterns of questioning. Drawing on all coded and scored implementation data, I developed summary tables of each teachers' enactment, categorizing their instruction as either high, mid, or low in terms of alignment with *Framework* practices.

To understand teachers' sensemaking processes, I coded all teachers' interviews for (1) sources of ambiguity and uncertainty; (2) sensemaking resources; and (3) views of *Framework* instruction. Sources of ambiguity and uncertainty included *conflicting goals, absence of measures*, *limited resources*, and *role ambivalence*. Sensemaking resources included both contextual and personal resources: *curriculum materials*, *school leadership*, *formal learning communities*, *informal collegial support*, and *teaching histories*. Once these data were coded, I developed case summaries for each participant, focusing on these three themes. I then created data displays (Miles, Huberman, & Saldaña, 2014) that highlighted salient excerpts, organized by these themes. This allowed me to see patterns emerging across the cases and potential similarities across school sites. I then created data displays that integrated summaries of teachers' sensemaking patterns and their implementation, organized by participants. This allowed me to discern relationships between sensemaking and implementation and patterns across teachers and school contexts. During this time, ambiguity surfaced as a key differentiating factor in teachers' implementation. Further, Joan and Marcus emerged as exemplar, contrasting cases of the role of ambiguity in shaping sensemaking and implementation.

Findings

As outlined previously, the reform – as conceptualized in this analysis – integrates three primary components: (1) engaging students in science practices, (2) pressing students to reason about phenomena, and (3) positioning students as active participants in their science learning. In Marcus's class, students tended to engage in practices of scientific modeling and explanation and have deeper discussions about their observations and emerging understandings, prompted by Marcus's presses for reasoning. Although Marcus certainly maintained a position of authority in the class, student ideas were held as legitimate fodder for further discussion, and the class was encouraged to suspend knowing or achieving the "right answer" in favor of exploring the multiple, possible explanations for an observed phenomenon. In the case in which Marcus chose to conduct a demonstration for students rather than having students conduct the modeling activity themselves, he utilized the extra class time this instructional decision afforded to engage students in deeper dialogue about the phenomenon. In Joan's class, students also had opportunities to engage in science practices, such as making predictions with and using models to represent phenomenon; however, these activities tended to serve as a means for achieving a correct understanding of scientific content without much probing beyond the surface. In a lesson in which students used a model of convection currents (using hot and cold water and food coloring) to make predictions and generate initial explanations about what causes the earth's mantle to move. Marcus ended the class with the sentiment, "We don't know all the answers yet;" however, Joan attempts to close the loop by stating "that's what we've got going on there" (referring to the observed convection currents in the model simulation). Further, significantly less student voice was evidenced in Joan's classes, both in terms of opportunities for students to share their ideas with the whole class and, during the whole-class exchanges, fewer opportunities for more than one student to provide an idea or response. Questions from Joan were generally seeking known answers, and while questions may have started as an elicitation of student thinking, it was often followed with a closed-answer question or confirmation of the right answer.

Understanding Joan and Marcus's enactment through the lens of sensemaking

A close look at Joan and Marcus's sensemaking processes surfaces an explanation for the observed variation in their enactment decisions: the presence of ambiguity and the available resources particular to that source. Although both had similar resources and worked within the same supportive teaching context, the type of ambiguity that each experienced was markedly different and the kinds of resources that each needed to resolve those sources of ambiguity were also varied. Whereas Marcus experienced some ambiguity between the instruction suggested by the curriculum and by the *Framework* in ways that resulted in productive sensemaking; Joan experienced ambiguity around larger accountability expectations and practices that turned her attention away

from sensemaking that focused on her instruction. The materials that Marcus needed for sensemaking, then, were closer to classroom practice and situated more centrally within his organizational context.

Marcus: Ambiguity around instruction and supportive materials for sensemaking

As Marcus engaged with ideas from the curriculum, *Framework,* and NGSS he experienced ambiguity around instructional practices called for in these documents. As a result, Marcus's sensemaking focused on a few key aspects of the reform that diverged from his previous instruction, and his sensemaking contributed to the generation of materials that he and his team developed. These materials (described more fully in Authors, 2015) included adapted pacing guides, unit assessments, additional units that followed the *Framework* approach, and scaffolds for students to engage in practices.

Marcus described his instruction and views of teaching and learning as having changed since the start of the research project and trying reform practices. What was different about the *Framework* and PBIS curriculum was made apparent for Marcus. As he engaged in sensemaking, the PBIS curriculum and PD activities that instantiated the "just in time" pedagogy were particularly helpful resources for Marcus:

> [Before] it was like, 'Oh yeah. You have to introduce the vocabulary. You have to give these kids some background information before the lab 'cuz otherwise the lab won't mean anything to them.' Now my psyche has reversed on that. I really do see that you have to give them the lab. That's the experience that they're getting. Then you can help them make the connections with the vocabulary and the facts and the information after. I think, isn't that a direct result of the Next Generation Science Standards? Something they're trying to do?

Marcus had become aware of the ways the reform practices differed from his prior instruction, at least in part. Additionally, he talked about engaging students in practices and placing the heavy lifting of reasoning on the students (e.g. encouraging them to work with their peers to figure out something that stumps them). Marcus characterized the reform as, "Giving the kids hands-on experience, investigating, answering a question, collecting data, analyzing, doing the principles of things like problem solving, inquiry. *The content is almost secondary to the process."* Marcus's description demonstrates a depth of understanding of the reform, but not a fully accurate one. Namely, he identifies a distinction between process and content, and a sense of the value of focusing on the process of learning. However, the *Framework* focuses on the *blend* of content and process, which Marcus may be missing. Further, according to Marcus, the purpose of engaging in science practices is informed by an epistemology of learning that is organized around a problem or a question and using tools to answer that,

> [The reform is] the idea of learning a way of viewing the world and thinking about a problem and an answer and how to gather data, how to come to a conclusion. Just the whole thing about writing an explanation...Yeah, the process of learning.

Although evident that Marcus was still engaged in sensemaking from his reflection above - "just the whole thing about writing an explanation..." - what was clear to Marcus were a few key distinctions between his prior teaching approach and the reform.

Addressing the ambiguity caused through noticing these differences were some targeted materials that supported Marcus's instruction: the PBIS curriculum, PD activities, and the various materials developed by Marcus and his colleagues (e.g. interim assessments). As a result, when Marcus was interviewed midway into his second year of the study and enactment, his ambiguity was very minor. He described some misalignment between the curricular topics and the state's sixth grade standards, and his desire for greater horizontal coherence, but this ambiguity was minimal.

In addition to having supportive organizational conditions for implementing reform, Marcus also benefited from having the right alignment of resources to sources of ambiguity. That is, Marcus's ambiguity regarding changes in his instructional practice and issues of coherence were directly supported by the collective meaning making and resource development that he and his colleagues were engaged in.

Joan: Ambiguity around "figuring out [her] part in all of this"

Joan, by many standards, was recognized as an excellent science teacher at her school and within the district. She was considered a leader by her administration and colleagues within the 6th grade science team and in the school more broadly. She held a position on the principal's leadership cabinet, served as a mentor teacher to two other

teachers in the building, was the science department chair, and - in the first year of the study - was the 6th grade science team leader.

Joan had also received her science teaching credentials from an institution that she described as "top notch for its science teaching;" a program through which Joan was encouraged to design lessons that foregrounded "inquiry" and encouraged students to "do" science. She was Nationally Board Certified teacher and a regular attender of NSTA (the National Science Teachers Association conference). Furthermore, she was recognized by the PBIS curriculum publishers as being a strong implementer of the curriculum and was asked to facilitate PD sessions in other states during the time of the study.

As Joan engaged with ideas of the reform, she saw these ideas and practices as reflecting what she was "already doing" and not particularly new to her with regard to how she had been thinking about best science teaching practice,

> Well, I guess a lot of [the science and engineering practices] are things that I've tried to do anyway. Like, when I wrote my National Boards paper, several years ago at this point, the science practice I pulled out for Entry 1 was on using models. That was already in my brain, so that's not something that came out of this PD. That was something that had just gotten in there [my thinking] earlier...there have been times that I have done labs for years that are much more open-ended and just designed for [students] to choose. I [already] knew that [science teaching] shouldn't be all about me in front of the room teaching - it should be the kids doing and experiencing.

What did feel new to Joan, however, was the idea of students sharing ideas and communicating with each other throughout their learning. She shared, "I like having different groups do slightly different things, so that they can share with each other. [I've added to my instruction] that final step of [students] sharing and communicating with each other. [That] was something I've taken away [from the PD in this study]." Overall, Joan's interpretations of the reform was that it aligned with her current approach to instruction and her overall commitments to science teaching. Further, what felt new and different about the reform only implied, from Joan's perspective, minor changes to her instruction (such as flipping an activity or integrating more opportunities for student discussion).

Particularly salient for Joan as she made decisions about what of the reform to implement were her perspectives of her students' needs and her close adherence to the local and state standards. Joan, for example, modified lessons outlined in the PBIS curriculum to address what she felt like were age-related oversights on the part of the curriculum developer. That is, Joan saw middle school students as needing more "procedures" to follow and being unlikely to engage in the lesson without some misbehavior. She explained,

> I do feel like sometimes all of the student-driven, student-initiated stuff would work beautifully in a model class, but in the real world can fall apart. For example, there might have been some things that maybe I did as a demo or did as a demo with my toughest class, but then [let] my other kids mess with things more directly...The kids just—they seem to do better at following some kind of procedure... Timing is a huge issue and so a lot of stuff gets cut due to that...The time that [PBIS suggests] for [a lesson activity] and the time it really takes, is just not realistic...something would have to give there. What typically ended up giving would be the full-blown investigation expos at the end [of a unit]. I mean I really tried to—while having them share—ya know that piece that I'm saying I've gotten from this. Try to do it in a timely manner because...the behavior of the students can then impact the timing.

Joan describes a tension here between "the piece that [she's] gotten from this [study]" and the realities she feels of teaching middle school students. On one hand she values what feels new about the reform, but she also admits that this - students discussing more with each other - is the very aspect that gets cut when she is short on time. She also indexes a very real challenge of teaching in a *Framework*-oriented way: giving up some control can feel out of control for many teachers, and in many ways requires a learning curve for both teachers and students. She describes students' behavior affecting what of the lesson gets completed and her understanding that students at this age require more structure that may - but not necessarily - contradict an open-ended approach to engaging in science. So although the student-driven approach to instruction is one that she aligns herself with, she ultimately made decisions to cut out some of these aspects of the curriculum materials in order to move more quickly through the science content.

This emphasis on timing derived from Joan's commitment to ensuring that her students were exposed to the content they would eventually be tested on, per the state standards. Arguably, this commitment is part of

why Joan was seen as an excellent teacher. Good teaching, particularly within the K-12 school system, is measured in part by how well students perform on state exams; and, in a school known in its district as high-performing, safeguarding this reputation was even more of a priority.

As Joan made decisions about what to integrate into her classroom from the curriculum and PD, she ultimately foregrounded her state's standards and skills she anticipated her students needing as they navigated school science. This commitment to her students and to her practice came into tension with the messages about science teaching and learning she was receiving through the PBIS curriculum and PD about NGSS and the *Framework*, which created ambiguity for Joan with regard to her role as someone adopting the reform. She shared that she was having a hard time "wrapping [her] mind around" the "fluid story" of NGSS, in which concepts gain complexity over time and across science disciplines, as this fell in stark contrast with the "compartmentalized" approach of her current state standards. Further, she described trying to "figure out [her] part in all of this" and being "worried about getting [students] from Point A to Point B and getting that done
well and then trying to shift gears and going another direction when I know that the people next year aren't going to be continuing [using a *Framework*-oriented approach]."

As Joan made instructional decisions that were aligned to more traditional approaches, she focused on the benefit such experiences would provide her students:

> [In the ecology unit] I think that we had actual notes on PowerPoint. I'm like, "Okay, guys. We're gonna get real old-school and traditional here for a little bit." What's a little sad though is at the same time, I knew that I was preparing them for what they were gonna experience in 7th grade...It was a little bit of a way in their interest in preparing them for that again.

Joan's attention rested on the ambiguity between what currently was and what was to come in science education more broadly. Reflecting this sentiment, Joan had shared that a *Framework*-oriented approach offered the "higher purpose" she was ready for: "...as we try to kind of think about where science education is going, I was kind of ready for some higher purpose in what I do and this [change] is exactly at the right time for me." And although this "higher purpose" did support Joan in envisioning a future path for science education and a framework for improving her current practice, she was left feeling stuck with how to actualize these ideas within her local and state context.

What stood out as new or different about the reform, and thus catalyzed sensemaking for Joan, was the competing agendas of priorities for student learning in science:

> I don't necessarily see conflicts [between the NGSS and the state standards] as much as, depending on who you're talking to, there's a different part to this. When I talk to people higher up the science chain [such as researchers], they really care about where kids are coming from and where they're going and the story of science as it leads through a child's educational task. Then when you talk to somebody at the state level who's maybe not a science person, they don't care about that. They care about the students knowing the content well. It's trying to look at the big picture stuff and then maybe the day-to- day stuff. We're [the teachers] the only person who cares about both.

As Joan reconciled these competing agendas, she ultimately made instructional choices perceived as beneficial for her students, given the current state expectations for science learning. Notably, what is not evidently different or new for Joan are ideas about her instructional practice. She may not make decisions to enact lessons fully student-driven or inquiry-based, but this is by intentional choice (as Joan describes it). What is suggested for instruction through the reform is not pressing in Joan's decision-making; however, making sure her students progressed forward in state, district, and school-sanctioned ways was.

Conclusions and implications

As Joan and Marcus engaged with ideas regarding NGSS and the *Framework* and made decisions about what ideas to integrate into their practice, both the presence and the texture of ambiguity played a significant role in shaping these processes. For Marcus, ambiguity that centered on his instruction led to noticing aspects of the reform that differed from his current instruction and drove sensemaking that resulted in changes to his practice. Through collaboration with his colleagues, he reduced the minimal ambiguity caused by the reform through the development of materials supportive of his instruction. For Joan, however, the ambiguity she experienced was located more externally on issues of local accountability. What was noticed as different was the competing agendas for student learning and science education (vis-a-vis the state standards), but not on her practice. As a

result, Joan arrived at the conclusion that the reform was what she was "already doing" (see also Spillane, et al., 2006) and felt paralyzed by a lack of clarity regarding to the role she should or could play.

Additionally, these findings suggest that supporting deep engagement with reform requires productive mechanisms to foster this engagement. In this analysis, *ambiguity* emerged as this mechanism. Important was that this ambiguity was paired with relevant, appropriate resources to serve as levers for ambiguity to support change to practice. Important too was the *location* of this ambiguity and the availability of resources specific to that source. Ambiguity close to practice, as in the case of Marcus, supported teachers' noticing and engagement with difference. On the other hand, as evidenced through Joan, ambiguity focused on external accountability measures that lacks adequate sensemaking resources can lead to ongoing confusion and paralysis.

Given these findings, PD designers should pay close attention to the sources and location of ambiguity as they emerge for teachers as they interact with reform, situated in their instructional contexts. Teachers need learning opportunities that intentionally surface sources of ambiguity associated with instruction and provide guided facilitation focused on materials-development that is reflective of reform and solutions to common challenges (e.g., issues with pacing or adapting lessons to fit more than the "model student") (see also Allen & Penuel, 2015). Teachers also need guidance for how to – borrowing from Joan - "make sense of their role in all of this" through artful activities and discussion focused on difference guiding documents, messaging, and their implications for teachers' instruction.

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