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Reframing Organizational Contexts from Barriers to Levers for Teacher Learning in Science Education Reform

Carrie D. Allen ^a and Sara C. Heredia^b

^aDepartment of Educational Psychology, University of North Texas, Denton, Texas, USA; ^bTeacher Education and Higher Education Department, The University of North Carolina Greensboro, Greensboro, North Carolina, USA

ABSTRACT

A growing body of work regarding teacher learning and implementation of reform has pointed to the significant role organizational contexts play in shaping teachers' engagement with reform and their implementation decisions. Within science education, the adoption of the Next Generation Science Standards (NGSS) and standards reflective of the *Framework for K-12 Science Education* by states in the US and Canada resurfaces a need to attend to teachers' contexts in designing for the integration of these standards. To date, however, instructional contexts are generally cast as barriers to implementation and there is a scarcity of conceptual tools being utilized that support mature understandings of teachers' learning and decision-making in context. In this paper, we review prior literature on the relationship between teachers' organizational contexts and their learning and implementation of reform in science and other disciplines. We then present a conceptual framework rooted in organizational theory that can support nuanced understandings of teacher learning and implementation and guide the development of teacher-learning contexts. We argue that using a lens of organizational sensemaking complicates the teacher–context relationship for learning and implementation of reform and recasts teachers' contexts and local expertise as important levers for learning. We conclude with a set of practices to guide the design of professional learning contexts that reflects this framing and that may enable deeper engagement and learning of science teachers in the context of reform.

KEYWORDS

Professional development; teacher learning; science standards; reform implementation

It was late in the summer of 2011 and the *Framework for K-12 Science Education* (Framework; National Research Council [NRC], 2012) had just been released. A team of experts and researchers (including Author A), and some who had contributed to the writing of the Framework, were convened to deliver professional development for teachers in a large school district within one of the Lead States (NGSS Lead States, 2013). The 6th-grade teachers in this district (roughly 100 total) were beginning a 2-year RCT study examining the efficacy of curricular materials in supporting teachers' instruction of Framework and NGSS (see Allen & Penuel, 2015).

It did not take teachers long to express their excitement about the ideas in the Framework. The focus on depth, over breadth; the emphasis on doing science through engagement in practices; the “just-in-time” approach to instruction, such as frontloading

CONTACT Carrie D. Allen  carrie.allen@unt.edu  University of North Texas, Denton, TX 76203-5017

Authors are co-equal first authors.

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phenomena rather than science content or vocabulary; and the opportunities for literacy-rich science learning were all especially compelling.

It also did not take long for teachers to raise implementation questions. During the morning session on the first day, teachers began to ask questions about assessments and relevance to current standards:

T1: Even though I'm an older teacher, I love new ideas, but I still want to give students background information. How do you all feel about that?

T2: What's the assessments [sic]? How are these aligned with standards?

T3: This sounds wonderful and great, but I'm concerned about how this kind of teaching would affect students' assessment.

By the afternoon, teachers' implementation questions had pushed more prominently to the surface and the tensions these questions were causing were palpable. As part of the afternoon session, teachers watched a video of a middle school science classroom engaged in argumentation about student-developed models. While students led the discussion and used accountable talk moves (e.g. I agree because ...), the teacher served as a facilitator, engaging very infrequently in the conversation. During a discussion of the video, one teacher raised the concern that content was not being frontloaded to students. In her school, all teachers are expected to have a "word wall" and present those terms to students at the start of each lesson. Following this stated concern, a teacher commented: "I don't hear scientific language being used by the students. If students can't say that something is kinetic energy, then they aren't really learning, they are just discussing." At this, the room erupted inside conversations. Teachers were turned to their near neighbors, speaking in concerned tones, many shaking their heads and gesturing to the front. The room became so noisy that I, Author A, could no longer hear the response to the teachers' comment.

A teacher near me turned and shared that she understood teachers' concerns about the lesson format. In most buildings, teachers' jobs will be "in danger" if their lessons did not include all components listed in their evaluations—such as the assessment of the day, a list of standards addressed, and vocabulary words present in their "Word Wall." While the noise did eventually quiet down, teachers' questions seemed paralyzingly present as they participated in Day 2 of the workshop. For a good number of teachers, their participation that second day ranged from indifference and boredom to outward hostility.

Teacher learning with the context of new science standards

What is described in the preceding vignette is likely familiar to those who have offered professional development to science teachers at any point over the past decade. The educational landscape of accountability and standards¹ is one that barrages teachers with messages about what types of instruction are best for their students and how to demonstrate effective teaching and learning. As the teacher toward the end of the vignette poignantly described, these messages and expectations are not trivial. Jobs, schools, and student

¹While what is described in the vignette takes place in a prior era of accountability (NCLB), teachers still experience similar accountability pressures. With the increase in science testing and adoption of new standards, science teachers may feel even greater pressures than in previous decades.

opportunities are all on the line. It is understandable, then, that teachers are hesitant (and at times calloused) toward “new ideas.”

With the introduction of a new vision for K-12 science education in the United States (NRC, 2012) and a growing number of districts and states adapting their science standards to reflect this vision, the field has centered around the substantial shifts that teachers will need to make to their instructional practice and approaches to supporting teachers toward making these changes (National Academies of Sciences, Engineering, and Medicine, 2015). The common rhetoric sounds something like this: The Next Generation of Science Standards (NGSS) and *Framework* suggest a significant shift in how to approach science teaching and learning; these approaches likely diverge from what we know about current teaching practices; and therefore we need to consider ways to best support teachers in their learning and implementation of these ideas. While we do not disagree with this line of reasoning and have participated in this conversation ourselves, we do find this messaging too narrow when considering the phenomena of teacher learning in the midst of science education reform.

A growing body of work suggests that when considering science teacher learning and implementation of reform, our focus should take a wider lens (Bowers, Merritt, & Rimm-Kaufman, 2020; Manz & Suárez, 2018). Specifically, teacher learning and implementation of reform are processes that cannot be divorced from their local contexts (Allen & Penuel, 2015; Heredia, 2020; National Academies of Sciences, Engineering, and Medicine, 2015; Spillane, 1999). Instead, such processes are intimately shaped by local perceptions, practices, and demands. As teachers engaged with new ideas and aim to make changes to their instruction, they must do so within and against what can be competing agendas and conflicting messaging about what constitutes effective instruction and what approaches are best for students. As we consider how to support science teacher learning and implementation of NGSS and the *Framework*, then, our attention should not rest solely on how to facilitate science teacher’s content learning or instructional shifts, but on the multitude of shifts and shifters (those responsible for change) that need to take place across the local education system in order to actualize the changes suggested by this reform.

Although an increasing number of scholars agree that a focus on the educational system is necessary for authentic and lasting changes within classroom practice (Bryk, Gomez, Grunow, & LeMahieu, 2015; Coburn & Penuel, 2016), there is still a scarcity of tools for conceptualizing science teacher learning through this systemic lens. Instructional contexts are often cast as barriers to teachers’ implementation (e.g. Maeng, Whitworth, Bell, & Sterling, 2020), without consideration for how to design with and for the actualities of these contexts for teacher learning and instruction. While the field becomes more aware of how organizational contexts influence science teacher learning, we need ways of seeing these contexts as levers for learning and tools for the design of professional learning.

In this paper, we present a conceptual framework to support the research and design of science teachers’ professional learning that attends to teachers’ organizational contexts and frames implementation work as a collective, system-wide effort (Heredia, 2020). In what follows, we begin with a review of the ways organizational features have been described as barriers to science teachers’ learning and implementation of reform. Then we describe the concept of organizational sensemaking to help shift away from understanding organizational features as barriers to levers that shape and influence implementation decisions.

We review how organizational sensemaking has been used to understand reform implementation in science education and other disciplines, and make an argument for how organizational sensemaking surfaces the findings important to the design of teacher learning. We then present four practices for the design of teacher professional learning that utilizes organizational sensemaking to intentionally leverage contextual dimensions that shape and inform teachers' uptake of reform. We conclude with how these practices, when used in concert with other best practices for science teacher professional learning, may support instructional coherence for teachers and greater understanding and adoption of science reform practices.

Organizational contexts as barriers to teacher learning and reform implementation

Historically, research on teacher learning has focused on the myriad challenges teachers face as they work to implement reform teaching practices in their classrooms (e.g. Anderson, 2007; Carlone, Haun-Frank, & Kimmel, 2010; Crawford, 2000; Eick & Reed, 2002; Furtak, 2006; McDonald & Songer, 2008; Roehrig & Kruse, 2005; Smith & Southerland, 2007; Wallace & Kang, 2004). Most studies of implementation of reform-based science teaching have focused on *internal* barriers to reform, such as teacher understanding of content (Roehrig & Kruse, 2005), their experiences with authentic science experiences (Eick & Reed, 2002), or their perceptions of science teaching and learning (Roehrig & Kruse, 2005). We focus here, however, on literature that identifies *external* barriers to implementation, such as teachers school and district contexts, in terms of how they influence teacher learning and implementation of reform-based science instruction.

Teachers' work environment has been shown to impede upon science teachers' implementation of reform-based teaching practices and curriculum in their classrooms. Oftentimes these external features are related to competing school and district initiatives, which can manifest in a variety of factors that present as barriers and challenge reform-based instruction. These barriers include limited opportunities for teachers to plan with colleagues at their schools (Davis, 2003; Penuel, Riel, Krause, & Frank, 2009; Roehrig & Kruse, 2005), school administration prioritizing initiatives related to accountability measures (e.g. improving students' scores in math or ELA) (Anderson, 2007; Carlone et al., 2010; Furtak & Heredia, 2014; Roehrig & Kruse, 2005; Settlage & Meadows, 2002; Smith & Southerland, 2007), a lack of class time or issues with pacing of curriculum and school scheduling (Allen & Penuel, 2015; Roehrig & Kruse, 2005), and differences in how district leaders interpret science education reform (Falk & Drayton, 2004; Spillane & Callahan, 2000).

The amount of time science teachers have to plan and reflect on enactment with colleagues can affect their ability to implement reform (Davis, 2003; Penuel et al., 2009; Roehrig & Kruse, 2005). Common planning time within the school day, as well as physical proximity to one another play a role in science teachers' perceptions of barriers to successful use of new curricular resources (Davis, 2003; Furtak & Heredia, 2014; Roehrig & Kruse, 2005). For example, Davis (2003) found that of the sixth through eighth-grade teams implementing a new science curriculum, the sixth-grade team was able to implement the curriculum seamlessly into their classroom and met regularly with colleagues to discuss their implementation efforts. In contrast, the eighth-grade team had irregular contact with

each other and fragmented interaction with the sixth- or seventh-grade team, which led to a more challenging time implementing the new curriculum in their classrooms. However, even when science teachers have adequate time to work with one another, competing initiatives at the school level can usurp their time away from a focus on science (Roehrig & Kruse, 2005).

One often cited constraint on science teachers' implementation of reform-based teaching is related to messaging around students' scores on high-stakes exams. Falk and Drayton (2004) found a variety of effects on classroom practice when Massachusetts added science to measures of adequate yearly progress. They found the degree to which science teachers changed their classroom practice depended on the interpretation and response of the district leadership to the assessment, rather than the increased use of the test for accountability purposes. For example, one school district, led by the superintendent and science coordinator, prioritized increasing student scores on the state exam over a focus on instructional practices that would promote inquiry in science classrooms. In contrast, the neighboring district continued their reform efforts toward inquiry, believing that the work students were doing with inquiry would better prepare them for the open-ended portion of the exam. In the district that switched their focus to increasing test scores, science teachers were observed drilling students on vocabulary, practicing answering questions similar to those on the exams, and increasing content coverage over the course of the school year.

Teachers also regularly report issues of pacing and time allotment to science as barriers to reform (Carlone et al., 2010; Roehrig, Kruse, & Kern, 2007; Sandholtz & Ringstaff, 2014). Elementary teachers cited their difficulty with including science instruction during the day due to the focus of administrators to spend the majority of their time teaching math and ELA. For example, Sandholtz and Ringstaff (2014) found that although early grade elementary teachers had an increase in science teaching confidence and reform-based instructional practices as a result of professional development, their amount of time spent teaching science did not change. The authors speculated that the lack of instructional time suggested that contextual factors constrained teachers' instructional time, such as the administrative focus on reading instruction. Similarly, in Roehrig and Kruse's (2005) work, scheduling decisions had implications for high school chemistry teachers' use of a reform-based curriculum (Roehrig & Kruse, 2005). The curriculum was structured around a 50-minute class period, but multiple schools in their study had block scheduling. These 90-minute blocks did not fit with the design of the curriculum and often left teachers trying to combine two lessons into one or leaving students idle for the last half of class.

While most of these studies emphasize ways these organizational features resulted in constrained or truncated change to teachers' classroom practice, there is some evidence of how science teachers negotiated their teaching practice to include some modifications for the accountability system, while staying true to their desires to teach science to their students (Carlone et al., 2010; Smith & Southerland, 2007). Reform is an ongoing process, one in which teachers are shifting, pushing, and tweaking their practice in ways that attend to their commitments to science instruction and equitable teaching for their students within the constraints with which they work (Carlone et al., 2010).

Treating organizational context as a set of potential features that may support or impede science teachers' implementation of reform may gloss over the nuance of science teachers' work in their local environment and ultimately diminish the integral role of local context in shaping instructional decision-making. Further, and importantly, viewing context in this

way may mask the real needs science teachers have for learning about and implementing reform. Therefore, we aim to shift away from this framing to consider how organizational contexts can be integrated and leveraged into teachers' learning processes in order to support reform. To make this shift, we draw on a conceptual framework that affords attending to the ways reform is shaped in organizational contexts and the processes through which science teachers make decisions about what reform ideas and practices get integrated into these contexts and ultimately their instructional practice.

Utilizing organizational sensemaking to reframe local barriers as levers for teacher learning and implementation of reform

We suggest organizational sensemaking as a conceptual framework that attends to the number of organizational challenges and influences that science teachers are likely to engage with as they make decisions about reform. From organizational theory, sensemaking is a way to describe the process through which people make meaning of and respond to change in their work environment (Maitlis, 2005; Maitlis & Christianson, 2014; Weick, 1995; Weick, Sutcliffe, & Obstfeld, 2005). This use of the term "sensemaking" is much different in meaning and utility than other definitions of sensemaking often found in social psychology and science education. In science education, "sense-making" is generally used to describe learners' processes of engaging with and understanding connections between science phenomena, content, and practices (e.g. Braaten & Windschitl, 2011; National Research Council, 2007). What is central about the aberration we take from these uses of sensemaking is the emphasis on organizational (or work environment) contexts. Henceforth, when we use the term sensemaking we are referring to organizational sensemaking.

Assumed in sensemaking is the role of the work environment in shaping the processes through which organizational actors come to understandings about what is novel, unexpected, and confusing (Maitlis & Christianson, 2014); and how they—both individually and collectively—"structure the unknown" (Waterman, 1990, p. 4). 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—*How does this new thing fit into my existing organization? What does this new thing mean for me and my role within my organization?* Uncertainty is brought on when members of the organization lack the resources to fully understand the introduced change and how it can be integrated into their existing organizational practices. Ambiguity is experienced when there are too many resources or sources of information, such as conflicting goals or contradictions (my leadership wants me to do X, but this change suggests Y), which can make it difficult to make decisions about what changes need to be made and why. Through the process of sensemaking, actors work to reduce ambiguity and uncertainty and resolve the disruption caused by the introduced change.

Sensemaking processes are collective in nature, rooted in social interaction and negotiation (see Coburn, 2001). As members of an organization interact over time around ideas of reform, they negotiate its meanings and, at times, form a shared interpretation of it (Coburn, 2001; Spillane, Reiser, & Reimer, 2002). It often occurs in discourse-rich environments (Currie & Brown, 2003)—such as meetings or professional learning contexts—where members are discussing their ideas and involves making one's ideas known to others in their organization (Weick, 1995). Additionally, people's sensemaking is influenced by the

actual, imagined, or implied presence of others (Weick, 1995). Within organizations, “decisions are either made in the presence of others or with the knowledge that they will have to be implemented, or understood, or approved by others” (Burns & Stalker, 1961, p. 118).

As individuals make sense of changes to their work environment, they rely on a variety of resources to both interpret and act on those changes. Weick articulated these resources as vocabularies, or concepts, from their personal and organizational experiences (Weick, 1995). These vocabularies can be categorized as social, personal, and material resources (Ball & Cohen, 1999) utilized by organizational actors for their sensemaking. For example, as science teachers make sense of new curriculum intended to support the implementation of NGSS- and *Framework*-aligned instructional practices, they may gather with their colleagues (*social resource*) to engage in some of the activities in the new curriculum (*material resource*) to better understand what changes they need to make as they implement the new activities. As they work through those new activities together, they may draw on their beliefs about their students (*personal resource*) to make adaptations to the curriculum to fit their classroom context.

While prior studies of reform implementation in science have pointed to the organizational contexts as barriers to teachers’ implementation of reform efforts (Smith & Southerland, 2007), sensemaking affords a way into understanding the *processes* through which perceptions of reform are developed—such as understandings about what of reform fits into existing district- and school-level practices and structures—and decision-making about implementation, given these perceptions, are arrived at (e.g. Coburn, 2001, 2004, 2006; Coburn & Russell, 2008; Penuel, Gallagher, & Moorthy, 2011; Spillane, Reiser, & Gomez, 2006; Sun, Penuel, Frank, Gallagher, & Youngs, 2013). Prior work that has used sensemaking in this way has pointed to the ways in which teachers can co-construct meanings of reform (Coburn, 2001; Manz & Suárez, 2018) or retrofit reform ideas to past experiences with other reforms (Coburn, 2004; McFadden, 2019; Spillane et al., 2006), which may diverge from the intent of those who developed the new reform. Further, they point to the ways that leadership vision can shape teachers’ perceptions of and decisions about what of reform to focus on or implement (Allen & Penuel, 2015; Coburn, 2006). These studies also highlight the ways in which competing reform efforts or conflicting goals for instructional improvement can interfere with science teachers’ productive decision-making regarding reform (Allen & Penuel, 2015; Bowers et al., 2020; Heredia, 2015, 2020).

Retrospective analyses of science teacher sensemaking

Within science education, researchers have been using organizational sensemaking to understand variation in teachers’ responses to professional development and their uses of professional development ideas and curricular materials. Marco-Bujosa and colleagues (2017) used a sensemaking framework to consider differences in science teachers’ enactment of educative curriculum materials that intended to support teachers’ pedagogical content knowledge regarding scientific argumentation. Their analysis suggests that when teachers both engaged in their own learning and made curricular adaptations appropriate to their local context, they showed greater gains in pedagogical content knowledge about science argumentation. This study, along with others (Kawasaki & Sandoval, 2020; Voogt et al., 2011), suggests that teachers’ goal-setting for their learning is an important practice

that supports teachers in recognizing changes they can make to their instruction that reflects new reform efforts.

Teachers' goal setting in professional development can support them to craft coherence between the learning goals of the professional development and other school-based goals for their learning (Heredia, 2020). In her analysis of high school science teachers integrating science-specific formative assessment practices in their classrooms, Heredia (2020) analyzed teachers' sensemaking of these practices as significant organizational changes occurred—new administration staff, tighter teacher evaluations, and pressures to improve state exam scores. When the teachers found alignment between the learning goals of the professional development and their school-based accountability efforts, the teachers leveraged the professional development resources to transform their assessment practices. However, when the organizational changes surfaced significant ambiguity between the professional development and school-based accountability efforts, science teacher sensemaking of science-specific formative assessment was constrained, resulting in reduced use of professional development resources. For example, the science teachers focused the development of formative assessment tasks aligned to content on a newly implemented district pacing guide, prioritizing this over other representations of student learning of the same content presented in the professional development.

In their analysis of teachers' sensemaking of a professional development on the NGSS and *Framework*, Allen and Penuel (2015) found that science teachers interpreted professional development ideas and made decisions about what was feasible to implement vis-a-vis the support available in their schools. In particular, teachers who had more supportive school leadership and available colleagues to bolster their sensemaking were able to engage more deeply with the ideas of the *Framework*, NGSS, and associated curriculum materials and find ways to modify materials (from professional development and curriculum) to meet the somewhat competing messages about how to structure their instruction (e.g. district pacing guides and suggested pacing of the reform-oriented curriculum). For those without these supportive resources, their sensemaking was “constrained” (p. 141), fixated on one aspect of the reform (in this case, the curriculum materials) rather than the many dimensions of it.

These studies on science teachers' organizational sensemaking in professional development provide evidence for the ways in which teachers leverage their instructional contexts in their learning of reform. First, as teachers are learning about reform, they are also engaged in the onerous task of trying to find where and how reform practices *fit* into their existing environment. Second, when and where this sensemaking is happening is certainly not isolated to formal teacher-learning contexts (e.g. professional development workshops). contexts. This work is happening in the hallways of teachers' schools or in the lunch room with colleagues. Further, ambiguity and uncertainty (the fodder for sensemaking) are present across both these formal learning and practice spaces. Second, science teachers' efforts to reduce the ambiguity and uncertainty brought on by reform can be supported in ways that result in instruction reflective of reform (e.g. through collegial support, curricular materials, time to plan). However, teachers often lack the necessary support needed for sensemaking that productively shapes practice—particularly during professional development—and instead engages in sensemaking that is short-circuited (and ultimately gets viewed as barriers).

Moving from retrospection: drawing on sensemaking to design for teacher learning

While prior research has utilized a sensemaking framework retrospectively to understand teacher learning and implementation decisions, we suggest utilizing organizational sensemaking to prospectively inform design. As Allen and Penuel (2015) state,

An implication for PD is that we need to provide the same kinds of “active learning” opportunities for teachers around issues of coherence that we value around science content. In other words, teachers need opportunities to engage in collaborative and sustained sensemaking to see, understand, and work through incongruities they perceive between goals and strategies promoted in PD and goals and strategies promoted in their local educational contexts. (p. 147)

Similarly, Manz and Suárez (2018) call for professional development providers to surface and help manage the uncertainty that may arise for teachers as they learn new teaching practices:

We suspect, based on our prior and continuing work supporting NGSS, that issues related to teacher and student uncertainty and decision-making informally emerge during these PD sessions, we encourage colleagues to make these issues visible and subject to explicit discussion in the field and in the design of PD for teachers. (p. 791)

As these studies directly call for, professional development—as integral sites of teacher learning—can and should include explicit opportunities for teachers to engage in sensemaking around what is ambiguous and uncertain for implementation in their organizational contexts.

Collectively, the prior research on science teacher sensemaking of reform suggests that science teacher educators should (1) organize teacher learning in ways that *intentionally* surface the ambiguity and uncertainty teachers are likely to face as they engage with reform *while in the context of* formal professional learning; and (2) organize teacher learning to *resolve* ambiguity and uncertainty within and across teacher-learning contexts (e.g., professional learning workshops and classroom interactions) through necessary social, personal, and material resources. Organizing professional learning in this way affords an opportunity to facilitate teacher sensemaking while recasting barriers of implementation as *necessary levers* for learning. Guided by this architecture for facilitated sensemaking, we offer four practices for the design of science teachers’ professional learning within the context of reform.

Practices for designing professional learning to facilitate sensemaking

We turn now to a set of four practices that can aid in designing professional learning to facilitate science teachers’ organizational sensemaking of science reform, based on our review of the literature. These practices are intended to complement and expand upon existing best practices for teacher professional learning, which include sustained, active learning opportunities that (a) are based in content and classroom instructional practices, (b) provide opportunities for teachers to work collaboratively, and (c) are coherent with other aspects of the teachers’ work environment (Desimone, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001; National Academies of Sciences, Engineering, and Medicine, 2015).

The first two practices are aimed at *intentionally surfacing* organizational sensemaking, and are—we would argue—most often absent from current professional learning designs. These practices are: (1) anticipating sources of uncertainty and ambiguity teachers may experience due to their organizational context and (2) triggering sensemaking during professional learning meetings.

These practices are then followed by opportunities to *reduce ambiguity and uncertainty* through (3) collective meaning-making and materials development and (4) sustained professional development and iteration *around perceived barriers to implementation*. Although collective meaning-making and sustained professional learning opportunities are already guiding principles utilized in effective professional development, we argue that these steps take on new texture and telos when informed by practices (1) and (2). In what follows, we describe each practice in more detail.

Practice 1: Anticipating sources of ambiguity and uncertainty

An integral component when designing professional development for organizational sensemaking is *anticipating* the possible sources of ambiguity and uncertainty that may arise for science teachers as they engage with the ideas of the reform so that these sources can be incorporated into the professional learning design. Put another way: What are teachers likely to see as contextual barriers to their adoption of the ideas and practices presented during professional development?

To consider this step, let's return to the vignette that started this article. During the professional development on the *Framework for K-12 Science Education*, teachers were immediately concerned with a number of accountability questions. These concerns included how the ideas presented during the professional development aligned with current assessments, what new assessments might look like, and how a lesson might fit into the building-level expectations for lesson plans and pacing. Such concerns are also reflective of what we know from prior literature. For example, we know that teachers are likely to experience ambiguity and uncertainty around conflicts in pacing between their current district standards and reform practices introduced in professional development (Allen & Penuel, 2015; Roehrig & Kruse, 2005). Prior work also suggests that teachers may receive conflicting messages from district and school leaders about the purpose of reform, what to prioritize in their instruction, and the role of science education (Falk & Drayton, 2004; Heredia, 2020; Spillane & Callahan, 2000).

Awareness of these common challenges can serve as a guide for professional development facilitators as they approach their plan for professional learning. Consider the difference it might have made if the workshop facilitators had been prepared to address the question of assessments with structured time and designed activities specific to this concern. Rather than address the concerns briefly and push forward with the workshop agenda, what if the facilitators had instead responded to these comments with slides, activities, or discussion specific to assessment and standards concerns? In addition, they may have foreshadowed an activity coming later in the afternoon or the next day intended to support teachers in working through resolutions for these concerns (a focus of teachers' collective meaning-making and materials development).

While prior literature (and experience) provides a productive starting place for this work of *anticipating*, it is also imperative that facilitators become familiar with the local

environments in which participating teachers are working. There are a number of ways this information-gathering can be done prior to the first workshop. Science teacher educators might talk with the administrators and district leaders within the contexts they are providing professional development to identify how messages about science teaching and learning reflect (or not) ideas of the reform and of the professional development.

Gathering this knowledge moves beyond alignment with standards and assessment used in the local context (Penuel, Fishman, Gallagher, Korbak, & Lopez-Prado, 2009) to locating how district ideas about science teaching and learning are coherent with ideas about reform (as presented in the professional development context) (Heredia, 2020). Similarly, professional development providers can ask teachers to bring their pacing guides, set lesson plan templates, and other instructional management artifacts with them to the professional development. These artifacts can then be used to surface tensions between the timing teachers anticipate the activities, ideas, and materials of professional development will take to implement and the timing of their school day or the pace of content delivery.

We argue that it is the responsibility of the facilitator to legitimize sources of ambiguity and uncertainty surfaced by science teachers in professional development. This is done when the sources of ambiguity and uncertainty are used to focus discussion and active learning throughout the professional development experience.

Practice 2: Triggering teachers' sensemaking of organizational "fit"

Sensemaking is triggered when what is unique about reform is recognized and what changes need take place in the work environment (as a result of the reform) are noticed (Weick et al., 2005). This triggering of sensemaking can often happen in professional development contexts in which teachers are introduced to the ideas present in reform (such as the workshop on the *Framework* described in the vignette). When we talk about teacher sensemaking within science education, we are often focused on supporting teachers in seeing what is new or different about the introduced reform and their current practice, as teachers can interpret new standards like the NGSS and *Framework* as what they are "already doing" (Allen, 2016; Furtak & Penuel, 2019; Spillane et al., 2002) or yet another set of standards with new semantics. A common practice in effective professional development is to engage teachers in active, content-based learning experiences (van Driel, Meirink, van Veen, & Zwart, 2012) in which science teachers are working with materials or artifacts that are close to their classroom practice (Ball & Cohen, 1999).

While crucial for supporting teacher learning and implementation of reform, active learning experiences focused on the classroom are not enough. As teachers in the earlier vignette came to the end of the second day of professional learning they were *consumed* with questions of fit. They had had a number of well-structured activities that demonstrated aspects of the *Framework* modeled in classroom practice, including content and grade-level specific lesson activities that could be incorporated to bring about the ideas represented in the *Framework*. While these activities were effective in that teachers were noticing what was different about the *Framework* and their current practice; yet, much of teachers' gaze was on conflicting goals (Allen & Penuel, 2015) between the *Framework* and their instructional guidance and expectations within their schools. Because these questions of fit will impact teachers' perceptions of reform (Coburn, 2004; Spillane et al., 2006), it is important to also

Table 1. Practices for organizational sensemaking, including goals and example approaches.

Practice	Goals	Example Approach
1 Anticipating Ambiguity & Uncertainty	Anticipate barriers to implementation, organizational practices in conflict with reform.	Gather working understanding of local accountability practices. Design activities focused on potential barriers.
2 Triggering Sensemaking of “Fit”	Supporting teachers in identifying what is new or different about reform. Supporting teachers in noticing issues of “fit.”	Plan structured activity focused on noticing differences in reform lesson design and current lesson plans.
3 Resolving Ambiguity & Uncertainty	Providing opportunity for teachers to address concerns collectively regarding what does not fit and work toward appropriate modifications.	Plan time for teachers to develop modified assessments, lesson plans, or pacing guides. If possible, involve school- and district-level administrators in this process.
4 Sustaining Sensemaking	Facilitate sustained engagement with ambiguity and uncertainty through ongoing support.	Teachers bring examples of what they have enacted in the classroom, challenges they are encountering as the implement changes, and work on additional lessons/units.

intentionally trigger teachers’ sensemaking around these questions and associated sources of ambiguity and uncertainty.

Given that questions of fit *will* surface for teachers—either in professional development as the vignette described or once they are back in their classrooms trying to integrate reform practices—we argue that it is best to trigger this sensemaking early in professional development process so science teachers can begin the work of reducing ambiguity and uncertainty, rather than having these sources emerge for the first time in local context while teachers are isolated from the material and collegial supports provided by professional development. Further, we expect that new challenges will surface over time as science teachers try out NGSS- or *Framework*-aligned practices in their classrooms, especially as other unrelated changes might be happening within their organizational context (Heredia, 2020) and sustained professional development can support science teachers continued sensemaking.

Practice 3: Resolving ambiguity and uncertainty through collective meaning-making

Once science teachers’ sensemaking is triggered and possible sources of ambiguity and uncertainty regarding the NGSS and *Framework* are surfaced, teachers can begin the *work* of sensemaking: reducing ambiguity and uncertainty through collective meaning-making and materials development. Science teachers can leverage the social resources present in the professional development and draw upon distributed expertise among their peers (Sun et al., 2013) and the professional development facilitator, as an expert in the messages of reform external to the school or district (Coburn & Russell, 2008), to generate possible pathways toward crafting classroom practices reflective of the NGSS and *Framework* that seem tenable, given their organizational constraints. For example, teachers might generate a solution to the Word Wall challenge—they could include the Word Wall (or the intent of the Word Wall) but still take a “just-in-time” approach (Penuel & Reiser, 2018) to teaching vocabulary, adding new vocabulary to their Word Wall as the need for that term arises in students’ investigations. Similarly, they might develop shared assessments that address current standards while also reflecting

a 3-dimensional nature to attend to their concerns about assessing student learning that is reflected in the state assessment.

During this time, it becomes optimal to include multiple stakeholders responsible for enacting change, such as principals or district-level science coordinators, as teachers' efforts are likely shaped by messaging coming from these leaders (Falk & Drayton, 2004; Hayes, Heredia, Allen, & Settlage, 2017). This is particularly important within science education in which other reform agendas can have the tendency to overshadow science (Carlone et al., 2010; Furtak & Heredia, 2014; Roehrig & Kruse, 2005; Settlage & Meadows, 2002; Smith & Southerland, 2007). Collective meaning-making about the Word Wall, then, could include the very principals who may be looking for this instructional practice—what solutions do they have for addressing this conflicting goal?

In addition to collaborating with other educators, teachers can coordinate shared understandings of what NGSS and the *Framework* ask of instruction and develop pathways forward with those making determinations about instructional priorities (Manz & Suárez, 2018). The development of shared ideas about reform-aligned instruction is especially integral for teachers and school administrators, as it assuages teachers' concerns regarding "fit" of the NGSS with their current building-level evaluation practices and it provides school leaders with the information needed to adequately support teachers' implementation of the NGSS and *Framework*-aligned instruction (Hayes et al., 2017; Heredia, 2015, 2020).

Practice 4: Sustaining sensemaking through sustained professional development

Sustained opportunities for science teachers to learn and make sense of the NGSS and *Framework* are integral to creating lasting changes to classroom practices (Garet et al., 2001). Further, sustained engagement with conflicting messages, missing or misaligned accountability measures, and other sources of ambiguity improve the likelihood that teachers will implement instructional practices that are aligned with standards (Allen & Penuel, 2015).

As science teachers move from professional development into their work environments and classrooms, they are likely to encounter new forms of ambiguity and uncertainty as they make changes to their classroom practice (Maitlis & Christianson, 2013; Spillane et al., 2006). Informal discussions and interactions in more formal teacher learning communities and messages from school leadership will work to shape ideas of reform once back at work (Coburn, 2001). Further, as teachers try out *Framework*-aligned instructional practices, responses from students (Allen & Penuel, 2015; Spillane et al., 2006) and student outcomes (Furtak, Morrison, & Kroog, 2014) will serve to further mold their perceptions of reform.

As science teachers move between enactment in the classroom and reflective professional development settings, they can leverage experiences in both spaces to deepen their understanding and pathways toward implementation (Kazemi & Hubbard, 2008). Science teachers can bring artifacts from their enactment of reform practices that highlight new or persistent sources of uncertainty or ambiguity and the professional development leader can facilitate discussion to attend to the challenges that arose during enactment (Heredia, Furtak, Morrison, & Renga, 2016). This iterative sensemaking can lead to further modification of new tools and practices for the classroom that integrates science teachers' developing understanding of reform (Heredia et al., 2016) and lead to greater coherence between reform and existing classroom practices.

Indicators of teacher learning and successful implementation

In this section, we discuss various indicators of science teacher learning and effective implementation of NGSS and the *Framework* as they engage with professional learning designed to facilitate their organizational sensemaking. Traditional consensus models measure the effectiveness of professional development as increases in student learning (Desimone, 2009). This still remains an important measure for professional development; however, we argue that professional development designed for facilitated sensemaking also opens up rich opportunities to understand science teacher learning as an organizational process and to find other mechanisms to measure success and effectiveness of professional learning. We expand on three examples of other mechanisms to measure success, including science teachers' decision-making processes, changes to schools' routines and practices in relation to science instruction, and localized adaptations in reform implementation.

If we focus on science teachers first, facilitated sensemaking gives researchers an opportunity to observe and understand science teachers' decision-making processes and learning as a function of their organizational contexts. While there is a long history of research into teachers' decision-making processes (e.g. Borko & Shavelson, 1990), the frameworks that emerge from this work rarely consider organizational contexts for teacher decision-making. For example, Clough, Berg, and Olson (2009) proposed a model for science teachers' decision-making processes that focused solely on the science teacher working within her classroom. They noted external barriers and constraints to science teachers' classroom practices but suggest that science teachers simply need to do a better job explaining their practice to overcome those barriers. Professional learning that facilitates science teacher sensemaking can help us to better understand how these institutional pressures matter for science teacher decision-making processes and expand these frameworks to better prepare science teachers to implement reform practices.

In addition, we can identify decision-making processes related to productive patterns of sensemaking that lead to more sustained implementation of reform. For example, Hayes, Wheaton, and Tucker (2019) found that the specific attention to how a stewardship project, as part of an environmental education program, aligned to NGSS and supported teachers to justify their inclusion of a stewardship project in their science curriculum. Further, Author (under review) has demonstrated that two teachers in the same school exhibited different patterns in their sensemaking of reform curricula related to the source of ambiguity that they worked to resolve through their professional learning. The teacher that surfaced local sources of ambiguity made more significant shifts to his practice, as compared to the other teacher, who focused on sources of ambiguity at the state and national level.

Facilitated sensemaking as a model for professional learning might also help us to better understand organizational learning as more and varied organizational actors share science education reform efforts across a school or district. Recently, there has been greater interest and focus on the role of school and district leadership on science instruction (McNeill, Lowenhaupt, & Katsh-Singer, 2018; Wenner & Settlage, 2015; Whitworth, Maeng, & Bell, 2018). For example, McNeill et al. (2018) found that K-8 principals have limited knowledge of the science practices and focus on general teaching strategies when observing science instruction. These authors suggest a systems approach to reform to support principals to understand and view science instruction as described in recent reform efforts. Facilitated sensemaking, as described here, could support this effort. In our example above, we

described how we might engage science teachers in modifying their use of a Word Wall to support just-in-time teaching of content. Inclusion of principals in this learning environment could support their expanded view of the use of a Word Wall to support students' engagement with the science practices to support content development. This collective work gives science teachers and their administration some common language and experience to leverage in informal and formal classroom evaluations. Measurements of effectiveness or success of this model would include changes to science teacher evaluation rubrics to include expanded views of science instruction; i.e. a focus on investigative practices, as well as sensemaking and critiquing practices (McNeill et al., 2018).

Lastly, we want to consider the tension between fidelity of implementation of science-education reform as described in reform documents and mutual adaptation (McLaughlin, 1976) called for within the context of facilitated sensemaking. Fundamentally, facilitated sensemaking as a model for professional learning demands that facilitators are flexible and responsive to the needs of the science teachers within their specific contexts. That said, the *Framework* and NGSS do indeed present an ambitious vision for science education that should remain central to the professional work of the participants (National Academies of Sciences, Engineering, and Medicine, 2015). In advocating for teachers' local adaptations of reform we are not suggesting that the core ideas and practices of NGSS and *Framework* be abandoned or watered down so that they "fit" within teachers' school environments. However, we are suggesting that reform ideas cannot be understood divorced from the contexts in which they will be introduced. We argue that this current science reform context presents a rich opportunity to consider how best to support robust, authentic, and lasting implementation of three-dimensional science learning for all students.

Conclusion

In our experience, the very real concerns that teachers face when making decisions about reform implementation are often sidelined in professional development, and the difficult task of parsing discontinuities between reform ideas and local expectations and practices is placed on already-overburdened teachers with limited capacity. This is especially true in science education where instructional time, professional development opportunities, and collaborative planning with colleagues are already limited (e.g. Roehrig & Kruse, 2005). Our goal in this paper was to present a set of practices that can aid in surfacing and attending to teachers' learning and implementation needs within reform, and that recognizes the significant role teachers' contexts play in shaping these efforts. Our hope is that, with conceptual tools, such as organizational sensemaking, we can design learning opportunities for teachers that produce a more robust understandings of the goals of reform and more sustainable, lasting changes to teachers' practice. This restructuring of professional development foregrounds the needs of science teachers in their efforts to integrate reform in their schools and districts while engaging them as central actors in this process. Such an approach avoids what can often be an unintentional positioning of teachers as the object of reform (e.g. teachers needing to change) and instead recognizes the importance of teacher's ownership of reform ideas and their agency in the reform process (Buxton et al., 2015; Heredia, 2018).

Disclosure statement

We have no conflicts of interest to report.

ORCID

Carrie D. Allen  <http://orcid.org/0000-0001-6540-9155>

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