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Noticing instructional challenges in artifacts of teaching

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Abstract
This study investigates challenges of enactment teachers notice when analyzing artifacts of teaching in a professional development focused on supporting the enactment of NGSS-aligned modeling instruction. Five secondary science teachers participated in a semester-long video club. Transcripts of the segments of their meetings in which they analyzed artifacts of practice were coded to characterize what they noticed in videos and student work samples from their own and others' classrooms of students engaging in sensemaking. Through an inductive and iterative approach, three main linguistic challenges were identified related to the teachers' noticing of students' disciplinary thinking: learning how to communicate with precision using modeling conventions, how to communicate with precision using scientific vocabulary, and how to support students explaining and defending their models. The findings of this study extend and affirm prior research on teachers' noticing of student thinking by highlighting the integrated nature of disciplinary noticing and the entanglement of learning science concepts and the language of science. The results also indicate that artifact-rich professional development designed to improve science teachers' interpretation of their students' thinking can support teachers as they work through problems of practice they encounter in their attempts to enact responsive science teaching.

1 | INTRODUCTION

The release of the Next Generation Science Standards intends to address shortcomings in science instruction that are overly reliant on treating the teaching of science as conveying a discrete body of facts (National Research Council, 2012; NGSS Lead States, 2013). These standards promote a shift in emphasis to students' sense-making of phenomena utilizing the practices of science in authentic ways (National Research Council, 2015; Passmore et al., 2014; Reiser et al., 2017; Windschitl et al., 2018). These practices include: asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information (NGSS Lead States, 2013). These practices are not intended to be practiced discretely but rather used in concert to investigate, explain, and critique explanations of disciplinary core ideas and cross-cutting concepts (Osborne, 2014). In so doing, they move beyond learning about content and practices to learning how to "do" science (American

Association for the Advancement of Science, 2009; Tekkumru-Kisa et al., 2015).

The authors of the NGSS identify several "shifts" necessary to achieve the vision of the new standards in practice. Among these are creating multiple opportunities to elicit and interpret student thinking and supporting equitable participation for students as they engage in ongoing discussions of their evolving explanatory models of how and why events happen (NGSS Lead States, 2013; Penuel & Reiser, 2018). Instruction that centralizes discussion of students' explanations intertwines rich classroom discourse with rigorous tasks that are designed to make space for students' ideas and tools to support responsive and equitable science instruction (Colley & Windschitl, 2016; Haverly et al., 2020; Tekkumru-Kisa et al., 2015). For teachers, this demands much greater attention to and interpretation of students' thinking (Cartier et al., 2013).

This shift to center students' evolving thinking poses challenges for practicing teachers, despite research indicating that developing models and constructing explanations yield the greatest gains in student learning (Cherbow et al., 2020; Inkinen et al., 2020; Maskiewicz, 2016; Reiser et al., 2017). One challenge is that this model of instruction is not widely enacted in science classrooms and is thus unfamiliar to teachers. Teachers may have had few opportunities to develop a vision of responsive science instruction and to learn how to design and lead instruction that centers and is responsive to students' emerging understandings (Cartier et al., 2013; Colley & Windschitl, 2016; Kang et al., 2013; Miller et al., 2018; Patchen & Smithenry, 2014; Thompson et al., 2021). A related challenge to centering student thinking is that it shifts authority away from teachers as the sole proprietor of knowledge to both teachers and students as co-creators of learning, which requires that teachers position themselves differently to students and their ideas (Stroupe, 2014; Windschitl et al., 2018). Finally, this model of instruction challenges the nature of knowing in science, by elevating practices such as argumentation and reasoning over the memorization of discrete facts (National Research Council, 2012). This challenge is even more pronounced in culturally, linguistically, and racially diverse classrooms where students' funds of knowledge and typical modes of interaction have been largely absent from curriculum and science practices (Brown & Ryoo, 2008).

Video-based professional development has been shown to support both the development of a vision of this form of instruction as well as teachers' learning and enactment of discourse practices that can advance student-centered instruction (Barnhart & van Es, 2015; Gaudin & Chaliès, 2015; Roth et al., 2019). Research shows that teachers who attend, interpret, and respond to student thinking in the moment of instruction—what is referred to as teachers' noticing—can more flexibly leverage students' ideas during instruction (Barnhart & van Es, 2020; Richards et al., 2014; Tekkumru-Kisa et al., 2015). We build on this research to ask: what awareness and insights into student thinking do teachers develop when they view and discuss videos of efforts to enact NGSS-aligned modeling instruction?

To situate our study, we first provide an overview of the role of modeling in the context of reform science teaching, with a specific focus on the language demands placed on students associated with constructing and explaining scientific models. We then discuss the promise of video-based professional development for making visible the challenges learners experience to support teachers enacting responsive science practices. We then provide details on the study context, research design, and data collection and analytic procedures.

2 | THEORETICAL FRAMEWORK

2.1 | Modeling as a complex practice in science

The NGSS specifies eight distinct science and engineering practices, with developing and using models being one. Modeling in science consists of creating a visual or numerical representation of a system or a phenomenon to convey one's conjectures about how or why something works (NGSS Lead States, 2013; Windschitl et al., 2018). Building explanatory models in NGSS involves communicating a claim or argument about a process and revising iterations of the model based on evidence collected through investigation (NGSS Lead States, 2013; Windschitl et al., 2018). Students' models serve as public artifacts that organize their analysis and critique of scientific phenomena (Colley & Windschitl, 2016). The modeling process thereby integrates both understandings of disciplinary core ideas and concepts, as well as ways of knowing and communicating in science, positioning it as an "overarching" practice that connects all of the other practices (Adams et al., 2018; Hakuta et al., 2013; Osborne, 2014).

The public nature of modeling as both a means of sense-making and communicating one's evolving arguments are distinctive from previous didactic models of science instruction (Lemke, 1990; McNeill & Pimentel, 2010). The function of a model as an explanation, a tool to capture ongoing changes in thinking, and an object of collective critique in NGSS makes it a language-intense process that "offers rich opportunities and demands for language learning at the same time that it supports science learning" (Quinn et al., 2011, p. 2). Through modeling, students come to learn that information in science is conveyed in various modalities: written text, numbers, diagrams, and symbols (Cheuk, 2016; Lemke, 1990). As students create and refine their models to reflect the growing sophistication of their science understanding, they must also develop precision in their use of the science language and in the modeling conventions of the specialized register of science (Santos et al., 2012). For example, learning specialized uses of particular words in science versus everyday language (e.g., adaptation, momentum) is essential for student learning because the scientific term carries precise understandings about scientific phenomena (e.g., evolution, kinetics). Similarly, the details of drawn objects in a model (e.g., length of an arrow) convey specific meanings (e.g., direction and magnitude of a force) that may not apply when situated in an everyday context. Thus, precision of language in multiple modalities is an essential component of developing, explaining, critiquing, and refining models.

Furthermore, building, explaining, defending, and revising explanatory models positions students with greater agency than when they are provided accepted canonical models in textbooks or lectures (Lemke, 1990; Rosebery et al., 2016; Stroupe, 2014). With that level of agency comes more linguistic responsibility to explain, critique, and defend models with precision (Quinn et al., 2011). Therefore, as science teachers make modeling an integral part of instruction, they need increased awareness of the literacy demands placed on students, the linguistic and cultural resources students bring to shape their thinking and learning about science phenomena, and the types of discourse practices that can support learners explaining and defending models (Brown & Ryoo, 2008; Cheuk, 2016; Davis et al., 2017; Gray & Rogan-Klyve, 2018; McDonald & Rook, 2015).

2.2 | Expanding conceptions of noticing for responsive teaching

We turn to research on teacher noticing to frame teachers' attention and sensemaking of student thinking for enacting responsive teaching. Across the literature is a wide consensus that core to responsive teaching is teachers' ongoing attention and sensemaking of student thinking and using their evolving understanding of students' thinking to move students' learning forward (Barnhart & van Es, 2015, Blömeke et al., 2015; Jacobs et al., 2010; Luna, 2018; Luna & Selmer, 2021; Richards & Robertson, 2016; Tekkumru-Kisa et al., 2022; Sherin & van Es, 2009; Thomas et al., 2021; van Es & Sherin, 2021). More recent research refines and expands the fields' understanding of noticing for responsive teaching. Some research demonstrates the discipline-specific nature of teachers' noticing. For example, Walkoe et al. (2022) show that elementary students have preliminary ideas about algebra in early grades and support teachers identifying and reasoning about students' early algebraic thinking. Relatedly, Jaber (2016) found that participating in professional development to promote responsiveness to students' science thinking supported one teacher's noticing and responding to student thinking, as well as increased awareness of his students' epistemic affect as an integral part of their engagement in science. This finding is similar to Kang (2021) who documented a novice teacher's efforts to enact responsive and equitable science instruction and found that this teacher attended to the intellectual, relational, and linguistic challenges that students experienced in the lesson. These findings are consistent with other research that identifies the social, relational, political, and linguistic features of teaching and learning that teachers attend to when they create classroom contexts that are responsive to learners (e.g., Louie, 2018; Turner et al., 2012). Together, this research suggests that teachers' noticing is integrated. That is, attention to student thinking may be coupled with teachers' understanding of students' positioning, or teachers' understanding of students' language use may be connected to their interpretations of students' emergent science thinking and their understanding of students' histories and identities.

We draw on research that positions teacher noticing as developing increased awareness and understanding about learners' experiences to become attuned to how these experiences arise in teaching and can be leveraged for learning. Mason (2009) explains that students enter schooling with abilities to make sense of the world around them and that noticing involves ongoing inquiry "into how learners' powers can be provoked and evoked, how those powers are pertinent to the subject matter" (p. 207) so that teachers can position learners to leverage their knowledge, experiences, and understanding for learning. By positioning noticing as deepening awareness through observation and inquiry, cultivating teachers' noticing supports their ongoing learning about student thinking and the complexity of enacting responsive teaching practices (Breen et al., 2014; Maskiewicz, 2016; Sherin, 2002; Thompson et al., 2021). Thus, noticing becomes a generative site for teacher learning because it expands teachers' awareness and interpretations of students and their ideas during instruction.

Research finds that artifacts of practice are particularly powerful in supporting teachers' learning to notice for responsive teaching (Gaudin & Chaliès, 2015). Analysis of video, samples of student work, and assessment data afford opportunities for teachers to develop a vision of responsive practice and to learn about the complexity of student thinking as it arises in teaching (Brouwer, 2011; Goldsmith & Seago, 2011; Johnson & Mawyer, 2019; Kazemi & Franke, 2004; Talanquer et al., 2015; Tekkumru-Kisa et al., 2018). Collective analysis of artifacts also allows teachers to develop a common language of practice and locates teachers' learning in practice (Ball & Cohen, 1999; Borko et al., 2011). Because professional development allows teachers to remove themselves from the routines of their classrooms, they can slow down teaching to gain deeper insight into the complexity of responsive instruction and expand their awareness of the challenges that both they and their students encounter as they engage in modeling practices (Putnam & Borko, 2000; van Es & Sherin, 2010). Research also finds that professional development anchored in practice can support teachers learning to enact responsive instruction in science classrooms (Barnhart & van Es, 2018; Osborne et al., 2019; Roth et al., 2019). This study builds on this line of research to investigate how bringing teachers together in video-based professional development provided a context for them to expand their awareness and understanding of the complexity of student thinking that emerged in their efforts to enact model-based science instruction.

3 | STUDY CONTEXT AND RESEARCH DESIGN

The context of this study was a semester-long video club attended by five secondary science teachers (Barnhart & van Es, 2020), informed by principles of artifact-rich teacher professional development (Barnhart, 2021). All the teachers had at least 10 years of experience and were concurrently engaged with designing district-wide NGSS-aligned argumentation tasks just prior to NGSS adoption in California. Additionally, because a significant portion of their students had a first language other than English, (53% in one school and 42% in the other) these teachers had previously engaged in sustained professional development concerned with supporting students' academic language acquisition. Four of the five teachers were multilingual themselves and two learned English as a second language.

The video club met five times, about once a month for 5 months, and each meeting was between 60 and 90 min long. The goal for this video club was two-fold—to hone teacher noticing of students' science thinking and to stimulate enactment of responsive instruction utilizing the construction of explanatory models. To support teachers' envisioning responsive teaching in practice, the group collaboratively analyzed videos and student work from published sources (ambitiousscienceteaching.org and www.timssvideo.com) chosen by the first author for the first three meetings. These meetings began with the first author providing context for the classroom artifacts, followed by participants attempting the task featured in the artifact, and then viewing and discussing each video segment. Video clips were selected that featured whole class and small group discussions of students' models as well as student work samples. These meetings featured between two and three clips each (seven clips total) with an average length of about two minutes.

As teachers shifted to enact lessons that centered students' ideas, the first author video recorded and selected artifacts (e.g., video and samples of student work) from two participants' classrooms for analysis in the last two meetings. The teacher whose classroom was featured in the meeting provided the context for the artifacts. Artifacts included five student work samples and one clip of about 90 s. Each meeting was held after school in one of the participants' classrooms. The meetings were video recorded and transcribed.

4 | DATA AND ANALYSIS

Data for this study includes the video club meeting transcripts. The first author transcribed the meeting recordings and segmented them by activity (e.g., introduction to the clip, analysis of the artifact, and discussion of the rubric) (Barnhart & van Es, 2020). As noticing of student thinking in artifacts of teaching is the focus of this study, only segments concerning artifact analysis were analyzed further. The first author further segmented the artifact analysis sections of the meeting into idea units defined by a set of turns at talk centered on a particular topic (e.g., student thinking about gas laws) or object (e.g., student-generated drawing of sound waves) (Schäfer & Seidel, 2015) resulting in 38 idea units for the first three meetings and 15 idea units for the last two meetings.

We then coded a subset of the idea units using Sherin and van Es's (2009) noticing framework (i.e., actor, topic and stance dimensions) and Kang's (2021) three dimensions of responsive noticing: intellectual, relational, and linguistic. We wrote analytic memos to document our impressions about teacher noticing for each artifact (Miles et al., 2020). This initial analysis revealed that teachers' attention to students thinking about students' sense-making was also tied to linguistic challenges of the lesson. Thus, the next phase of analysis entailed examining the nature of the teachers' discussions of these linguistic challenges. Using an inductive analytic approach, we reviewed our initial memos and codes to categorize teachers' noticing of the linguistic challenges that arose during the enactment of model-based instruction (Miles et al., 2020). We then looked for confirming and disconfirming examples of the categories in the transcripts and used these to refine how teachers attended to and made sense of the linguistic challenges of the lesson. Below, we present our findings, using examples from the teachers' enactment to illustrate each category.

5 | FINDINGS

Our central finding is that when teachers collectively analyzed artifacts of efforts to enact responsive teaching, they became attuned to the linguistic challenges connected to developing, critiquing, and communicating explanatory models. Here, we describe how the teachers in this video club identified and discussed three main types of linguistic challenges: students' learning to communicate with precision using modeling conventions, students' learning to communicate with precision using scientific vocabulary, and supporting students explaining and defending models. We explain each type in turn.

5.1 | Challenge 1: Communicating with precision using modeling conventions

Students' explanatory models of natural phenomena are intended to make visible what is happening, how it is happening, and why. Constructing explanatory models involves using combinations of symbols, words, and numbers to communicate the author's thinking to others (Lemke, 1990; Santos et al., 2012). Thus, students need to have multiple opportunities to learn how to coordinate these elements to communicate their ideas. As students refine their thinking, they realize they also need to refine their models to represent more precisely the important details of their explanation (Lee, 2013). How best to define a set of conventions ahead of time that "provide enough structure without constraining students' creativity or funneling their thinking about the science" (Windschitl et al., 2018, p. 125) can be difficult.

The challenge of modeling conventions arose in Meeting 4 as the group analyzed work from William's physics class. Students were asked to model the molecules and forces in a soda can filled with steam before and after it was immersed in a cold-water bath. There was some debate amongst the group about what the arrows in the students' drawing were meant to represent—magnitude of pressure, direction of pressure, or direction of air or water molecules:

> Vincent: I think kinetic theory traditionally uses arrows and dots. They may know a little bit about using the arrows and dots, but probably not as well as they need to. Knowing the longer the arrow the faster they go, the shorter the arrow the slower they go, and the direction.
> Mitch: Like in the modeling curriculum, they teach everybody a visual language of how to write down motion maps. So, they teach people, look, if you make these arrows longer it means this. [gestures] If you make more arrows, it means this. And then they start all these discussions. And then for a while because they're doing that the first couple questions on the worksheet are just, you know, here's a ball rolling at constant speed, draw the motion map. Just to make sure everybody's on the same board with the symbols that they're going to use. Then, when they talk about their symbols, the symbols mean something. But, if you don't do that piece, I mean I never do it, clearly, the kids need guidance. They can't just invent their own visual language. That's asking a lot.

Vincent wondered if students knew the conventions of motion from previous experience with kinetic theory and Mitch suggested that students must be explicitly taught the conventions using simple situations prior to engaging in modeling a more complex phenomenon. They continued their discussion about modeling conventions later when wondering what the dots in another student's model were intended to show:

> Mitch: How do you encourage students to draw things that don't leave us with questions? How do you encourage kids to like, well now don't make it half-ass? I'm going to count. If they knew, I'm going to count how many dots you have inside the can before and after.
> William: Yeah.
> Mitch: Right? That's me, I'm going to do that. Then maybe they would think, well I better put more.
> Tara: Yeah, I think like anything else, doing these representations is a skill that requires practice.
> William: Yeah.
> Mitch: Yeah, it does.

Mitch notes that students must learn not only the symbolic conventions of modeling but the expectation of precision the symbols convey in science. The group acknowledges that the skill of symbolic representation requires repeated opportunities for students to practice but Mitch also feels responsibility as the teacher to make that expectation clear to students. Balancing students' authority in developing their own models with teachers' explicit metamodeling talk is essential for enabling modeling to be a vehicle for student sensemaking (Gray & Rogan-Klyve, 2018).

5.2 | Challenge 2: Communicating with precision using scientific vocabulary

Another challenge the participants noticed was students' use of science vocabulary. "Accurate" use of science vocabulary was something the participants wanted to include in their common assessment rubric for students' science explanations. Two different types of situations arose during the analysis of students' models. First was students' inaccurate use of canonical science terms. In Meeting 5, the teachers examined work from Mitch's class in which students recorded and graphed the period of a pendulum using five different pendulum lengths of their choosing. Students were not told ahead of time what factors influenced the period but were encouraged to speculate on a pattern they saw in their data. The teachers were perplexed by one group's explanation: "The length changes the pendulum and how fast the period moves. It increases and then begins to become more consistent." The teachers noted the students' use of the word "period" in their explanation:

> Tara: And then even their use of the word period, I think, is interesting, like
> Mitch: Yeah. [Shakes head]
> Tara: They're writing, they're using the word period as if the period is the actual fob that is moving.
> Mitch: Right.
> Tara: And I don't know that they really think that but I'm not sure.
> Ron: But that's the way they wrote it, yeah.

Rather than writing about the period as a measurement of time, students wrote about the period as if it was a moving object. An additional complication in the students' work was that the theoretical relationship of the length of the pendulum and the time of the period was described correctly but did not actually match the data the students collected (which was linear). That combined with the students' use of "period" led the participants to wonder if the students were just writing what they thought the teacher wanted to hear rather than what their data showed and what they actually thought. An over-emphasis on correctness can cause students to retreat from sense-making and revert to parroting "correct" responses (Campbell et al., 2016; Russ et al., 2009). A challenge for teachers is to press for precision in ways that encourage students to focus on deepening their sensemaking rather than funneling them toward canonically correct answers (Hagenah et al., 2018).

A subtly different issue was the lack of precision in students' use of science vocabulary versus everyday use. This often led to questions about how well the students understood the phenomenon. In Meeting 3, participants were puzzled by one student's model of sound waves emanating from two different-sized tuning forks:

> Mitch: The short one was going faster.
> Tara: "The waves go faster."
> Vincent: Yes, he introduced speed in there.
> Tara: Right, which, my impression is that sound travels at a constant speed.
> Vincent: Yes, yeah.
> Tara: So, I'm wondering if he's thinking about speed as in like the compression waves come. [gestures]
> Vincent: Mmm hmm faster or slower.
> Tara: Faster meaning like more frequent versus like the speed at which the wave is traveling [gesture]. I don't know how he's like, what his conception of speed is here.
> Vincent: Right.

The student's use of the word "speed" rather than the more precise term of "frequency" to describe this situation caused the participants to wonder what exactly the student knew about how sound moved. Later, participants debated what was more important, understanding the relationship or understanding how to use the science vocabulary:

> William: Here's a question I have, if they're drawing out on a picture and they're not they're not stating it in words, then yeah, one can make the argument they don't know what the vocab term is. But the vocab term itself isn't the same as the phenomenon. So, what's more important? The vocab term or the phenomenon? … Sometimes I have a tough time. I want those kids to know the right vocab term, right? You want that concept clear, but if they get that, if they get what's going on, to me, even for an English language learner, he might not know the vocab terms.

> Ron: He may have the right idea, but he may not be able to put it into words. Cause I have a student like that.
> William: Yeah, but they know what's going on.
> Ron: Yeah.
> William: Heck, he might know what's going on more than the kid who actually knows the vocab term.

All students experienced some difficulty mastering the voluminous amount of science terminology, but communication in "science" language was further complicated for these students by the fact that nearly all spoke a first language other than English. Communicating in school required them to translate from Spanish to English. Communicating in science added an additional step and demanded increased precision to accurately reflect their evolving understanding. In Meeting 5, the teachers puzzled over a student's pendulum explanation and wondered if the student's explanation revealed a limited understanding of the science concept, the science term, or if having to write complex explanations in a second language limited their ability to clearly communicate in science. Ron explained:

> My experience tells me that it's more likely to be a language problem than a [science problem]. Because I think a lot of my kids still have trouble expressing what they really know. They know what's going on, but they have trouble spitting it out in a correct uh, manner. And putting it in writing is hard for them.

These teachers valued students knowing the science concepts and most of the conversations were focused on analyzing what students said and wrote with that goal in mind (Brown & Ryoo, 2008). However, imprecise use of language frequently led to questions about what students understood and what type of support was needed, linguistic or conceptual, making it hard to decide how best to respond.

5.3 | Challenge 3: Supporting students in defending their explanations

A third challenge that arose had more to do with the more generalized practice of publicly defending their model-based explanations than with the precision of their language or modeling conventions. The video club participants recognized that in these defenses, they were asking their students to engage in a different kind of classroom discourse, one in which they had to go beyond providing "correct" answers, but to explain the thinking behind their answers to their peers. This "new" discourse was unlike the traditional IRE pattern students were familiar with (Cazden, 2001). Laurel, and Mitch elaborated on this challenge in Meeting 5:

> Laurel: There's a social aspect to it where they may have told me they feel confident when I'm at their table but as soon as they're up front like, they lose their confidence and they're not confident in their writings and they're certainly not confident in using their science vocabulary.
> Mitch: I think that's true that the critical thinking part on your feet, being questioned about something, you create it and you're responsible for it. That's a skill that is desperately important. And that you see crumble away for lots of different reasons. And it's such the nature of science, right? You took the data, you defend it, you answer questions about it, and it's the nature of scientific argument … The model should be that they present their data and hopefully they can feel comfortable defending questions about it and just like, you know, when you go to JPL and you see all the scientists up there defending their data. That's what you want to have happen in your classroom.

One response to the challenge of shifting the classroom discourse was to provide students with more opportunities to talk through explanations and to acknowledge that their explanations were a work in progress. Mitch explained:

> I mean what seems to work, both in the work and in the videos, it is messy and what you want kids to do is talk to each other and try to clarify what they really think. And that takes all kinds of stumbling over the vocabulary and the language and somewhat with the drawings there is some stumbling that is inherent. That's what learning is on some level. So, you do have to throw them out there not completely prepared for the new concept because it's got to break new ground in their head and experience it.

The video club participants wondered how much structure and support was appropriate during early efforts of discussing students' interpretations of data. In Meeting 2, Ron and Mitch raised this issue after watching a video of a teacher facilitating the discussion of data amongst students in a biology lab group:

> Mitch: It makes me think that these interactions are really hard to pick apart and they seem like people, as soon as people talk over each other there's a little miscommunication. No matter how careful you are as a teacher there's a lot of impatience, things are going fast … It makes me think in your classroom it would be nice if you could craft conversations that were slower and more deliberate … because it seems so frenetic, it seems so animatedly frenetic and I'm like, do they even understand that the depth of the thing they're trying to get ahold of?
> Ron: And that's one of my frustrations is, because every group is going to be at roughly about the same point at the same time, but how can you be at all the labs to discuss the at the same time? I've never been able to figure out how to do that.

These teachers recognized that a shift in which students' discussions about their interpretations of data become a central practice places new demands on both the students and on themselves as organizers of the instructional space. This change was unfamiliar and uncomfortable for many of the teachers and continued in the next turns of talk:

> Tara: So, she's modeling some type of press. Like she's pressing on some ideas. I think one of the things that we're charged with doing is we model how scientists would press each other with regard to their ideas, right? So, the students take up this role and start pressing each other.
> Mitch: Right.
> Ron: But how can students press each other when they don't know what the final result or the final discussion point should be?

Ron's frustration raises the subtleties in teachers' practices that are required to support students' explanatory modeling. Here, he recognizes that this form of instruction requires more than only changing the task, or supporting vocabulary, or adopting a different discourse, or adopting different roles. Rather, it requires all of these aspects of instruction to be enacted in a coordinated effort, for which teachers and students clearly need support.

6 | DISCUSSION AND CONCLUSION

Our findings show that as teachers engaged students in modeling activities and gave them more responsibility for sustaining discussions about their ideas, the teachers became more attuned to students' ideas as they were integrated with the linguistic challenges of model-based instruction. Specifically, we found that the teachers gained increased awareness of the language demands of model-based teaching, attending to the precision of language and students' learning of the highly specialized vocabulary and modeling conventions required to communicate a sophisticated understanding of science concepts (Quinn et al., 2011; Santos et al., 2012). This is particularly significant as it indicates teachers' developing increased awareness that science learning is entangled with the discursive practices of the discipline that cannot be separated into distinct lesson objectives (language or science) and was not a one-way transmission of knowledge from teacher to student (Lemke, 1990; McDonald & Rook, 2015).

These findings also extend prior research on teachers' noticing by demonstrating the integrated nature of teachers' awareness of multiple features of classroom interactions. While there is value in distinguishing the objects of teachers' noticing – such as noticing epistemic affect or noticing student thinking (Jaber, 2016; Luna, 2018) – research also finds that teachers who enact equitable and responsive teaching attend to a variety of aspects of their students and classroom interactions (Kang, 2021; van Es et al., 2022). With a greater imperative to move mathematics and science instruction toward equitable teaching and learning, important questions for future inquiry concern how teachers' noticing of student thinking is integrated with other features of classroom interactions, such as how students come to be positioned to have agency in their learning as teachers come to interpret students' thinking from anti-deficit, strengths-based perspectives.

We also found the teachers problematized rather than normalized the tensions and challenges they identified through artifact analysis and their efforts to enact model-based instruction (Little & Horn, 2007). Not only were they sensitive to the increased linguistic challenges of modeling tasks, but they also took ownership of their responsibility as the facilitators of these learning situations to provide opportunities for students to practice, struggle, and improve. Because the video club conversations were initiated around interpreting rather than evaluating students' reasoning, the challenges associated with their students' imprecise use of technical vocabulary and modeling conventions were viewed as barriers *they as* *teachers* had to overcome to more fully understand what and how their students were thinking (Rosebery et al., 2016). The problem of practice was therefore located in their instruction rather than in their students. Previous work indicates that deliberate efforts to cultivate an interpretive stance through the use of tools and facilitation moves (van Es et al., 2020) play an important role in how teachers view problems of practice and in turn, their proposed responses to them, and also provide opportunities for teachers to learn in the context of teaching (Davis et al., 2017; Sherin, 2002; Stroupe, 2014). Thus, supporting teachers' in adopting an inquiry stance not only encourages integrated noticing, but also becomes a site for teacher learning.

While the results are encouraging, it is also the case that some of the teachers continued to narrate teaching from a transmission model while simultaneously attempting to enact student-centered practices. Fisher et al. (2018) documented that professional development designed to develop disciplinary noticing, attitudes, beliefs, and disciplinary knowledge for teaching resulted in uneven change across these various areas. As the field's understanding of teachers' noticing and enactment of responsive teaching develops, so too must research seek to understand how existing professional learning models help and limit teachers developing a tolerance for ambiguity and more asset-based perspectives toward student learning.

The shifts required to achieve the promise of the NGSS are substantive, both in terms of their potential to open up meaningful learning opportunities for students and in terms of changes in teachers' classroom practices. Engaging and supporting students in developing, refining, and explaining mechanistic models of natural phenomena is cognitively and linguistically demanding, and modeling can broaden the resources students can draw on to meaningfully participate in science. Artifact-rich professional development can support teachers as they learn to notice students' sense-making, as well as the challenges that these new forms of teaching and learning pose. Further exploration of how teachers use what they notice will enhance professional development efforts to support teachers in their efforts to enact instruction that lives up to the vision of the NGSS and responsive science teaching.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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