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Characterizing the formative assessment enactment of experienced science teachers

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Abstract

Teachers' use of formative assessment (FA) has been shown to improve student outcomes; however, teachers enact FA in many ways. We examined classroom videos of nine experienced teachers of elementary, middle, and high school science, aiming to create a model of FA enactment that is useful to teachers. We developed a coding scheme through a validation-in-use approach to characterize teachers' practices using three streams of data that included teachers' self-interviews about the purposes and outcomes of their FAs, our analysis of their noticing/interpreting and acting, and their comments on intentions behind the teaching acts they considered significant. In contrast to cycles of eliciting-noticing-interpreting-acting, we found noticing/interpreting to be central to FA enactment, driving teachers' eliciting or advancing acts. We characterized ways of noticing/interpreting as more authoritative or dialogic and observed that eliciting acts and advancing acts occurred along a similar range. Teachers' in-the-moment purposes and larger learning goals were synthesized as they made choices about teaching acts. The model is framed in terms of utility to teachers to examine their own FA practices, with the aim of becoming better equipped to strategically enact FA in intentional ways to achieve their purposes.

KEYWORDS

formative assessment, interpreting, noticing, responsive teaching

Recent education policy documents, including the *Framework for K-12 Science Education* (National Research Council [NRC], 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013), promote a vision of science learning that foregrounds engagement in scientific practices while developing content understanding within and across disciplines. Realizing this vision in the classroom has been a central challenge of science educators and researchers who have made efforts to develop and study environments in which students learn science by doing science, including building explanations from data, reasoning using causal arguments, making decisions, using experiences and knowledge, among others (e.g., Berland et al., 2016; Engle, 2006; Forman & Ford, 2014). Understanding how experienced teachers create these opportunities for students requires the examination of teaching and learning in the classroom as they occur.

A pedagogical vehicle that skilled teachers commonly use to support their students in learning scientific practices and content is formative assessment (FA). FA improves outcomes for students (Bennett, 2011; Black & Wiliam, 1998; Ruiz-Primo & Furtak, 2007), including among underperforming learners (Stiggins & Chappuis, 2005), who benefit in their conceptual understanding, attitudes, motivation, and effort (Black & Wiliam, 1998, 2009; Brookhart, 1997; NRC, 2012; Ruiz-Primo, Li, Tsai, & Schneider, 2010; Sato, Wei, & Darling-Hammond, 2008). When FA is effective, teachers elicit and support students' thinking that conduces to their making decisions, building explanations, and generating arguments in relevant contexts (Coffey, Hammer, Levin, & Grant, 2011).

Teachers' FA practice has been studied by elements, e.g., eliciting (Franke et al., 2009), noticing (van Es & Sherin, 2008), acting (Lineback, 2015). It has also been studied according to responsiveness to substance (Coffey et al., 2011), and responsiveness to building on student ideas (Thompson et al., 2016). Research has also been devoted to developing models that describe how different elements of FA fit together (Cowie & Bell, 1999; Haug & Ødegaard, 2015; Kang & Anderson, 2015; Ruiz-Primo & Furtak, 2007; Sezen-Barrie & Kelly, 2017). This paper describes our approach to modeling FA enactment as we synthesize aspects of others' elements and models. Our work addresses a problem of practice: science teachers need practical guidance to reflect on their own discourse practices while enacting FA to support students' sense-making (Sevian & Dini, 2019).

We take a design-based approach that elevates validation-in-use so that the products will be useful to science teachers in their classrooms as well as to researchers seeking to understand their FA practices. We attempt to describe FA enactment in a way that teachers can characterize their own FA practices and use the model to make more intentional choices. We aim to provide a tool useful to teachers in analyzing the classroom discourse in their FA enactment, so that teachers may develop an awareness of a range of possible actions they can take in a given interaction, as well as the purposes that influence these actions.

With this aim as a backdrop, we highlight three additions to understanding elements and models of FA enactment. First, we recognize the centrality of noticing and interpreting, with cycles that originate in and return to this aspect. Second, we pay attention to reasons why teachers choose two main types of actions (eliciting and advancing) based on what they notice and interpret. Finally, we characterize the range of ways of enacting each of three aspects of FA (noticing/interpreting, eliciting, and advancing) and show that they depend on both overall lesson purposes and in-the-moment purposes associated with specific teacher-student interactions.

1 | LITERATURE REVIEW: FORMATIVE ASSESSMENT

Researchers have studied both elements of FA and models of how the elements come together. Some of this research occurs across both science and mathematics education, while other studies have focused on one or the other.

1.1 | Models of FA

While there is broad consensus that FA is meant to give teachers understanding of their students' thinking so as to improve instruction, researchers have found that FA can take different forms (Bell & Cowie, 2001; Black & Wiliam, 1998; Black, Harrison, Lee, Marshall, & Wiliam, 2004), including in the relationships among the elements of FA (e.g., eliciting, noticing/interpreting, acting). Cowie and Bell (1999), for example, described *planned* FA as a cycle of eliciting, interpreting and acting on the information that the teacher collects during a predetermined lesson. They specify that the teacher's purpose for the planned FA "determined how the information was collected, interpreted and acted upon" (Cowie & Bell, 1999, p. 103), making the different elements in the cycle interrelated and mutually determined. They describe a slightly different model for *interactive* FA, where the teacher notices an "ephemeral" idea, recognizes its significance and then responds to an individual's thinking during unanticipated teacher-student interactions that emerge during classroom activities.

Instead of planned versus interactive FA, Ruiz-Primo and Furtak (2007) describe a spectrum of formal (typically curriculum-embedded assessments about a topic) to informal (improvisational teacher-student interactions arising from any classroom learning activities) FA that depends on the degree of premeditation. Shavelson et al. (2008) elaborated a midpoint on this spectrum as "planned-for-interaction" in which a teacher prepares certain questions in advance and poses them at appropriate times during a classroom activity. Based on work by Cowie and Bell and others, Ruiz-Primo and Furtak (2007) developed the ESRU cycle of informal FA where a teacher elicits (E) students' ideas, hears a student (S) response, recognizes (R) the scientific value in the idea, and then uses (U) it for the ongoing lesson (as distinct from formal FA where a teacher gathers, interprets, and acts). They describe the value of the ESRU model (as compared to Initiation-Response-Evaluation [IRE][1]) as the way it elaborates effective eliciting in revealing student thinking, empowers students in recognizing their ideas and uses the ideas in ways not implied by "feedback" in an IRE-type interaction (Ruiz-Primo & Furtak, 2007). They report that a teacher who used complete ESRU cycles had higher-performing students than two other teachers who did not. In another study, Furtak, Ruiz-Primo, and Bakeman (2017) performed a sequence analysis of different kinds of teacher eliciting, student responses, and then teacher responses, identifying the frequency of particular sequences and possible effects on student learning. They report that students were more likely to offer ideas when responding to teachers' initial eliciting than after teachers' responding. They also describe how sequence analysis was useful in identifying how often a teacher's practice reflected particular patterns of discourse.

Haug and Ødegaard (2015) describe a similar cycle as Ruiz-Primo and Furtak (2007). Their cycle begins with teacher eliciting of student ideas, interpreting, and acting by adapting teaching or providing elaborative or confirmative feedback, at which point the cycle repeats itself. Sezen-Barrie and Kelly (2017) describe a hybrid model between ESRU and the IRE pattern as studied by Mortimer and Scott (2003), in which the teacher initiates a cycle of informal FA, listens to students' ideas, evaluates them according to their relevance, and then decides to ignore or recognize the responses. At this point, the teacher can choose to leave the cycle or use the ideas to craft a better explanation.

These researchers, and others, have used instruments based on these models to measure the quality of teachers' FA. Different methods, such as rubrics, scoring, or coding schemes have been used to examine different aspects of FA. Gotwals, Philhower, Cisterna, and Bennett (2015), for example, employed a rubric to assess the quality of teachers' FA practices on a progression from novice to intermediate to expert levels. They defined these levels based on the possible roles that a teacher and students take during FA, as well as how a teacher perceives and then uses students' ideas. Furtak et al. (2016) used a scoring scheme to evaluate how well teachers designed and then implemented FA as they progressed through a PD program. Haug and Ødegaard (2015) developed and implemented a coding scheme to analyze classroom transcripts for how teachers notice and use student thinking.

[1]The ESRU model is contrasted with the well-known Initiation-Response-Evaluation (IRE) pattern, where a teacher initiates a question, a student responds, and the teacher evaluates the response (Mehan, 1979; Sinclair & Coulthard, 1975).

1.2 | Elements of FA

There are various lenses on examining FA through elements, and researchers have used different language to mean similar ideas, for example, attending (attentiveness) versus responding (responsiveness). We organize the review into elements of FA as researchers and teachers often define them (Kang & Anderson, 2015; Levin, Hammer, & Coffey, 2009), namely: (a) eliciting students' ideas; (b) noticing the substance of those ideas; (c) interpreting what is noticed; and (d) acting to guide and support student learning.

1.2.1 | Eliciting

How teachers elicit students' ideas is often studied in terms of the impact of teacher questioning on student learning. Franke et al. (2009), for example, developed a coding scheme to understand how teachers' questions related to students' ideas. They categorized questions into general (not specific to anything a student said), specific (addressing something within a students' idea), probing sequences (two or more questions in deliberate sequence), and leading (moving students to particular answers). The authors reported that teachers' use of probing sequences of specific questions helped them better understand their students' thinking, informed instructional decisions, allowed students to clarify their thinking, and provided opportunities for other students to connect their understanding. Single questions did not have these benefits, particularly because student assumptions would remain unverbalized.

Oliveira (2010) broadly describes teacher questioning as both a social activity in forming identities and relationships, and a cognitive activity in developing students' thinking. He constructed a detailed framework, distinguishing three kinds of questions that facilitate information flows (called *echoic:* questions to check comprehension, confirmation checks, and clarification requests) from two kinds of questions that establish a topical focus (called *epistemic:* display questions in which the student can demonstrate knowing the right answer, and referential questions for what the teacher needs to learn from students). He reported that some categories of questions (confirmation checks, clarification requests, and referential questions) that are student-centered are conducive to students' inquiry, whereas others (comprehension checks and display questions) are teacher-centered and seek to establish canonical knowledge, much like the "leading" category of Franke et al. (2009).

Numerous studies of classroom discourse have demonstrated common patterns in teacher questioning. Among these patterns is one in which a teacher initiates a question, a student responds, and the teacher evaluates the response. As noted earlier, this pattern has been called Initiation-Response-Evaluation, or IRE (Mehan, 1979; Sinclair & Coulthard, 1975). The IRE pattern acts as a channel for "closed" questioning, that is, one correct answer (Hardman, Smith, & Wall, 2003), which enables efficient correction of students' ideas, but usually at the cost of students' agency (Lemke 1990). Another pattern related to IRE is what Barnes, Britton, and Rosen (1971) identified as "pseudoquestions." These probes are fake in that the teacher already knows the answer to them, and the students know that the teacher is looking for a specific answer (Roth, 1996; Rowland, 2003). Thus, seemingly open questions can be taken up by students as closed-ended so that the discourse devolves into a game of "guess what's in my head" (Wellington & Osborne, 2001). Teachers who frequently ask pseudoquestions, often in long sequences embedded with teacher reasoning, can unintentionally restrict their students' thinking and mislead them into believing that they are creatively problem solving (Blanton, Westbrook, & Carter, 2005).

1.2.2 | Noticing and interpreting

Between a student's response and a teacher's follow-up, the teacher engages in an often implicit process of noticing student discourse and behavior, and interpreting their meaning. Some researchers separate noticing and interpreting

(Levin & Richards, 2011; Levin et al., 2009; Russ, Coffey, Hammer, & Hutchison, 2009; Talanquer, Bolger, & Tomanek, 2015; Talanquer, Tomanek, & Novodvorsky, 2013). Other researchers consider noticing and interpreting as inextricably linked (Richards & Robertson, 2016; Tekkumru Kisa & Stein, 2015). In mathematics education, the term "professional noticing" is used by many researchers to mean paying attention to what students do and say when solving mathematical problems and interpreting what students may be thinking (Chamberlin, 2005).

Sherin, Jacobs, and Philipp (2011) showed that mathematics teaching that addresses students' learning needs depends on teachers' noticing abilities. By virtue of the complex space of the classroom where many things are happening simultaneously, teacher noticing is necessarily selective: teachers choose to notice some things and ignore others. What teachers pay attention to, or not, plays a large role in how lessons unfold (Miller, 2011), thus some studies have focused on what teachers do not notice. Teachers frequently fail to notice and interpret the disciplinary substance of their students' thinking (Coffey et al., 2011), which then limits how they can use students' ideas to support learning (Russ et al., 2009). Noticing is also multidimensional in that teachers can notice issues related to the subject matter, student behavior, and other things simultaneously (Erickson, 2011). From a disciplinary perspective, Goldsmith and Seago (2011) described mathematics teachers' noticing in three areas: teachers' use of evidence from classroom artifacts to support their claims about students' thinking, attention to the potential in students' thinking, and attention to the details of the mathematical content. Schoenfeld (2011) emphasized that what teachers notice is tied in part to their orientations or stances, which are largely determined by teachers' epistemological stances in specific moments and their domain-specific beliefs related to curricula (van Driel, Bulte, & Verloop, 2007). Teachers notice what it means to learn a discipline in different contexts, such as laboratory learning versus class discussions (Russ & Luna, 2013). For instance, Schoenfeld contrasted how a teacher with one orientation may look for nascent understandings of algebra and then build upon these beginnings, while a different teacher with a different orientation may notice a student's misconceptions and emphasize the benefits of clear explanation in dispelling them. Schoenfeld argues that these orientations often shape different approaches to teacher eliciting, which points to the interconnectedness of the elements of FA.

Researchers have systematically characterized preservice science teachers' (Talanquer et al., 2015) and mathematics teachers' (Colestock & Sherin, 2015; Crespo, 2000) assessment stances in noticing and interpreting. Individuals with an evaluative orientation tend to pay attention to students' ideas with the main goal of diagnosing and correcting their misunderstandings, while those showing an interpretive orientation focus on listening to students' ideas with the purpose of making sense of student understanding. These stances have parallels to earlier work by Davis (1997), who identified characteristics of evaluative versus interpretive listening. In evaluative listening, a teacher is "listening *for*" a specific explanation as compared to "listening *to*" the student. In the former, the explanation is evaluated against what the teacher perceives as correct, while in the latter there is a concern for interpreting the sense in a student's explanation. Adding to the evaluative and inferential noticing approaches, Tekkumru Kisa and Stein (2015) also saw preservice science teachers in a mode of descriptive noticing; that is, paying attention to observable aspects of what is occurring.

In mathematics education, some researchers have worked on making visible teachers' attention to student thinking. Colestock and Sherin (2015) examined several teachers' classroom practices by having them tag important moments of classroom video as they recorded a lesson, and afterward explain what they noticed in those moments. The authors then elaborated more detailed approaches (or stances) toward student ideas, as ways that teachers understood the pedagogical significance of those ideas. Assuming that the stances were partly driven by teachers' goals for instruction, the authors connected the goals to six stances they found (goals are noted in parentheses): indicators of learning (track student learning), problems to be addressed (deal with obstacles to learning), resources to be collected (monitor the range of ideas in the classroom), foundations to build on (connect and build on student ideas), messages to decipher (make sense of student thinking), and products of a process (reflect on lesson design). In this way, Colestock and Sherin showed that how teachers responded to students' thinking depends on what they saw in the thinking, which, in turn, was connected to goals. Dyer and Sherin (2016) also studied the reasoning underneath mathematics teachers' interpretations of students' thinking. They describe three categories of interpretations: connecting different moments of noticing about a student's thinking, relating a student's thinking to the structure of a mathematical task, and figuring out how to test students' thinking.

van Es (2011) argues that teacher noticing needs to be seen within a learning process, and points to how teachers' related abilities can develop. van Es constructed a framework for elementary school teachers learning to notice students' mathematical thinking. Using data from a video-club involving teachers discussing and analyzing classroom videos, she showed how teachers traversed four levels of noticing over ten club sessions. In the beginning, teachers attended to "the overall classroom environment, the class's behavior and learning, and the teacher's pedagogy" (van Es, 2011, p. 141). In the next phase, they primarily focused on teachers' pedagogies with a few observations about students' mathematical thinking. Then, there was a substantial shift: discussions focused on particular students and their mathematical thinking. In the final phase, teachers connected their noticings about students' thinking to specific teaching approaches.

1.2.3 | Acting

Noticing and interpreting are largely implicit processes but, like eliciting, acting is overt. Acting is often studied in relation to instructional goals or purposes. How teachers act upon students' responses in the classroom also depends on what teachers notice. Researchers have clarified a wide range of teaching acts. Relevant ideas are collected under the umbrella of responsive teaching (e.g., Robertson, Scherr, & Hammer, 2015), and also a wide net of both research and practice work, particularly with preservice science teachers, in Ambitious Science Teaching (ambitiousscienceteaching.org).

One major emphasis of acting is delivering a clear explanation, correcting students' ideas either implicitly or explicitly. Ogborn, Kress, Martins, and McGillicuddy (1996) characterized explaining science in the classroom as telling "how events work out so that the result is no longer arbitrary; so that it makes sense" (p. 10). Teachers follow a process that involves creating differences, constructing entities, and transforming knowledge (Ogborn et al., 1996). Similar to making explanations clear, acting can also be based on evaluating and furthering students' abilities to verbalize appropriate words, phrases, and scientific terminology. Teachers may act by asking questions that push students toward higher-order thinking (Oliveira, 2010), and they may ask leading questions that move students in stepwise logic toward a canonical conclusion (Franke et al., 2009).

Another goal of acting is to generate discussion. Pierson (2008) observed teachers making connections among different ideas and students' own experiences, considering follow-up actions and experiments, and seeing where their reasoning falls short. She characterized teachers' actions as ranging from minimal to considerable evidence of taking up student ideas. She found a positive relationship between the extent to which teachers fostered these types of discussions and student learning. Coffey et al. (2011) noted that responsive teaching acts may extend beyond showing respect for and being encouraging of students' contributions; they can also capitalize on the disciplinary substance that students bring to learning. Chin (2007) showed that teachers' questions that foster such discussions can leverage students' ideas in practices of science, for example, observing, comparing, hypothesizing, predicting, inferring, measuring, and formulating conclusions.

Some researchers have focused on the relationships between teachers' actions and students' sensemaking. Franke et al. (2009) pointed out that while leading questions may be used by teachers, this does not preclude students from sensemaking on their own. Some have characterized teaching acts in terms of whose thinking teachers emphasize. The coding scheme that Pierson (2008) developed distinguishes two levels of high responsiveness to students' ideas: emphasizing the teacher's versus students' thinking. Lineback (2015) constructed a framework that considers levels of responsiveness (responsive, nonresponsive, delayed responsive) and focuses (e.g., requesting students to explain or exemplify a term, requesting that students extend/elaborate student comments). Her scheme of redirections affords greater resolution at lower levels of responsiveness, including non- and minimally responsive acts.

2 | RESEARCH QUESTIONS

The review portrays a rich landscape in how elements of FA have been conceived and studied, as well as differences in how these elements have been formed into a variety of models. In light of these complexities, we sought to characterize the ways in which elements of FA interrelate, with the ranges of stances that teachers take, and the purposes behind their thinking and acting when they are enacting FA. Within formal FA that teachers used (i.e., planned activities taken or adapted from the curriculum in use, and questions or problems that teachers designed as part of lesson planning), we examined the informal FA (i.e., emergent discussion) that took place as the teachers taught using these activities. We used experienced teachers' own video recordings of their classroom FA, and characterized their FA enactment. To bolster validation-in-use of the resulting model, we involved teacher leaders and used several data sources in the research process. We developed a model of FA enactment useful to both teachers and researchers, and through this work, addressed three research questions:

- What are the different ways elements of FA are enacted?
- What is the overall structure of FA enactment?
- What are teachers' in-the-moment purposes behind FA enactment?

2.1 | Theoretical framing

In this study, we refer to the definition of FA summarized by Bell and Cowie (2001) as a process "to recognize and respond to student learning to enhance that learning during the learning" (p. 536). Our goal was to examine the ways in which teachers enact FA. We found it difficult to cleanly separate formal and informal activity according to the definition of Ruiz-Primo and Furtak (2007), because teachers' actions in the moments of enactment are often not formally planned, although they may be using a formal FA that was designed and intended to be implemented in a certain manner. We, therefore, took a broader view, based on Bell and Cowie (2001), that considers any teacher-student interaction that has purposes related to learning and is situated in *discourse* to be FA enactment.

The role of discourse has been studied extensively. Discourse is widely hypothesized as central to science learning. This hypothesis is predicated on Vygotsky's (1987/1934) idea of word meanings, as learners develop regulation of their talking behavior from "outside" to impose the social language on inner speech. Education researchers have studied the nature of discourse (Lemke, 1990; Mortimer & Scott, 2003), as well as promoted it in various ways in the classroom through pedagogical strategies like Accountable Talk (Michaels, O'Connor, & Resnick, 2008). Broadly speaking, teachers' coordination of classroom conversation—with individuals, in a small group or whole class varieties—has been shown to positively impact students' scientific reasoning (Ballenger, 2009; Engle, 2006; Michaels et al., 2008; Mortimer & Scott, 2003). The extent of that impact depends on the nature of the discourse patterns that emerge.

Our positioning includes the assumption that teachers interact in different ways, and can modulate these ways differently with different students, as well as at different times in whole-class teaching. Mortimer and Scott (2003) parse teachers' communicative approaches by examining sets of utterances according to their degree of interactivity (interactive vs. noninteractive) and the viewpoints allowed (authoritative vs. dialogic), with shifts among these different modes driven by the teacher's purpose at a given point in a lesson (Scott, Mortimer, & Aguiar, 2006). These distinctions are based on linguistic and learning theories developed by Bakhtin (1983)/1934), Wertsch (1991), Vološinov (1986)/1929), Vygotsky (1987)/1934), and others, who proposed that existence, language, and thinking are in dialogue, that understanding requires orienting oneself to another's utterances, and that learning is a process of meaning-making that takes place in the social plane of the classroom as well as in internal dialogue in learners' minds.

We follow others who have studied teachers' classroom interactions using framing (Russ & Luna, 2013; van Driel et al., 2007) and stances in teacher noticing/interpreting (Talanquer et al., 2015). We assume that there are ranges of ways that teachers interact with student thinking and consider that these ranges are influenced by teachers' epistemological beliefs about teaching and learning, their views on what it means to know a discipline and what the discipline is, and their purposes considered for curriculum, instruction, and assessment in different contexts in which students learn the discipline.

3 | METHODS

3.1 | Context

A major goal of this study was to develop a model of FA enactment useful to science teachers. Therefore, we involved them at various stages of the research process through a design-based approach. The process of development of these products is discussed in detail in another paper (Sevian & Dini, 2019), and we briefly highlight the relevant features below.

Because we were concerned with validation-in-use, teachers helped test and develop products of the research. There were three main groups of teachers who were involved in validation-in-use cycles. First, a set of five science teacher leaders (Teacher Set A), who had already been involved with three of the study authors in developing PD for STEM teachers, contributed their own classroom videos that we used as practice data for developing the analytical approach and as examples in PD led by them. Second, 40 science teacher leaders (Teacher Set B) from across the school district (ranging from pre-K to high school) participated in a two-day teacher leader retreat. These teachers were selected to participate based on their availability and an effort to include representation of all kinds of schools in the district (K-5, K-8, Grades 6-12, K-12, dual-language and newcomer/English language learner schools, and selective schools).

Third, 10 science teachers from a variety of schools in the district (ranging from Grade 4 to high school) participated in the 6-month PD program that supported the FA practices of STEM teachers (Teacher Set C). Teachers in Set C were recruited for the 6-month PD program via emails to 120 science teacher leaders in the district, 14 of whom responded with interest, and 10 were able to commit to the meeting dates and homework requirements.

The 6-month PD program and the first day of the teacher leader retreat were planned by three of the study authors and Teacher Set A, who led the PD. These two PD venues provided data on how teachers used the emerging coding scheme, and the teachers' input was incorporated to improve the analysis and the tools (Sevian & Dini, 2019).

3.2 | Compliance with ethical standards

This study was approved by the Institutional Review Boards of both the university and the school district. All teachers in Sets A, B, and C provided written consent to participate in the study. Students of teachers in Sets A and B (and their parent or guardian if under age 18) also provided written consent when included in videos and/or when written work was collected. All students and the teachers in Set A chose their own code names.

3.3 | Participants

Classroom videos and related data from Teacher Set C comprise the primary data corpus of this study. Data were analyzed from nine of the 10 teachers in Set C because one teacher's data set was incomplete. For the

TABLE 1 Summary of teacher Set C profiles

Teacher	Gender	Level/subject	Years experience
Ares	M	High school/physics	17
Gelos	M	High school/physics	10
Jupiter	F	High school/biology	9
Khione	F	High school/chemistry	9
Koncordia	F	Middle school/planetary science	17
Lapetus	M	Elementary school/life science	17
Nike	F	High school/physics	4
Paean	M	Middle school/earth science	6
Terra	F	High school/physics	4

analysis, these nine teachers were assigned code names of Greek gods. The nine teachers taught elementary (1), middle school (2), and high school (6) science. The elementary and middle school teachers were science generalists, and the high school teachers taught biology (1), chemistry (1), and physics (4). Six different schools in the district were represented, and the teachers had between 4 and 17 years of experience teaching in this school district with a mean of about 10 years (four also previously taught in other districts). The population of students in the school district is very diverse: 32% identify as African American/Black, 9% as Asian, 14% as White (non-Hispanic), 42% as Hispanic, and 3% as other races/ethnicities. The teacher population in the district is less diverse. One teacher was Hispanic and eight were White; four teachers were male and five were female. Background information about the teachers in Set C, whose data are drawn upon for the findings in this paper, is summarized in Table 1.

3.4 | Data collection

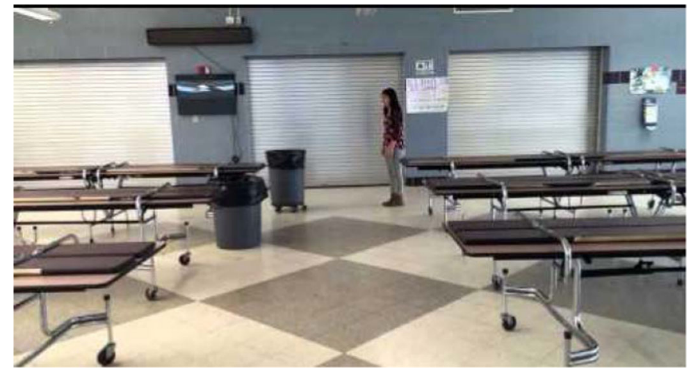
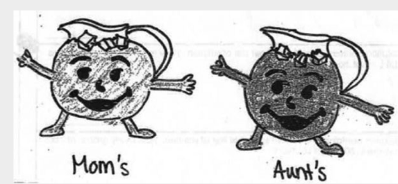
Because we aimed to characterize teachers' FA enactment, we leveraged aspects of Goodwin's (1994) ethnographic method to gather a range of data that would provide different perspectives on Teacher Set C's FA. These data were drawn from teachers' self-interviews about the FA activity, classroom recordings of the activity itself, their comments on portions of the activity, as well as field notes taken by researchers at all PD meetings and anonymous evaluations administered by external evaluators after each workshop. Teacher Set C's FA activities are summarized in Table 2.

Centering on the videos and artifacts, the data set for each teacher was comprised of three streams with specific affordances elaborated below. The FA activity tasks were selected or designed by the teachers. We recognize that the qualities of the tasks themselves can lend the activities more or less toward rich discussion and elicitation of students' ideas, but also depend on how teachers used the tasks.

3.4.1 | Stream 1: teacher's self-interview

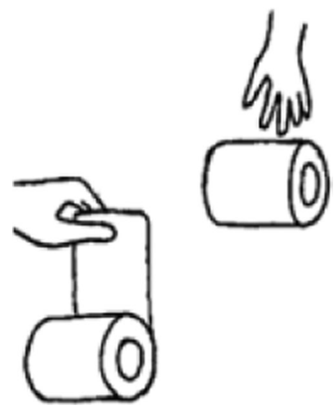
The emphasis of this data stream was each teacher's overall purposes for the FA. In articulating their purposes, teachers produced representations of their work that benefited their reflective practice, as well as our understanding of it (Goodwin, 1994). This activity is well described by Goodwin's third practice for professional vision, namely producing and articulating material representations to make sense of phenomena. This stream helped us compare teachers' intended versus enacted purpose(s) for the science activity (Bartos & Lederman,

TABLE 2 Teacher Set C formative assessment (FA) activities in the videos analyzed

Teacher	Level/subject	Summary of FA, including visuals if included as part of activity
Ares	High school/physics	In a video, students see a girl named Emily pushing a trashcan across the cafeteria and then letting go of it. The trashcan eventually comes to a stop. Students are asked to estimate the force that Emily applies on the can if the mass of the trashcan is 5.0 kg and the height of Emily is 1.600 m. 
Gelos	High school/physics	Students are asked to build any circuit. They must then measure voltage, current, and resistance at each element, then make a change and predict what will happen.
Jupiter	High school/biology	Students answer questions about brain structure and function as related to the specific symptoms of a stroke victim. The stroke victim walks slowly with one-foot dragging, and does not speak but can communicate with facial expressions. Students are asked which foot is affected, where in the brain the stroke may have occurred, and what other symptoms the stroke victim may have.
Khione	High school/chemistry	Students are asked to compare the concentrations in two pitchers of KoolAid, and explain how the KoolAid could have been made with those concentrations. 
Koncordia	Middle school/planetary science	Students are asked to discuss a “Do Now” question: Does someone who is in a different place on Earth see the same moon phase that you see? Explain.

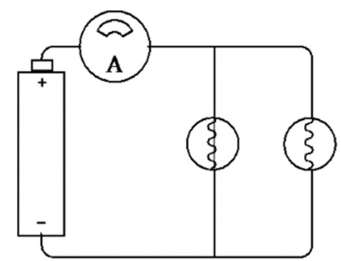
(Continues)

TABLE 2 (Continued)

Teacher	Level/subject	Summary of FA, including visuals if included as part of activity
Lapetus	Elementary school/life science	Students are given a paper with sketches of different stages of the life cycle of a bean plant (five of the eight sketches are shown). They are asked to cut them out and organize them on a paper while describing the life cycle of a bean plant. 
Nike	High school/physics	Students are asked to predict which paper towel roll will hit the ground first. Then they are asked where to drop the rolling paper towel roll so that it hits the ground at the same time as the other roll when dropped from 2 m. 
Paean	Middle school/earth science	Before conducting a lab about the rock cycle, the teacher asks the students to discuss a “Do Now” question: Does the rock cycle affect the mass of the Earth system?

(Continues)

TABLE 2 (Continued)

Teacher	Level/subject	Summary of FA, including visuals if included as part of activity
Terra	High school/physics	Students are asked the rank the ammeter currents in three different circuits and explain their reasoning. One of the circuits (referred to by the teacher as Circuit B) is shown. 

2014). Teachers audio-recorded their responses to six questions, as a self-interview, as soon as they completed their FA video. The first three questions focused on the teacher's goals for the FA (topics students were currently learning, the purpose of the FA, and what the teacher wanted to know about student thinking). The remaining questions asked what the teacher learned from the FA (what went well, what could be improved, what could be the next steps based on what was learned). Audio files from these self-interviews were transcribed for analysis.

3.4.2 | Stream 2: researchers' coding of classroom videos

The emphasis of this data stream was teaching acts in the FA videos. The teachers were asked to video an FA activity in their classroom from their own vantage point. Teachers were provided with harnesses to which their smartphones could attach. Each teacher videoed 10–20 min of FA activity within the flow of a lesson. Videoing began when they introduced the activity, continued as they talked with students, and then ended after they wrapped up the activity. To avoid audio loss, the teachers also placed voice recorders at the tables or lab benches around which consented students were clustered. Teachers also provided researchers with associated student work from consented students, a classroom map with code names of students, and the blank FA task.

Our data analysis method required a triangulation of different sources, including teachers' coding and commenting on their videos. Due to the structure and limited time of the PD, this work could only happen for specific segments, thus we selected two from each teacher's video. To select these segments, we parsed each teacher's entire classroom video into all of its segments. Segments were identified by having a clear beginning and end of a discussion between the teacher and one or more students. Criteria for selecting two segments for analysis included audibility, representativeness of all of the segments in the video, and the presence of disciplinary substance in the discussion. The selected segments (referred to from here forward as clips) ranged from 53 s to 5 min 11 s, with a mean of 3 min 5 s. Auxiliary audio from the separate voice recorders was overlaid as necessary to improve the audio quality of each clip. The full video of each teacher was also transcribed and then summarized in narrative form. These full FA activity narratives, along with the transcripts of the video clips, were compiled for each clip. In total, 18 clips were analyzed, two for each of nine teachers. Using a coding scheme described in the Findings, the researchers coded each clip while keeping in mind the context of the entire FA activity (Goodwin, 1994). As described by Goodwin, researchers coded these videos as a way to systematically classify classroom discourse so as to understand it.

3.4.3 | Stream 3: teachers' reviews of classroom videos

The emphasis of this data stream was what the teachers saw happening during their videos. This stream provided opportunities for teachers' self-reflection and for member checking (Strauss & Corbin, 1997). During a workshop that occurred a few weeks after the teachers submitted their videos, teachers focused on analyzing their own and a few of their colleagues' video clips, commenting on one of their video clips during a workshop, and on their other as homework. By choosing to explain particular utterances in the FA, teachers foregrounded elements of the complex social space of the classroom (Goodwin, 1994), providing us with additional insight into their practice. In this regard, a limitation of the data is that by virtue of the time lag, it is possible teachers engaged in post hoc rationalization of their behaviors.

To facilitate commenting on the videos, teachers' video clips were placed on an online video platform (torshtalent.com) with transcripts and the FA task. Teachers used the commenting feature in this platform to tag significant moments of their choosing with two kinds of information: (a) what they noticed in students' thinking and how they interpreted it, and (b) the intentions behind their teaching acts. We did not provide categories for noticing/interpreting. Examples of teachers' written comments included (a) "Students didn't really know what they were looking for." (b) "I saw Big Boss thinking about relationships (current goes down if resistance goes up and the voltage stays the same)." (c) "Student is unable to name the root, she calls it a stem instead."

We shared our evolving coding scheme of teaching acts, and encouraged modifications and additions if teachers considered their acts to be better represented by something not in the scheme. Examples of codes we provided were *extending* (statement or questioning that extends a student's comment while clearly displaying the teacher's agenda) and *requesting elaboration* (asking a student to justify a statement or propose a mechanism). Examples of teacher-contributed items included *repeat* ("'remind me' as a way to get students to practice communicating again to develop confidence in their message") and *affirm/refute* ("I confirm that D's interpretation of the problem is correct, she continued to move forward in her thinking").

3.5 | Data analysis

3.5.1 | Validation-in-use of the coding scheme

Following a design-based approach (Cobb, Zhao, & Dean, 2009), as well as aspects of grounded theory (Strauss & Corbin, 1997), our process to develop the coding scheme involved several rounds of work among different sets of people (for details, see Sevian & Dini, 2019). We worked from an initial model based on a prior focus group study (Clinchot et al., 2017; Levin et al., 2009; Windschitl, Thompson, & Braaten, 2018), which was strongly influenced by Levin et al. (2009) and the model of Ambitious Science Teaching (Windschitl et al., 2018). This model involves cycles of eliciting, noticing/interpreting, and acting. In considering eliciting, we initially focused on types of questions teachers asked (Chin, 2007; Franke et al., 2009; Oliveira, 2010). To develop an initial set of codes for noticing/interpreting, we began with the study by Talanquer et al. (2015), which distinguished processing student responses in light of canonical correctness (*evaluative*) versus sensible ideas (*inferential*). In considering teachers' actions in the classroom, we first adapted Lineback's (2015) redirections as a preliminary guide for thinking about possible acts.

Together with teacher leaders from Teacher Set A, we first used the coding scheme to analyze their classroom videos, reorganized the scheme, and then retested it with the same group using more videos. In this phase, the team agreed that the acting portion of the coding scheme was easier to use because teaching acts could be identified in videos, while noticing/interpreting had to be inferred. As we discussed the videos, we recognized that (a) teachers have multiple purposes during FA enactment that depend not only on the goals for all students' learning, but also on specific goals for individual students that refer to prior knowledge about the students, and (b) creating narrated accounts, or vignettes, of the FA enactment that capture this information—explicitly in the comments teachers provide and implicit in what they do—is useful to characterizing a teacher's FA enactment. After this, the vignettes of each video clip were drawn from the three data streams and field notes.

The acting portion of the coding scheme was then tested with teachers in Teacher Set B during an all-day retreat. In one pivotal exercise, the science teacher leaders experienced, as if students, two lessons about electrochemistry, a science topic that few teachers knew well. Two entertaining lessons were taught with the extremes of acting (directive vs. responsive). The teachers defined one lesson (the *directive* one) in terms of student "passivity" and being "fed information" in a scaffolded manner that was "interactive and engaging" (learner experience), and students as "passengers on the teacher's ship" (teacher's experience). They defined the other lesson (the *responsive* one) as "loud and argumentative" with students "relying on themselves and their peers" which could be "frustrating" (learner experience), with the teacher offering questions, "repeating what students said," and "guiding and facilitating" with "less scaffolding" (teacher's experience; Field Notes, 3/10/2017). We realized that the effects of the teachers' acts on the students help both the teacher and researcher understand the act better and ultimately characterize it more completely.

Sometimes a teacher elicited in indirect ways and it was not clear what question lay underneath a teacher's utterance (e.g., I don't understand what you mean by…), even though the teacher clearly indicated intent to learn more. This made it difficult to apply categorizations of teacher questioning from the literature. For example, teachers narrated students' individual work to challenge them to add information (e.g., when Nike noted a method switch evident on a student whiteboard—"Oh, so you switched from torque to energy"—and she wanted to find out why students had switched methods), or narrated discussion among students as it progressed (e.g., when Jupiter said, "So he doesn't think spinal cord now"). For these reasons, we found it more productive to separate teachers' actions into two types: *eliciting* and *advancing*, which led us to a revised model of FA enactment in which noticing/interpreting is followed by acting either to elicit or to advance.

The revised coding scheme was then used by teachers in Teacher Set C to analyze their classroom videos during two half-day workshops. In the process, researchers took notes during extensive conversations with teachers about the structure of FA enactment and teaching purposes driving this.

3.5.2 | Use of the data streams in a defined process

Following the back-and-forth design approach (Cobb et al., 2009), the authors continued the work of stabilizing and refining the coding scheme. We applied the scheme to the first half of the data (one of two video clips from each of the nine teachers). During this phase, four researchers independently analyzed each of the nine video clips following a well-defined process. The process involved evaluating the FA task in terms of its accessibility to students and the degree to which it reveals student thinking. Using this as context to better understand the teacher's perspective in the dialogue among students and the teacher, the researcher then looked at the teacher's pre-post FA reflection responses to identify the teacher's intended purpose for the FA, and watched the clip with the transcript and related student work. At first, the researcher attempted to characterize the noticing/interpreting aspect of each act. However, we judged these characterizations to be too fraught with uncertainty. We recognized that noticing/interpreting is largely an implicit process, as discussed in the Literature Review, and, therefore, considered that there were insufficient data to confidently characterize the noticing/interpreting behind each individual teaching act.

We modified this approach to consider the main focus of the noticing/interpreting for sets of teaching acts rather individual ones, because collectively across all streams of data in a clip, there was sufficient evidence for inferring this. This analysis proceeded by forming an initial account of what the teacher may have noticed in the clip and how the teacher appeared to be interpreting it. The researcher then coded teacher utterances while referring back to the clip, student work, and pre-post FA reflections as necessary, keeping in mind what was coherent in the noticing/interpreting inferred about a set of teaching acts. The researcher finally examined how the *teacher* characterized his or her acts and noted what the teacher thought motivated them. In sum, by using the three streams of data in a coordinated way, we could confidently characterize the major focus of noticing/interpreting across the set of teaching acts in a clip.

The outcomes of these analyses were discussed among the researchers, and any disagreements were reconsidered in light of the three data streams until reaching consensus. Understanding nuanced interaction dynamics required close reading of the transcripts in light of teachers' Stream 3 comments, as well as employing aspects of conversations analysis (Schegloff, 1992)—paying attention to tone of voice and verbal emphasis of the teacher and students, and facial expressions and gestures of the students in the clip.

Before completing the coding of the first nine clips in this manner, the existing elements in the coding scheme stabilized and no new elements emerged. Two researchers then set off on a second phase, continuing to analyze each teacher's second clip in the same stepwise manner, and compiling the results with the summaries from the first clips. Throughout both phases of this process, we convened eight data analysis meetings with five researchers not involved in the project. They analyzed eight video clips using the same methods, allowing us to develop a form of construct validity as we aimed for a consistent operationalization of the constructs in our coding scheme (Dalgety, Coll, & Jones, 2003).

4 | FINDINGS

We developed and tested a coding scheme on nine teachers' (Teacher Set C) classroom videos (Stream 2) in coordination with the teachers' self-interviews (Stream 1), their own analyses of their videos (Stream 3), and associated artifacts provided by the teachers. Here, we report on emergent themes relevant to our three research questions.

4.1 | Different ways each element of FA is enacted

Our goal was to create a useful analytical tool for teachers that would not be overly complex for teachers to use in reflecting on their practice. Thus, we characterized each element of FA enactment as being more similar to one of the two extremes of manifestation of that element. Specifically, we holistically characterized the noticing/interpreting aspect of an entire clip as being more *evaluative* or *inferential*. We characterized particular teaching acts within a clip as eliciting that is more *narrow* or *open*, or advancing that is more *directive* or *responsive*. To make these determinations, we considered whether the classroom discourse was more authoritative or dialogic (Mortimer & Scott, 2003), respectively, in particular referring to whose point of view was in dialogue. A univocal view (Wertsch, 1991) of the scientific perspective corresponded to authoritative, while a multivocal view in which more than one perspective was actively in dialogue corresponded to dialogic. In what follows, we provide evidence for these characterizations. It is noteworthy that the vast majority of teacher utterances were straightforwardly categorized and representative of the examples given. Examples of utterances that were somewhat difficult to code are also discussed. The final coding scheme is presented in Table 3 and provides specific instantiations of the scheme.

4.1.1 | Noticing and interpreting

Teachers entered interactions with students by noticing and interpreting their thinking, either prompted by an initial question or after observing students' discussions or work. Teachers' comments (Stream 3) helped us interpret classroom dynamics and teachers' noticing/interpreting. Consider, for example, the excerpt shown in Table 4 (*in italics are the teacher's comments on acts he deemed significant to comment on*) from teacher Ares and a group of students who were tasked with calculating the force exerted by a student pushing a rolling trashcan. Students had to measure distances and times to calculate accelerations, from which they could infer forces using Newton's second law. Goodwin's (1994) conventions were followed for transcription markings.

At the beginning of this interaction, Ares expresses confusion about the students' discussion of a single net force. He focuses on the fact that there are two-time intervals to consider in the problem, and his initial questions (Turns 4, 6, and 8) allude to this. However, the students hold to their point of view that specifying a total force is sufficient. Ares' teacher notes (associated with Turns 8, 10, 12, 18, and 20) affirm that he sees the students' position as problematic, needing to be corrected, and the sad-face emoji he inserted also expresses this. Ares' takes an evaluative approach to noticing/interpreting in this exchange, focusing on the canonical correctness of the students' ideas, which continues through the remainder of the video clip. Evidence for this approach lies in the

TABLE 3 Coding scheme to characterize teachers' classroom formative assessment videos

Element of FA enactment	More narrow/evaluative/directive	More open/inferential/responsive
Teacher eliciting	*Narrow* approach: questioning students to find out their thinking over a restricted space of possible ideas, e.g.: • *Detailing*. Teacher wants to find out how a student thinks about a particular detail (e.g., vocabulary word, variable in an equation). • *Distilling*. Teacher reduces the complexity of a problem for a student by focusing attention and wanting to know about one aspect. • *Corroborating*. Teacher checks with other students to see if they had the same answer. • *Re-focusing*. Teacher reasks a question because student(s) did not answer in the manner expected.	*Open* approach: questioning students to find out their thinking over an open space of possible ideas, e.g.: • *Clarifying*. Teacher checks for meaning or gives space for the student to provide more details about their assumptions by asking a clarifying question. • *Reflecting back*. Teacher summarizes student utterance so that student continues to build ideas. • *Considering*. Teacher rebroadcasts a student's question, asking other student(s) to discuss it.
Teacher noticing and interpreting	*Evaluative* approach: processing students' responses in light of canonical science, e.g.: • *Judgment*. Teacher categorizes students' responses as correct or incorrect, matching to a baseline answer (e.g., looking for specific usage of vocabulary). • *Misconceptions*. Teacher anticipates or recognizes particular common errors or misconceptions in students' thinking. • *Gaps*. Teacher identifies gaps in understanding that need to be filled. • *Projection*. Teacher interprets what student says through the lens of the science story.	*Inferential* approach: focusing on the sensibility of students' responses toward building on the students' ideas, e.g.: • *Assumptions*. Teacher identifies underlying assumptions driving students' thinking. • *Experience-mapping*. Teacher recognizes students' mapping an individual experience to explanation, and vice versa. • *Inconsistency*. Teacher identifies an inconsistency in a specific student's reasoning. • *Specific confusion*. Teacher recognizes student confusion. • *Cross-purposes*. Teacher recognizes that two or more students are talking about different issues. • *Affect*. Teacher recognizes students' emotion as an important factor to attend to.
Teacher advancing	*Directive* approach: guiding students down particular lines of reasoning or toward particular ideas through authoritative discourse, e.g.: • *Pulling*. Teacher asks a question or makes a statement that moves the student toward the teacher's line of thinking. • *Diagnosing*. Teacher asks a question to make visible to the student a deficit or mistake student(s) in students' thinking. • *Tracking*. Teacher gives feedback, often with inflection or gesture that student is	*Responsive* approach: creating opportunities for students to argue, to reason through various possibilities for themselves, to compare options, and to reflect on their own thinking, e.g.: • *Recentering*. Based on what the teacher has seen to that point, teacher orients students' attention to a common question to push their inquiry forward. • *Elaborating*. Teacher prompts students to: propose or elaborate a mechanism for their explanation(s); justify their claim(s)

(Continues)

TABLE 3 (Continued)

Element of FA enactment	More narrow/evaluative/directive	More open/inferential/responsive
	on the right track or not, or arrived at the correct answer (usually involves repeating student statement or a substitute for it). • *Explaining* (*delivering*). Explaining a topic, filling a gap in understanding, or providing an answer that does not necessarily build from a student utterance. • *Rhetorical questioning.* Teacher asks a question such that the asking of it provides clear clues to the answer.	or provide evidence to support them; describe the effect(s) of an action; connect to another idea; assess the merits and shortcomings of an explanation(s). • *Acknowledging refinement.* Teacher communicates that students have made specific progress in their inquiry and/or invites students to characterize that progress. • *Reflecting.* Teacher gives student space to think through a question or problem. • *Drawing out.* Teacher encourages students to continue providing their thinking.

TABLE 4 Exchange among Ares and several students

Turn	Speaker	Utterance	Teacher's comments
1	Camera	[[DarkHair]] had a question.	
2	DarkHair	OK, so we ***got*** the force net, but we don't have anything else though.	
3	Redhead	We have the force net.	
4	Ares	What do you mean you got the force net?	*Asked for clarification on what they mean by force net.*
5	DarkHair	Is 1.6.	
6	Ares	Which one? For which part?	
7	DarkHair	Total.	
8	Ares	What do you mean, total?	*Total force net? What is the difference between total force net and force net? This comment indicates students had difficulty breaking the motion up into two parts. I asked for clarification on what students meant by "force total."*
9	Redhead	The whole force net for her, for just her. Because we want the F-push, but the push isn't going to be happening whenever she let's go, so we only know that the force net is the force push minus the force normal—friction, friction, yeah.	
10	Ares	Okay.	*She is talking about the force net for Emily when she really needs to focus on the trashcan. Understands that at some point the net force equals the force push minus the friction force.*
11	Redhead	Yeah, but we can't get the force push, because usually we're given like u thingy ((uses finger to trace a mu in the air)). Yeah, we don't have that.	
12	Ares	Then how'd you get the 1.6?	*Asked students how they got the 1.6 value. Describe their mechanism for getting this number.*

(Continues)

TABLE 4 (Continued)

Turn	Speaker	Utterance	Teacher's comments
13	DarkHair	So=	
14	Glasses	F-net is mass times acceleration.	
15	DarkHair	So we found the speed of both, right? Of her pushing the box ((pointing to paper)), of her=	
16	Ares	((points to paper and nods to confirm what DarkHair says))	
17	DarkHair	Yeah, and now like she let go and it would be going the speed of her hand afterwards, right? Then we would figure out the acceleration, right? ((laughing with excitement))	
18	Ares	Wait, acceleration from which part?	
19	DarkHair	From here to here ((points to paper)).	
20	Ares	You have two different intervals, right?	*Clarifying, trying to find out which interval. I am leading them toward understanding the two types of motion of the trashcan)-: I want them to clarify what acceleration they are talking about.*

authoritative discourse patterns evident in the enactment: Ares positions himself as the authority wanting to facilitate an immediate shift in their approach to the problem.

In contrast, the following excerpt from teacher Khione and two students (in Table 5) demonstrates inferential noticing/interpreting, that is, treating student utterances as sensible beginnings for problem-solving. The exchange takes place during a whole-class discussion near the end of the FA that has students comparing KoolAid concentrations.

Khione's teacher comments associated with Turns 2, 4, 6, and 8 show how she notices and interprets the substance in Mookie's and Chinoo's thinking that some water must have evaporated to account for the darker color in one of the pitchers. While the students' utterances are possible correct responses in the FA, it is still evident that Khione did not anticipate the response (Turn 4) and processes the ideas as sensible. The dialogic discourse patterns are indicative of Khione's inferential approach to noticing/interpreting.

4.1.2 | Eliciting acts

After noticing/interpreting, the teacher either acts to elicit or to advance student thinking. In eliciting acts, a teacher seeks to find out more about what a student knows and thinks. Consider, for example, teacher Lapetus' eliciting act in Turn 4, as he asked a student, Beautiful, about her sequencing of images in the life cycle of a bean plant.

1. Beautiful: First we start with the bean, then the bean is growing, and there's a little=
2. Lapetus: A little what?
3. Beautiful: A little part of the bean coming out.
4. Lapetus: Okay. Do you know what that part is called, by any chance?

Lapetus wants to know if Beautiful knows the name of the part of the plant she refers to. He specifically probes whether the student knows a fact. In this sense, it is univocal (referring to canonical science) and fairly restrictive in the possible space of responses from Beautiful.

TABLE 5 Exchange among Khione and two students

Turn	Speaker	Utterance	Teacher's comments
1	Mookie	We came to the conclusion that some of the water in your aunt's KoolAid evaporated, making the concentration higher if they used the same amount of powder and water.	
2	Khione	So if they had originally started and some of my aunt's evaporated. Yeah that would make sense because then there would be a…	*Mookie thought of an alternative explanation where both mixture were made the same and the water leaving the mixture is what made the ratio of KoolAid: Water higher. I repeated the student's answer and asked them to restate it by the pause and questioning inflection in my voice. I wanted to make sure they understood what they were saying about the ratio.*
3	Chinoo	Less water, more powder.	
4	Khione	Okay. That's…I didn't even think of that. How about if we're not even…if Mom didn't make it from the powder stage. How about ***that***?	*Chinoo is showing that they understand the ratio concept as a determination of concentration. This is the next scenario that I want them to think about, to get them to add to the possible ways of changing the concentration of the mixture.*
5	Mookie	She didn't make it from the powder stage?	
6	Khione	Yeah.	
7	Mookie	What do you mean?	
8	Khione	Well, I don't ***know***!?	*Mookie was trying to understand another possible scenario but not with making KoolAid from powder. Not in our coding scheme: I was redefining the new question for the student, and then opening it up to the students to think about by gesturing to have them discuss it as a group and saying, "I don't know."*

As a contrasting case, consider the following exchange between teacher Terra and student D1910, who is trying to understand the difference between parallel and series circuits by comparing the behavior of the three circuits, one of which is shown in Table 2:

1. D1910: Doesn't the current equal each other when it's parallel ((referring to the two branches after the ammeter in current B))?
2. Terra: So you're saying the current here equals the current here ((pointing to the two branches after the ammeter in current B)).
3. D1910: Yeah.
4. Terra: Okay. And then if you wanted to compare that current ((in circuit B)) to this current ((in circuit C)), what would you get? How would you do that?

In Turn 2, Terra checks her understanding of what D1910 says about the currents being equal in the two branches of Circuit B. Having established this, she tries to find out how the student might compare Circuits B and C. Compared to the kind of question Lapetus asks Beautiful, Terra's question is much more open-ended, admitting many possible responses (multivocal), and quite a bit more dialogic in the forms of discussion that might ensue.

In our data, we found it useful to describe eliciting acts as more *narrow* or *open*. Narrow eliciting constricts the space of possible responses, while open eliciting widens the space of ideas that can be shared. A teacher's probes can be targeted to draw out specific ideas (narrow), which would reflect their control over the conversation (authoritative and univocal in the science perspective), or allow for a broader sharing (open), that is, conducive to more open exchanges (dialogic and multivocal in including several views). Distinguishing between narrow and open eliciting was the easiest coding category to implement. However, there were instances in which it was difficult to distinguish between narrow eliciting/directive advancing or open eliciting/responsive advancing. This ambiguity is discussed after the advancing section.

4.1.3 | Advancing acts

In contrast to eliciting acts in which teachers seek to learn more about how students are thinking or solving problems, teachers' advancing acts are meant to move students toward particular learning goals, by developing students' understanding using their own or others' ideas. We see this happening in the following example in which a teacher, Paean, elaborates his definition of "Earth system":

1. Students: Yes.
2. Paean: Yes. Okay so, Danny, I think what you were saying was pretty spot on. It's the Earth ((links fingers together)) and everything that encompasses the Earth ((breaks links and makes arcs outward with hands)) but nothing outside of what we would define as Earth.
3. Student 2: Yeah.
4. Paean: So it's not ***just*** the terrestrial land that we're on right now. It's the water, it's the air ((waves hands)), it's everything that we define as Earth ((motions a sphere with hands)). Does that make sense?

Paean has positioned himself as the authority, evaluating as correct what a student, Danny, has explained before this excerpted exchange (Turn 2). Paean provides additional details in his explanation to supplement what Danny has already contributed (Turn 4). In this way, Paean guides students toward specific ideas through instructional discourse (directive), involving gesturing and prosody, and the discussion is marked by authoritative discourse.

A contrasting example of how a teacher advances is evident in the following exchange in which teacher Khione responds to student BDDPT's explanation about what could have happened to the concentration of a KoolAid drink made by Khione's aunt:

1. BDDPT: Since your aunt made it better in the summertime, the sun is going to evaporate the water [...] it's not a combined mixture, so it can be separated so the solvent can get evaporated, which lowers the volume of that, which now increases the concentration of the solute that's in the liquid.
2. Khione: Okay so my aunt's gets redder and redder and redder, and then my mom goes and makes some that would have looked the same but now it doesn't.
3. BDDPT: Yeah, because there's an equal amount of solute in the solvent, which really balances out because there's more solute in solvent than there originally was.
4. Khione: Than it originally was, so ***over*** time something would have happened to it. ***That*** could be.

In Turns 2 and 4, Khione works to interpret and follow BDDPT's idea that the concentration of the aunt's beverage could be the same as the one produced by Khione's mother. She affirms as plausible his reasoning that the solvent could evaporate, leading to a higher concentration. Khione strives to make sense of the reasoning, empowering the student to articulate his idea (responsive). The discourse is dialogic in character.

There were a few instances that did not cleanly fall into a directive or responsive advancing, and for these, we consulted and came to an agreement. For example, consider the continuation of the dialogue between Terra and

D1910, after Terra briefly turned to a different student and then returned to her exchange with D1910 (continued from Section 4.1.2, Eliciting acts, above and in reference to the circuit diagram in Table 2):

10. D1910: But the voltage is the same. But it splits, cause it branches off, and then it split right here.
11. Terra: What splits? Voltage or current?
12. D1910: The current.
13. Terra: Okay. So the voltage is the same in each branch, but the current splits?

One interpretation of what Terra is doing in Turn 13 is that she is listening to her student's thinking and summarizing her understanding in the form of a clarifying question that acknowledges her attention to that thinking to help the student commit to a description. Thus, the utterance could be viewed as responsive advancing. However, Terra's comment on her teaching act was "Rephrases what was said to identify that D is on the right track." This informs us that Terra saw this as a directive advancing act because her intentions were to push the student in the right direction. She is sense-making alongside the student, revoicing the student's reasoning in a way that tracks toward the correct idea. In this light, the act could be directive advancing. The ambiguity arises as a feature of the perspective, whether from the student's or teachers' points of view. The next few turns also allow us to see whose sense-making becomes central to the exchange:

14. D1910: Yeah.
15. Terra: So what does that tell you about which one has more current?
16. D1910: A has more.
17. Terra: Why does A have more current?

Thus, Terra's intentions behind her teaching act in Turn 13, as indicated in her comment, are corroborated by the direction Terra took the exchange, that is, toward the teacher doing more of the sense-making by using directive advancing acts. In situations where we recognized both dialogic and authoritative aspects in a teaching act, we resolved these by considering Stream 3 (the teacher's comments) in the context of the direction that the exchange took.

In sum, we describe advancing acts as more directive or responsive. Directive advancing uses authoritative discourse that guides students toward particular ideas (univocal), while responsive advancing uses dialogic discourse that creates opportunities for students to discuss and think about their ideas (multivocal).

4.1.4 | Ambiguity in determining eliciting versus advancing

Not all teaching acts are eliciting or advancing acts. For example, some are related to classroom management. However, there was occasionally ambiguity in coding teaching acts as eliciting or advancing, even when it was clear that the act was related to the ideas in play. Consider again Terra's Turn 4 in Section 4.1.2, Eliciting acts. At that moment, she may not only have intended to learn about D1910's understanding of current, but also to have advanced it by implicitly requesting that D1910 provides reasoning to justify her thinking. Such a request reinforces D1910's engagement in the doing of science (in this case, generating evidence-based arguments), which might expand our notion of advancing beyond attempts at imparting content knowledge. In this sense, such a question can play a dual role of informing the teacher about a student's ideas *and* advancing the student's understanding of the scientific practice.

Without knowing more about Terra's explicit intentions in asking the question in Turn 4, it is difficult to say with certainty whether she is trying to advance student thinking or find out more about it. It is methodologically more appropriate to say that Terra's question is at least trying to discover something about what her student is thinking.

Sometimes, coding a teaching act as narrow/directive or open/responsive requires knowing more about the teachers' intention, which can be hidden. In these cases, data Stream 3 was particularly helpful to the data analysis.

4.1.5 | Summary of eliciting and advancing

There was a range of teachers' eliciting acts (narrow vs. open) and advancing acts (directive vs. responsive). Overall, 35% (89/254) of teachers' utterances were classified as eliciting acts and 47% (120/254) were advancing acts. The rest of their utterances were either related to classroom management or were short comments (e.g., "Okay" or "Mmhm"). Taking into consideration both of the video clips coded for each teacher, a view of the proportion of each teacher's narrow-to-open eliciting and directive-to-responsive advancing acts is seen in Figure 1. Teachers' positions in each dimension were normalized as the difference in the types of acts per total acts, such that each position ranged from −1.0 (narrow eliciting or directive advancing) to +1.0 (open eliciting or responsive advancing). Two teachers (Ares and Gelos) exhibited the only directive advancing acts, and one teacher (Koncordia) demonstrated only open eliciting, but other than these cases, all teachers had both narrow and open eliciting acts, as well as both directive and responsive advancing acts.

We coded the main focus of the teacher's noticing/interpreting in each video clip, as explained in Section 4, while we coded individual teaching acts within each clip. During their interactions with students, teachers elicited and advanced in many different ways along an authoritative to dialogic spectrum. We wondered what was driving these actions, thus toward our third research question, we explored more deeply the teachers' in-the-moment purposes. We began by looking at the most common patterns of acting in each video clip.

4.1.6 | Common patterns in how elements of FA were enacted

We organized vignettes of the videos into teachers' most frequent types of eliciting and advancing acts, along with the type of noticing/interpreting focuses they took. Then from this arrangement, we examined similarities and differences.

The most common combination of approaches was evaluative noticing/interpreting, open eliciting, and directive advancing. The majority of teachers (five of nine) demonstrated this combination. Teachers' acts unfolded in several ways. Most commonly, a sequence of advancing acts was aimed at correcting an error to help students efficiently solve a problem, such as that of Ares in Table 4. Some teachers responded to student ideas as irrelevant or to an

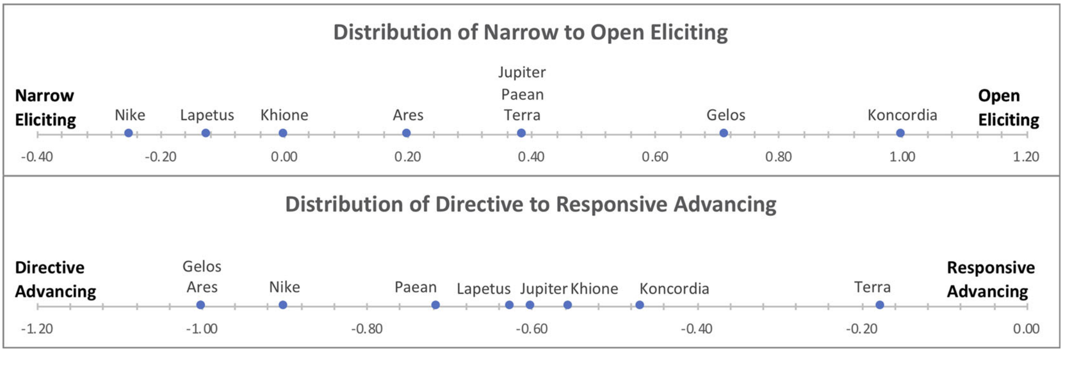


FIGURE 1 Positions of teachers in Set C in the possibility spaces of teaching acts that were eliciting (narrow to open) and advancing (directive to responsive) [Color figure can be viewed at wileyonlinelibrary.com]

explanation as insufficient. For example, Koncordia asked students to describe and justify why people around the world see the same phase of the moon, and then registered students' contributions as falling short of her desired explanation. She used repeated open eliciting by posing different versions of the same question. These teachers saw their role as imparting canonical knowledge and the students' role as learning what is correct. When viewing similar videos as a large group during PD, teachers said that, although this "feels scripted and intentional," students are also "left with concrete connections" (Field Notes, 3/26/2017).

A second set also included evaluative noticing/interpreting and directive advancing, and had narrow instead of open eliciting (three of nine). These teachers made choices to lead students toward knowledge deemed necessary to solve a larger problem. For example, Terra (in Clip 2) recognized that a group of students needed to overcome a hurdle of calculating the resistance of a circuit to investigate the predicted behavior of the current. She used narrow eliciting questions to find out if they remembered the equation to take that step, then a series of directive advancing questions to lead them through reasoning about an aspect of the current's behavior. Having revisited this prerequisite knowledge, she asked them to reconsider their original question. Terra's hope for her students' success influenced her use of many narrow eliciting questions. Generally, teachers who expressed that they wanted their students to successfully complete the FA did more narrow eliciting. This was consistent with teachers' comments during the PD: "students were more at ease with the concept" when it was "provided by the teacher" (Field Notes, 3/26/2017).

Terra was also the only teacher with mostly inferential noticing/interpreting combined with more open eliciting and a balance of directive and responsive advancing. Rather than learning *whether* students could reason through a solution, she described being interested in *how* students reasoned toward a solution. In her Clip 1, she first elicited students' ideas, then tried to advance the students' thinking directively (as in the example just above), but toward the end, she saw that they came to incorrect conclusions. She decided to ask the students to perform a calculation that they would then cross-check with their conceptual understanding. Terra saw her students as capable of working through the inconsistency that would arise. Terra was also the only teacher in our data set who allowed noncanonical ideas to linger.

4.2 | A model of FA enactment

Following the validation-in-use described in Section 4, the development of the coding scheme enabled us to create a representation of FA enactment cycles shown in Figure 2.

The main difference from prior models is the centrality of noticing/interpreting in FA enactment in science education, much as Sherin et al. (2011) argue in their work in mathematics education. We saw that the FA enactment in video clips, which were interactions among the teacher and students with clear beginning and end points, began in one of two ways: the teacher either entered by listening and noticing something and then acting, or by immediately asking an eliciting question to generate a response on which to base noticing. The teacher engaged in noticing/interpreting in between most teaching acts.

The video clips reflect many nonlinear sequences in which noticing/interpreting was followed by either eliciting or advancing, then noticing/interpreting occurred again, followed by either eliciting or advancing, and so forth. The cyclic nature of FA is in line with what others have shown (Cowie & Bell, 1999; Ruiz-Primo & Furtak, 2007). Our model of FA enactment has hidden complexity in how it is able to represent multiple paths of interaction.

4.3 | In-the-moment teaching purposes influencing FA enactment

As others have discussed (Cowie & Bell, 1999; Schoenfeld, 1998), teachers have goals for their FAs, and there also are more immediate influences on these goals that shape how teachers enact FA, which we will refer to as *in-the-moment* purposes, to emphasize that they have more specific influences than the overarching goals the

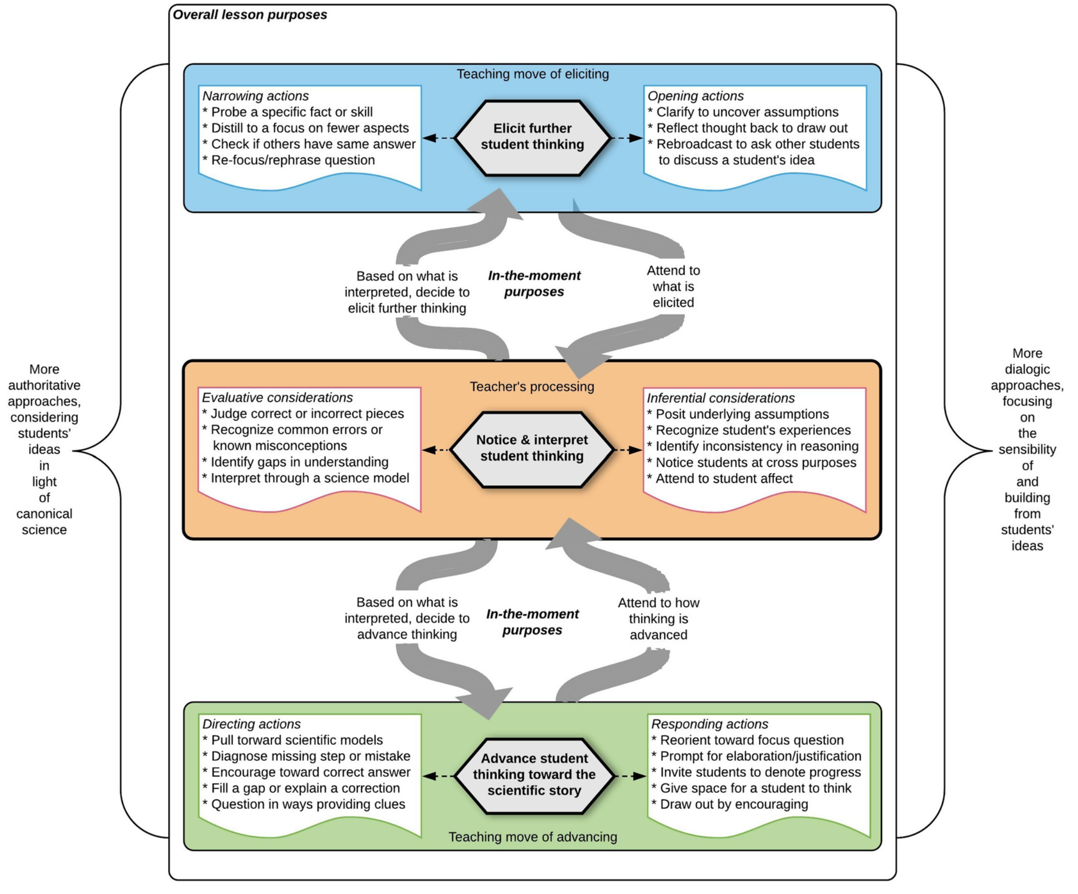


FIGURE 2 Model of FA enactment [Color figure can be viewed at wileyonlinelibrary.com]

teacher expressed for the FA. A summary of teachers' overarching FA goals from our analyses of the three data streams is provided in Table 6. The table shows that two teachers looked for students to communicate specific explanations: Khione was interested to learn the ideas her students could express about how to change the concentration of a solution, and Koncordia was interested in knowing if students could explain why everyone in the world sees the same moon phase. Other teachers, including Ares, Jupiter, Nike, Paean, and Terra, were interested in knowing whether their students understood and could apply key scientific ideas to solve specific problems. Finally, Lapetus was interested in learning what his students knew about the life cycle of the bean plant, and Gelos wanted to see where his students were in their content understanding, as well as how they were engaging in the practices of science. These stated goals sometimes manifested without additional in-the-moment purposes during specific interactions with students, sometimes they were blended with in-the-moment purposes to create combinations of purposes, and still other times they were backgrounded.

4.3.1 | Contextual factors influencing in-the-moment purposes

How teachers enacted FA depended on contextual factors that contributed to teachers forming in-the-moment purposes. Consider, for example, the following vignette, drawn from across the three data streams:

TABLE 6 Summary of findings in the three data streams

Teacher	Stream 1: teacher's self-interview	Stream 2: classroom video analysis	Stream 3: teacher's video review (representative examples)
Ares	See if students can measure physical quantities in a "real-world" context and successfully use them in Newton's 2nd law to solve a problem.	Check for and remediate student difficulties.	Clip 1: students do not recognize two intervals to separately analyze in the motion of the cart; Clip 2: students use wrong "tools" to solve the problem.
Gelos	Check where students are in their work, and in that process, see how they are understanding content or experiencing the doing of science.	Check for understanding of particular ideas and their relationship to scientific measurement.	Clip 1: student incorrectly thinks of battery voltage as oscillating; Clip 2: student correctly discusses effects of varying light bulbs on current.
Jupiter	See if students understand that different parts of the brain control different motor functions, and use that idea to infer impairment based on a stroke victim's symptoms.	See if students can make the right claims from available evidence.	Clip 1: student incorrectly thinks that stroke affects leading leg and could involve spinal injury; Clip 2: student thinks stroke is in left temporal lobe.
Khione	See if students correctly use vocabulary related to concentration and if they can think of the two ways of changing concentration.	See if students understand particular ideas and use vocabulary correctly.	Clip 1: student incorrectly considers brewing in this context, while another correctly identifies adding water as changing concentration; Clip 2: student proposes less water can account for color change, while others make correct statements.
Koncordia	See if students can explain why everyone in the world sees the same phases of the Moon.	See if students understand particular ideas. Drives them toward an answer (that is canonically incorrect).	Clips 1 and 2: students' reasoning does not correspond to the correct explanation that should involve "perspective."
Lapetus	See what students know about the life cycle of a bean plant by interpreting and sequencing its different stages, with special attention to the flowering stage that facilitates reproduction.	See if the students can name the different phases of the life cycle and order them correctly.	No comments in Clip 1; Clip 2: student incorrectly characterizes a root as stem.
Nike	See where students are in their thinking about rolling and if they can apply ideas about rotation to solve a problem.	Help students to reason through a solution.	Clip 1: students incorrectly calculate moment of inertia; Clip 2: students do not identify the pivot point, the force causing the torque, and the lever arm for torque.
Paean	See if students can apply the law of conservation of mass to systems undergoing physical change.	Check if students understand vocabulary terms (Clip 1); see how students understand particular ideas (Clip 2).	Clip 1: students' descriptions of system, mass, and density fall short; Clip 2: student discusses physical changes in rock cycle; student understanding useful to the extent that it connects to conservation of mass.

(Continues)

TABLE 6 (Continued)

Teacher	Stream 1: teacher's self-interview	Stream 2: classroom video analysis	Stream 3: teacher's video review (representative examples)
Terra	See if students remember and can apply circuit rules and their understanding of current, voltage and resistance to conceptual questions.	Check to see how students reason through to a solution.	Clip 1: student reasoning around current has underlying sense to be explored; a few student conclusions are either correct or incorrect; Clip 2: student approach to compare resistances could be productive; students make calculation errors.

> Khione approaches a group of four students as they are working on identifying different ways that the Mom and Aunt could have made KoolAid with different concentrations. After Mookie points out that the Aunt could have used more KoolAid powder than the Mom did, Espee suggests that instead the Aunt could have cold-brewed it, and the other students acknowledge that this could be. Seeking a definition of cold-brew, Khione asks what Espee means by "cold." Espee replies that it tastes stronger. Mookie asks, "What about the stronger red color?" and Khione quickly adds "Mmhm" to indicate that Mookie is asking the right question. Espee replies that this is concentration, and Mookie then agrees that this makes sense. Khione realizes that Espee has now succeeded in getting the group off course. Khione is frustrated with Espee's months-long obsession with cold-brew coffee and her insistence in viewing cold-brew as relevant to whatever she is learning in chemistry. Khione speaks loudly and clearly, explaining that brewing is a steeping process, in which the steeping gets the caffeine and coffee color out of the coffee grounds. As Khione starts to contrast this with making KoolAid, Mookie smiles and interrupts to say it would be nice to have some coffee right now. Khione raises her voice and speaks over him, stating that making KoolAid and brewing are not the same process. Mookie gets the point, and speaks the answer that Khione is looking for: "Her aunt has used more KoolAid powder, so it has a higher concentration." Khione repeats this in her own words as a way of asking whether she understands him accurately.

Khione's mounting frustration with Espee tipped her into an evaluative noticing/interpreting stance, which Mookie may have abetted by playing with her emotions in interrupting her. Khione subsequently directively advanced the students' thinking by explaining how brewing works, then guided the students to focus on mixing. Khione's exasperation over Espee's fascination with cold-brew shaped her purpose both in noticing/interpreting (Espee does not understand the difference between extracting via brewing and dissolving solute in solvent, and the other students take this up), and in Khione's choice of acting (advancing directively by explaining the difference so the students would see why Espee's conflation of these is wrong).

Khione's in-the-moment purpose was to correct a content error (a conflation of brewing and mixing). This purpose related to her overall FA goal of getting her students to express how two variables (solute and solvent amounts) affect solution concentration, but it was specific to the particular interaction where she perceived an obstacle in the students' learning path. Khione's evaluative stance was influenced by her frustration with Espee's enduring obsession with cold-brew and her sense of equity in caring for the other students' learning. Had Khione's stance been more influenced by something else (e.g., a conviction that science is about autonomy in sense-making), she might have had a different in-the-moment purpose (e.g., wanting students to argue out their differences, leveraging students' personal interests such as cold-brew, or desiring students to connect mechanisms and variables that influence them). She might then have noticed/interpreted something different (e.g., that Mookie and

Espee had different ideas of how KoolAid gets to be more concentrated) and exercised a different act aligned with a different in-the-moment purpose (e.g., an eliciting act of pointing out that they had different ideas and challenging them to identify what was different, or an advancing act of asking each to explain how the KoolAid became more concentrated). In summary, various contextual factors influenced teachers' in-the-moment purposes, which, in turn, shaped their enactment of FA as evidenced in their noticing/interpreting and acting.

4.3.2 | Patterns of in-the-moment purposes

Different contextual factors shaped what the teachers paid attention to, how they interpreted what they noticed, and whether and how they acted to elicit or advance based on their interpretations. To look for patterns, we examined the data to identify types of in-the-moment purposes influenced by common contextual factors. We observed three broad categories of in-the-moment purposes: developing students' content understanding, attending to students' learning processes, and nurturing students' positive qualities and attitudes.

With respect to developing students' content understanding, teachers intended to confront particular obstacles to learning specific content, probe the depth of conceptual understanding, and promote connections among concepts and procedures. For example, as in the vignette of Khione's FA above, Ares and Gelos focused on particular errors made by students and then remedied these with quick fixes. Other teachers (Jupiter, Koncordia, Lapetus, Nike, and Paean) also noticed errors and then prompted students to explain their thinking. For example, Koncordia posed a question and listened for specific misconceptions. When she identified a misconception, she began drilling with open eliciting acts to expose why the student had that misconception. Some teachers advanced more responsively under such circumstances. For example, after gently eliciting a student's thinking to understand her plant life cycle sequencing, and empathizing with her struggle, Lapetus gave her space to think further. Generally, most in-the-moment purposes had an emotional component (e.g., Ares wanted students to be excited about using physics to understand the world around them).

Another category of in-the-moment purposes involved attending to students' learning processes. Some teachers guided students stepwise, such as by fading scaffolds strategically. For example, Nike used a sequence of questions to help her physics students figure out which ideas (e.g., kinematics, torque, energy, angular momentum) would be most effective in solving the problem, and then walked away to let them work on it. Another emphasis was to improve students' scientific speaking. Gelos thought a student's dyslexia was a barrier to distinguishing current and voltage, and tried to help him find ways to remember which was which. Khione, Koncordia, and Paean similarly emphasized students' correct use of scientific vocabulary. Teachers also wanted to encourage productive relationships among students and themselves. Ares and Jupiter encouraged all students in a group to contribute toward the goal, Nike prompted her students to hold each other accountable, and Khione worked on building rapport with students by sharing personal stories (e.g., joking about her Mom's and Aunt's KoolAid recipe competition). Finally, teachers tried to balance demands for efficacy and efficiency. Ares and Paean emphasized the importance of focusing on certain aspects of problems and then gave students time to think, and Lapetus put effort into helping a student feel more comfortable to share her ideas so that she could think through the problem. Nike and Terra pushed to cover more problems faster so that students could have more opportunities to use their knowledge.

A third category of purposes centered on developing students' positive qualities and attitudes. Gelos asked his students to describe their predictions to build their confidence. In the alternative high school where he taught, students were often absent. He considered persistence and responsibility to be higher priorities than learning physics content. Jupiter taught at one of the district's elite high schools. Her interactions with students were driven by an intention to help them trust their own knowledge and not rely on the teacher to lead them. Common to both teachers was care for growing students' self-reliance.

5 | DISCUSSION

A view of FA enactment as a vehicle to transform teaching has attracted the attention of many scholars. The literature review shows how many researchers have already characterized FA enactment in terms of elements and developed research-based frameworks to inform teaching practice, for example, the ESRU model of Ruiz-Primo and Furtak (2007). Furthermore, mathematics education researchers have investigated how teachers notice and act on students' thinking (e.g., Colestock & Sherin, 2015; van Es, 2011).

In our study, we have drawn upon work from across these areas, and built a model based on validation-in-use that:

(a) emphasizes the centrality of noticing and interpreting in FA enactment;
(b) illuminates how in-the-moment purposes and larger learning goals were synthesized by teachers to make (perhaps unconscious) choices about eliciting and advancing acts based on what they noticed and interpreted; and
(c) provides a platform for teachers to intentionally plan actions based on the disciplinary substance they anticipate noticing during a lesson.

Our data analysis led us to position noticing/interpreting at the center of our FA enactment model. Based on what teachers notice and interpret, we saw two types of actions that they can take: to learn more about the students' thinking or to advance it toward a scientific explanation. The three elements of an enactment followed different patterns, including nonlinear sequences of eliciting and advancing that underscore the complexity of classroom interactions, as Cowie and Bell (1999) found in discourse following the IRPRP pattern and Ruiz-Primo and Furtak (2007) found in chains of incomplete ERSU cycles. While the scope of our data was insufficient to support claims about patterns of eliciting and advancing observed, future analyses of a larger set of teachers' classrooms or more lessons across time may allow for such inferences, as Furtak et al. (2017) have done.

Critically, how we characterized the three elements of FA enactment evolved within a validation-in-use process. Indeed, while more complex characterizations by other researchers exist for the different elements of FA enactment, our lens on validation-in-use maintained a filter on what could be useful to teachers' practice. For example, when discussing eliciting acts, the teachers articulated meanings associated with narrow versus open eliciting that corresponded with our understanding and application of these codes in our data analysis. The multiple rounds of usage and improvements of the coding scheme with three different sets of science teachers enhanced the usefulness of the model for teachers as a platform for planning lessons. In fact, during the 2 years since model development began, we have used it in multiple PD sessions at national, regional, and district meetings.

Noticing/interpreting is difficult to study because it is normally a hidden process, taking place in the mind of the teacher and largely underneath the surface of classroom discourse. Many researchers have thus opted not to separate it from visible teaching acts, which makes sense when additional in-the-moment meta-commentary or interview data is unavailable or inaccessible. We have followed others, including many mathematics education researchers, in separating out noticing/interpreting because it helps make explicit what teachers see that motivates their actions. We characterized teachers' noticing/interpreting by soliciting explanations from teachers about what they were thinking in the moment of their teaching in balance with our assessment of teachers' apparent stances more generally.

We adopted a characterization of noticing/interpreting based on Talanquer et al. (2015), considering noticing/interpreting to be more evaluative or more inferential. Our primary elaboration on that work was identifying the ways in which these stances manifested in the data of experienced science teachers. As compared to noticing/interpreting, characterizing teaching acts was generally more straightforward. We used the available discourse and nonverbal communication markers in the videos to distinguish between eliciting and advancing acts. We also recognized teachers engaging in a range of discourse from authoritative to dialogic (Mortimer & Scott, 2003) with both kinds of teaching acts. The discourse patterns helped us characterize eliciting as narrow (authoritative) versus open (dialogic), which relates most closely to how Sandoval, Kwako, Modrek, and Kawasaki (2018) treat teacher questions in the low-inference discourse observation protocol. There, they specify teachers' questions as "truly open" and "contestable" as compared to "closed" and "uncontestable," and they include an intermediate "semi-open question, with a circumscribed answer set." Comparing our characterization of eliciting to the schemes we reviewed (e.g., Franke et al., 2009 and Oliveira, 2010), we see that while theirs tend to be more elaborate, ours teases apart eliciting and advancing acts according to the intent of the teacher behind the act rather than the space created for students by the act.

The simplicity of our characterization is necessary to maintain its usefulness to teachers who use the scheme, in concert with the researchers who monitor their use. Despite its simplicity, we observed that most teachers in our study demonstrated versatility with authoritative to dialogic teaching acts, both in eliciting and advancing (Figure 1). This finding may offer leverage to address a challenge raised by Harris, Phillips, and Penuel (2012) and others, who have shown that teachers can more easily elicit students' ideas than advance them.

The research questions ask how teachers enacted FA and what in-the-moment purposes influenced their enactments. We observed teachers' and students' interactions with FA tasks, which ranged from Do-Nows to working on complex laboratory experiments. As students formed and discussed their ideas, teachers noticed and interpreted the students' ideas through the lenses of their in-the-moment and broader teaching purposes, attending to some aspects and ignoring others. While at different points most teachers enacted components of FA in different ways (Figure 1), there were particular in-the-moment purposes that were correlated to different ways of enactment. So we can say that FA enactment is complexified in at least two ways: a teacher can have a broad range of purposes, with those purposes referring to immediate views and longer-established knowledge about particular students, and more than one purpose can operate during a lesson or even a single interaction.

Our participants demonstrated a range of teaching purposes behind their FA enactment, just as Colestock and Sherin (2015) found that mathematics teachers notice with different purposes. The three types of in-the-moment purposes associated with teachers' FA enactment that we identified (i.e., developing students' content understanding, attending to students' learning processes, and nurturing students' positive qualities and attitudes) have connections with recent work by Kang (2018). She characterized intellectual, relational, and linguistic teaching purposes. Evidence of each of these purposes was present in our data, including, for instance, Khione who wanted her students to understand concentration as a ratio of solute to solvent (intellectual); Lapetus who wanted to give his students more time to complete their project given that they were stuck (relational); and Paean who helped his students understand the scientific terminology in the Do Now question (linguistic). Similar to how Schoenfeld (2011) and Davis (1997) showed that orientations shaped noticing, we found that such in-the-moment purposes contributed to the ways in which teachers enacted all three elements of FA (Figure 2).

We also found evidence of *multiple* in-the-moment purposes at play. This was most apparent in teachers' noticing/interpreting, but that could be an artifact of our approach to coding. Our video clips were selected, in part, on a basis of being bounded discussions with a student or group of students, and for this reason, there was one major noticing/interpreting focus characterizing each video clip, while there were multiple instances of acting related to this main focus of noticing/interpreting. For example, Lapetus combined a relational (Kang, 2018)/caring-influenced purpose (wanting a student to feel comfortable expressing herself) with an intellectual (Kang, 2018)/emotion-influenced purpose (finding out how much she remembered about life cycles of plants studied the prior year).

We recognize a limitation in relation to the approach through which we make these claims. In our work, in-the-moment purposes were inferred from our analysis of the teacher's classroom video (Stream 2) combined with the self-interview that detailed the teacher's goals for FA (Stream 1), and the teacher's comments (Stream 3) on the reasons behind the teaching acts, as well as field notes during the PD. It is possible that some teachers could have provided incomplete information in their comments. For example, some teachers may have perceived that intellectual purposes had a higher value (to us or to their peers) than relational or linguistic purposes, and may have refrained from commenting on the latter. Relatedly, as mentioned earlier, teachers could have engaged in *post hoc* rationalization of their behaviors as well.

5.1 | Implications for teachers working on their FA practices

We argue that the possibility to make strategic choices in FA enactment is opened up as teachers become aware of the elements of FA enactment, including the ranges of eliciting (narrow to open), noticing/interpreting (evaluative to inferential), and advancing (directive to responsive). Awareness can become well developed in video-based, teacher-led PD in which teachers retrospectively reflect on their teaching acts and imagine other possible actions they could have taken (van Es & Sherin, 2008). Indeed, pondering such choices pushed our teachers to think about and make explicit their in-the-moment purpose(s), and, in turn, how those purposes shaped their practice.

Furthermore, separating out noticing/interpreting is quite useful because it encourages teachers to focus on their understanding of student thinking in a given moment, which then helps to lay bare their intentions. For PD leaders, separating noticing/interpreting from acting makes it possible to work with teachers on planning for noticing/interpreting as part of lesson planning. We illustrate an example of using our FA enactment model in this way at the end of this Discussion.

Researchers have demonstrated that lessons often follow common patterns of communicative approaches. At the beginning of a lesson, teachers often elicit in open ways, notice/interpret inferentially, and act to advance responsively; and toward the end, teachers elicit in narrower ways, notice/interpret evaluatively, and advance directively (Lehesvuori, Viiri, Rasku-Puttonen, Moate, & Helaakoski, 2013; Oliveira, 2010). There are in-the-moment purposes behind these choices, many of which may be largely unrecognized by teachers. We conjecture that, as teachers work to be more intentional about their purposes, they can choose more strategically what and how to notice/interpret, and whether to elicit (more narrowly or openly) or advance (more directively or responsively), for deliberate reasons.

Teachers focusing on strengthening their FA enactment is powerful because, when they see their own teaching on display for themselves and others, they begin to see their teaching as a practice to be refined by focusing attention on things that go well and things that can be improved (Borko, Jacobs, Eiteljorg, & Pittman, 2008; Shepherd & Hannafin, 2009). Kang and Windschitl (2018) show that when a teacher focuses on students' opportunities to learn, it directs the teacher's attention to student meaning making and forms of participation. Focusing teachers' attention on how they enact FA in their own classroom videos made this possible for our participants.

What drives our work is the privilege of working with teachers who are continually striving to strengthen their science teaching. Jupiter exemplifies such effort nicely in her Stream 3 comments which referred to how the PD helped her become more conscious of her FA enactment. In particular, she recognized leading students using directive advancing acts at multiple points:

> *What I think I want to work on next time, which I caught myself doing as I was going through, is leading less. I felt like I was leading more, and that as I walked through, I was kind of realizing what I was doing, and listening a little more and leading less.*

This comment corroborates our assessments of her self-interviews and classroom video, namely that her hopes for FA would grow to be more consistent with how she would want to interact with students.

This points to a promising implication for how teachers can use the FA enactment model: as a planning device to design questions they anticipate during FA. We recently implemented this strategy in an all-day PD with 50 K-12 science teachers. The day began with teachers experimenting in teams to develop an explanation for how "fog" forms when dry ice is placed in water. This is a phenomenon that lends itself well to FA because the mechanism involves many complex processes (Kuntzleman, Ford, No, & Ott, 2015). The teacher leaders who facilitated the PD developed ahead of time four questions to ask at opportune moments:

- Is the foggy white stuff a gas? (open eliciting question to use when the characteristics of the fog are the topic of the group's conversation, with the intent to spur discussion about how people are thinking about the phenomenon and what could be causing it),
- Does this phenomenon have something to do with phase change? (narrow eliciting question to use upon noticing that someone is talking about phases, with the intent to focus the conversation on phases but not necessarily direct them to the "correct" answer),
- How does fog form on a foggy day outside? (directive advancing question to use when a discussion veers away from considering mechanisms, with the intent to move people toward a more scientific way of thinking about what is going on), and
- What are some possibilities that the foggy white stuff could be made of? (responsive advancing question to use when building upon an idea voiced by someone, that is, related to the chemical identity of the fog, to induce people to further their work in figuring out the ideas for themselves).

Each question corresponded to a situation that was likely to arise and that could be noticed by a facilitator. When asking a particular question, the facilitator would have an in-the-moment purpose for its use to productively move participants along.

At the end of the PD, after watching videos to characterize types of teaching acts and imagine alternative acts, we returned to the four questions from the dry ice activity and asked the teachers to recall when they heard them used. We then asked the teachers to propose what could have been fruitful situations in which to use the questions, and what effects each question might have had. This generated conversations about the disciplinary substance the facilitators had noticed. For example, in the four questions above, the open eliciting and responsive advancing questions attend to the identity of the substance in the fog, while the narrow eliciting and directive advancing questions attend to the mechanism for how the fog occurs. The final task of the PD asked teachers to design four questions for an upcoming lesson in their own science teaching.

These encouraging developments underscore the major implication of this study: teachers' ability to make choices in FA enactment is opened up as they become more aware of opportunities to notice/interpret and then elicit or advance their students' thinking. We observed how using our FA enactment model raised teachers' awareness, which helped them reflect on the substance of their students' thinking in relation to their own teaching acts and their in-the-moment purposes. These reflections also helped the teachers imagine other possible actions they could have taken, which increased their intentionality in FA enactment. Planning questions for in-the-moment purposes in situations that are likely to arise enabled teachers to plan for furthering students' productive thinking (Shavelson et al., 2008). This gave teachers a concrete use for the FA enactment model that was aimed forward in time.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

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