JOURNAL OF CHEMICAL EDUCATION

pubs.acs.org/jchemeduc

Article

Teachers' Noticing, Interpreting, and Acting on Students' Chemical Ideas in Written Work

Stephanie A. Murray, Robert Huie, Rebecca Lewis, Scott Balicki, Michael Clinchot, Gregory Banks, Vicente Talanquer, and Hannah Sevian*

Cite This: https://dx.doi.org/10.1021/acs.jchemed.9b01198

Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: Formative assessment is an important component of teaching as it enables teachers to foster student learning by uncovering, interpreting, and advancing student thinking. In this work, we sought to characterize how experienced chemistry teachers notice and interpret student thinking shown in written work, and how they respond to what they learn about it. Drawing on qualitative methods from different educational fields, we analyzed data collected during focus groups of middle and high school teachers. Using a "chemical thinking" lens, teachers' formative assessment practices were characterized as descriptive vs inferential in noticing, evaluative vs sense-making in interpreting, and directive vs responsive in acting. Four major patterns emerged in teachers' interpreting of student thinking and proposed acting. These patterns affected the diversity of ideas that teachers noticed in student work. Ways of using the findings are offered for chemistry teachers wishing to examine and diversify their own noticing practices, and for professional development efforts in this area.

KEYWORDS: *Elementary/Middle School Science, High School/Introductory Chemistry, Chemical Education Research, Testing/Assessment*

FEATURE: Chemical Education Research

INTRODUCTION

Teaching involves continuous decision making about what to do next based on observations the teacher makes about whether and how students are learning. Formative assessment (FA) can be defined as the "process used by teachers and students to recognize and respond to student learning in order to enhance that learning during the learning" (ref 1, p 536). FA is particularly important when the teacher seeks to support students' development of chemical thinking, which involves the application of chemical knowledge, practices, and ways of reasoning with the intent of analyzing, synthesizing, and transforming matter for practical purposes.[2] The chemical thinking framework approaches this by organizing the learning of chemistry in terms of crosscutting practices of chemistry rather than fragmented topics to be learned. In this study, we explored how *experienced* chemistry teachers engaged in FA during a chemical thinking task seeking to characterize how they:

- Attended to students' ideas (*noticing*),
- Inferred what their observations implied about student thinking (*interpreting*), and
- Decided what to do next based on their observations and inferences (*acting*).

These three teaching moves constitute the core of the mechanism of how teachers enact FA.[3] We were particularly interested in characterizing how chemistry teachers noticed, interpreted, and acted on student thinking as revealed through students' written responses to a high-level task[4] to gain insights into how to better foster chemical thinking through effective FA.

There are domain-general and chemistry-specific aspects to teachers' FA enactment. Since the chemistry-specific nature of these is situated within teaching moves that all teachers make, in this work we first characterize the domain-general aspects. We then take a chemistry-specific lens to examine teachers' noticing in the context of the specific assessment probe used in our study. While a wide literature exists on domain-general FA enactment, relatively little has been examined about the domain-specific nature of this central aspect in teaching chemistry. Our findings have implications for the practice of teaching chemistry as well as for professional development that supports continuous growth in teachers' ability to achieve the ambitious goals of the framework for the Next Generation Science Standards[5] in chemistry classrooms.

Received: December 23, 2019
Revised: July 17, 2020

NOTICING, INTERPRETING, AND ACTING

Teachers' Professional Noticing

The construct of *teachers' professional noticing* encapsulates what we separately call teachers' noticing, interpreting, and acting. Professional noticing is a variant of everyday noticing that refers to how practitioners of a profession develop specialized ways of seeing complex situations.[6] Researchers have proposed various definitions of professional noticing that incorporate different teaching moves. van Es and Sherin (ref 7, p 573) describe these moves as

> *...(a) identifying what is important or noteworthy about a classroom situation; (b) making connections between the specifics of classroom interactions and the broader principles of teaching and learning they represent; and (c) using what one knows about the context to reason about classroom interactions.*

This definition focuses primarily on what teachers notice and how they interpret what they see in their classrooms, but researchers who study teachers' professional noticing tend to consider that noticing and making sense of student thinking are inseparable from the teaching responses that follow. Given the different meanings associated with the term "noticing" in the literature,[7−20] in this article we use "professional noticing" to refer to the larger construct while "noticing" refers to one of its components.

Much of the early work in the area of teachers' professional noticing focused on characterizing the extent to which teachers build inferences from what they notice. Expert teachers have been found to consider students' ideas more interpretively than novice teachers, and tracking the development of their interpretive work over time has been used to characterize progression in teaching expertise.[7] For example, Talanquer and co-workers identified a series of domain-neutral and domain-specific dimensions of preservice science teacher noticing and interpreting that exist on a scale from novice to advanced.[8] Jacobs and co-workers have expanded teachers' Professional Noticing to include what teachers notice, how they interpret student responses, and how they decide to respond to students.[9]

A primary purpose of noticing and interpreting student thinking is to guide teachers' actions in the classroom. Research on teacher acting has taken many forms, including studies on how teachers explain science,[10] the communicative approaches they follow,[11] the questions they ask and the feedback they provide,[12] and the extent to which they engage in responsive teaching.[13] Ogborn et al. characterized explaining in the classroom by identifying critical components of teachers' explanations.[10] Mortimer and Scott developed an approach to describe the interactions of the teacher with students in terms of whose ideas are in play: Dialogic discourse is multivocal and includes students' perspectives, while authoritative discourse is univocal in the scientific view.[11] Under the umbrella of responsive teaching, researchers have explored how teachers incorporate student ideas into actions they take in the classroom.[13] For example, Coffey et al. examined the lack of disciplinary substance in teacher questioning,[14] while Lineback characterized different degrees in teachers' responsiveness to students' ideas.[15] Our paper seeks to unify several of these frames for examining teachers' professional noticing in the context of FA.

Teachers' Professional Noticing in the Context of Formative Assessment

Cowie and Bell pointed out that FA can include the spontaneous focus by a teacher on an ephemeral idea that has significance for learning, or it can be more deliberately planned.[16] When planned ahead of time, FA tends to include a task that is selected or designed by the teacher, and to occur in cycles of the teacher eliciting, attending to, interpreting, and acting on information.[16] Researchers in mathematics[17,18] and science[19−22] education have extensively studied both spontaneous classroom-based FA and how teachers plan for FA. Various models describing and providing teachers resources for both have been developed. The Ambitious Science Teaching movement emphasizes FA practices in professional noticing that include eliciting students' ideas, supporting changes in student thinking, and pressing for evidence-based explanations.[19,20] Ruiz-Primo and Furtak[21] have described a four-part cycle of eliciting students' ideas, hearing a student response, recognizing the scientific value in the idea, and then using it in the lesson. In our own research work, Dini and co-workers[22] developed a model of how science teachers enact FA in teaching moves that is discussed in more detail below.

The design of a task has a large role in teachers' professional noticing as well as other aspects of FA. The Ambitious Science Teaching project[19,20] has characterized rich tasks as being accessible, in that they have multiple entry points and are capable of revealing student thinking. FA tasks also set the stage for the level of intellectual demand that subsequently ensues in the classroom.[4] While an FA activity may be planned with cycles or phases, it can also have spontaneous moments, but both modes depend on the nature of the task.

In this contribution, we are interested in relationships among teachers' noticing, interpreting, and acting in the assessment of students' written work on a rich FA task designed to elicit students' chemical thinking. Our analysis is guided by the model of FA enactment of Dini and co-workers summarized in Figure 1[22] because this model describes the nature of teachers' actions rather than their sequence. In analyzing teachers' dynamic classroom FA, the model allows for the connected nature of noticing, interpreting, eliciting, and advancing. In addition, this model emphasizes the centrality of noticing and interpreting, rather than locating this in between eliciting and acting as other models do. Use of this model has a further benefit: It was developed within a teacher−researcher collaboration[3] and designed to generate principled practical knowledge,[23] which Bereiter describes as "know-how combined with know-why".

In the FA enactment model that guides our analysis (Figure 1), a teacher's FA moves begin with the teacher noticing student thinking and making an interpretation of what is noticed. Noticing and interpreting may result in two types of acting: (a) eliciting, in which the teacher decides to further explore student thinking, or (b) advancing, in which the teacher advances student thinking toward the scientific story. Any of the teaching moves in this model (shown in purple in Figure 1) can be approached in either a dialogic (blue) or authoritative (red) approach.[11] Each move is driven by the teacher's in-the-moment purposes[22,24] and is influenced by what the teacher knows how to do. Following each teaching act (eliciting or advancing), the teacher then returns to noticing and interpreting. The dialogic or authoritative approach of each teaching move is independent of that of the preceding or subsequent move. The model places value on both dialogic and authoritative approaches, because both are used intentionally by effective teachers to achieve their learning goals.

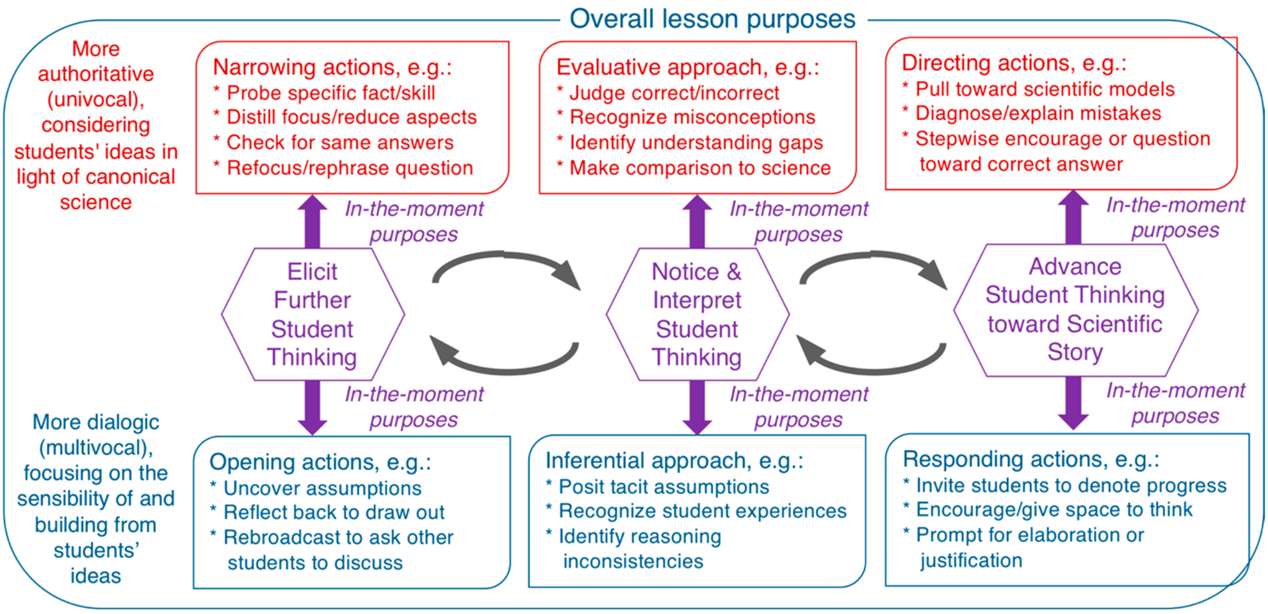

Figure 1. Formative assessment enactment model.

METHODS

Research Questions

In this study, we aimed to answer two research questions about experienced chemistry teachers' FA practices during the analysis of written work from an FA task:

- What are the major approaches that experienced chemistry teachers take to noticing, interpreting, and acting in response to students' ideas about chemical processes?
- What do experienced chemistry teachers notice when they evaluate students' written answers to a probe of how to control a chemical process?

Professional noticing has both domain-general and domain-specific aspects. How teachers notice, interpret, and act on student thinking can be characterized in domain-general ways, but these are influenced by what teachers notice, which is domain-specific. The response to our research questions was approached at these two levels of analysis.

Researchers, Setting, and Participants

This research was conducted by a collaborative team of chemistry education researchers, middle school science teachers, and high school chemistry teachers.[3] The participants in the study were experienced (>3 years) middle school science and high school chemistry teachers from across New England. Some participants were enrolled in a yearlong professional development program for chemistry teachers focused on chemical thinking, and their participation in this study occurred as the first activity at the first workshop of the year. Other teachers participated after a one-day workshop at a local museum, and after class time during a weeklong integrated science content course. The study was approved in advance by the research ethics committees at each of the sites from which participants were recruited, and all participants provided written informed consent.

The sample included 11 focus groups, each with three to five teachers, comprising 43 teachers in total. Teachers who participated in the focus groups had a range of 3−30 years' experience teaching science (mean experience = 10.4 years, median experience = 8 years). They taught in urban (N = 29), suburban (N = 10), and rural (N = 4) schools, and they taught chemistry in middle (N = 10) and high (N = 33) schools. Focus groups of 60 min duration were facilitated by a teacher on the author team and were audio-recorded. Observer notes describing speaker turns and gestures were also written by another coauthor during the focus groups. The focus group audio recordings were transcribed with the aid of the observer notes. Teachers were deidentified and labeled by focus group and assigned a teacher number within that group (e.g., G3-T4 for teacher 4 in group 3).

Formative Assessment Task Designed in the Chemical Thinking Framework

This study examines the nature of teachers' noticing through the lens of chemical thinking.[2] Open-ended tasks in which students are challenged to apply their knowledge to address a problem of practical concern make it possible to notice how students employ their chemical thinking. Such tasks can reveal chemistry-specific assumptions that shape not only answers to specific questions but also concepts that transcend all of chemistry. Paying attention to what a task reveals about student thinking depends, however, on what the teacher looks for. In this study, we used an FA task centered on controlling a chemical process and considering the causes and mechanisms for how changes occur. *Chemical control* is one of the six questions of chemistry within the chemical thinking framework.[2]

The focus group discussions in this investigation were based on student work produced using the Volcano Probe FA available on the ACS's ChemEd Xchange website: https://www.chemedx.org/article/volcano-probe. Administration of this probe with students involves first showing a silent 3 min video of a student making a citric acid and baking soda volcano demonstration for a second-grade class (see Figure 2). Next, students receive a two-page handout that provides the lists of chemicals and equipment seen in the video and a sketch of the setup. The first page of the handout asks students to identify three different things that the person in the video could do to make a bigger eruption and to justify these suggestions. On the second page, the balanced chemical equation for the observed

Figure 2. Still images from Volcano Probe silent video.

reaction is provided, and students are asked if they have any further ideas on what could be done to make a bigger eruption and to again justify their choices.

This FA task was completed by about 100 middle and high school students, and six representative student responses were chosen for analysis during the focus groups (see ChemEd Xchange website). Research in chemistry education has shown that learners tend to consider external parameters, such as temperature, as relevant for chemical control, but not internal parameters, such as chemical structure.[25,26] They also often assume that changes must be initiated by active agents[27,28] and struggle to differentiate factors relevant for kinetic versus thermodynamic control.[29] Thus, selected student work included discussion about external and internal conditions for controlling chemical reactions, reasoning at both macroscopic and submicroscopic levels, ideas referring to both kinetic and thermodynamic models, and qualitative and quantitative responses to the questions.

Data Collection

Focus groups were chosen as the primary method of data collection because they foster an environment where participants with similar experiences feel comfortable sharing their beliefs.[30] The shared experiences, vocabulary, and priorities of the group help shape a group dynamic that is primed to uncover why the participants notice, interpret, and act in the ways they do. Focus groups also allowed us to tailor the questions and guide the discussion as needed to uncover evidence of what and how teachers notice, interpret, and propose to act after reading student responses to the FA task.

Prior to starting the focus group discussion, participants were shown the Volcano Probe video and given the student handout. They then worked on the task as if they were students to become familiar with it. After this work, each teacher received copies of the six selected samples of student work (see ChemEd Xchange website) and was given time to review them. Facilitators of each focus group then scaffolded the discussion using a well-defined protocol (see Supporting Information).

Data Analysis

Using the focus group transcripts and teachers' feedback artifacts, analysis proceeded in four phases. The first phase was designed to inductively uncover common themes using Rabiee's "Framework Analysis" method.[30] All but two of the authors participated in this analysis phase. Trustworthiness in analysis was addressed by splitting into two subgroups which analyzed the same data (focus group transcripts and teachers' written feedback on the student work) and then discussing among co-researchers until consensus was reached. This first phase revealed common stances in FA taken by participating teachers, including prioritization of some types of student reasoning over others (quantitative over qualitative), tendency to look for certain structures in student arguments (claim−evidence−reasoning) or particular vocabulary in students' explanations, and proclivity to find something to value in each student's response or to consider some responses as valid and others as invalid (recognized misconceptions).

The second phase of analysis began by imposing, and later refining, a coding scheme derived from prior work on what preservice chemistry teachers notice and interpret about students' thinking in their written work.[7] During this process, two participants were removed from the sample (reducing it to 41) because their participation in the focus group was not substantial enough to allow for characterization (each of these teachers accounted for <5% of spoken words during their focus group). During this phase, we built from the framework developed by Talanquer et al.[8] to characterize noticing and interpreting on a scale of sophistication from novice to advanced. Individual teacher's phrases were analyzed, looking for instances of *noticing* (what teachers highlighted in students' answers) and *interpreting* (what teachers inferred based on what the student is saying). Nevertheless, rather than applying Talanquer's categories as indicative of levels of sophistication, we used them to characterize different approaches to noticing and interpreting that may be productive in different situations.

In this second phase, we built a new category of analysis called *acting* (what teachers proposed might be done to address an issue). We identified two main approaches to *acting*, one of them focused on proposing specific ways to direct students to the normative answers (directive) and the other focused on supporting students in articulating, evaluating, and advancing their own thinking (responsive). Figure 3 summarizes the final coding scheme for the three actions that resulted from this process.

The authors employed multiple ways of ensuring dependability of the data analysis. To aim for consistent operationalization of the constructs, we employed peer examination.[31] Our analysis was carried out in several meetings that included between four and eight other chemistry education researchers not directly involved in the project. The coding scheme evolved during the first three meetings, and the coding scheme did not change in the last two. At this point, the coding scheme was shared in a practitioner journal.[32] Following the last of these meetings, the first author (S.A.M.) recoded the data from all 41 teachers using the finalized coding scheme (Figure 3). To further address trustworthiness of the analysis, we employed independent coding−recoding among three of the authors (S.A.M., R.H., and H.S.). One author (S.A.M.) coded all the data, and two authors coded 7 participants each, with 3 cases in common (11 cases in total, or 27% of the data). Krippendorff's α was used to judge agreement because of its ability to account for

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

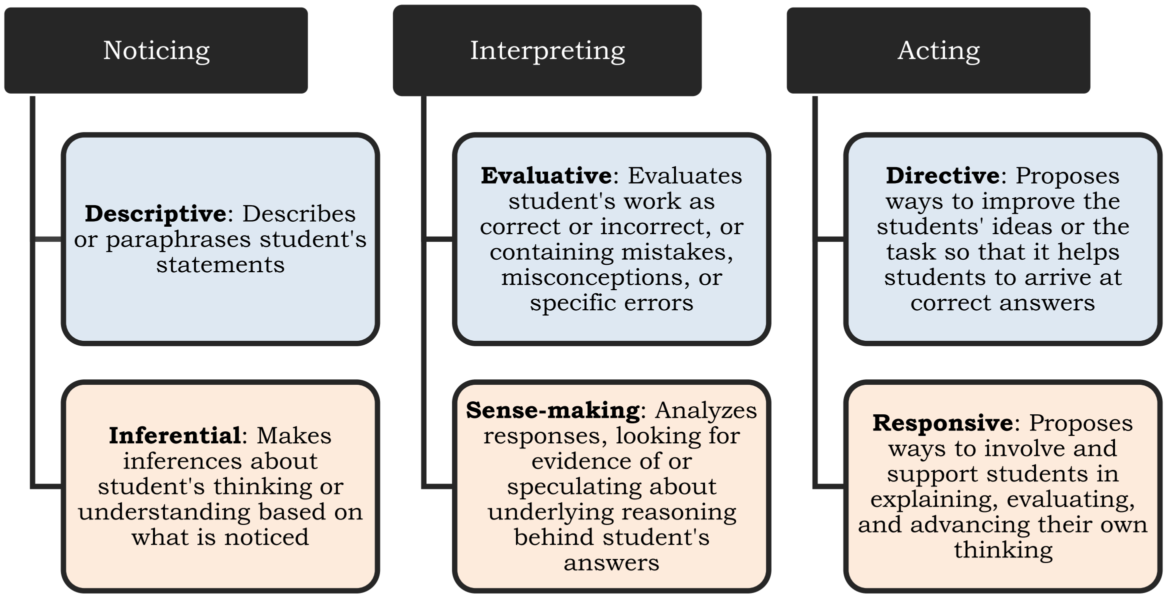

Figure 3. Noticing, interpreting, and acting coding scheme.

multiple raters,[33] and an α value of 0.739 was obtained. Dialogue among co-researchers was employed to resolve differences until consensus was reached. The first author then reviewed the codes for the remaining participants to ensure that the coding was aligned with the nuances that were surfaced through the coding−recoding process.

We next sought to characterize different approaches that participating teachers took toward FA. During this third phase, we grouped teachers into clusters based on similarities in their approaches to noticing, interpreting, and acting. Eight combinations of instantiations of noticing, interpreting, and acting are possible based on the coding scheme (e.g., inferential noticing, evaluative interpreting, and directive acting). However, only six of the combinations were observed. Noticing was coded in a different manner than interpreting and acting; how teachers described what they noticed either occurred by directly quoting or paraphrasing what a student wrote (descriptive) or attempting to infer what a student meant (inferential). These are neither authoritative nor dialogic.

In the final phase of analysis, we returned to the primary data to examine the ideas teachers paid attention to. For example, some teachers focused on students' manipulation of external parameters (e.g., temperature) to control the reaction, while others focused on students' selection of reactants, which indicated they were paying attention to internal control parameters (e.g., chemical composition). We built a coding scheme to characterize teachers' noticing more specifically. We again employed peer examination, coding−recoding, and dialogue among researchers to ensure trustworthiness of the analysis. A random sample of 4 teachers (10% of the data) was coded by two authors (H.S. and S.A.M.) after 17 code categories were established across general, topic-focused, and chemical thinking noticing. Initial agreement was 85%. All but one disagreement were determined to result from one researcher overlooking a few words spoken by a teacher. Following this process, all instances of these two codes were recoded, resulting in minimal changes. The final "noticing" codebook is presented in the Supporting Information, as this may have utility for teachers.

■ MAJOR FINDINGS

How experienced chemistry teachers notice student thinking in written work is largely domain-general, but it both is influenced by and influences *what* teachers notice, which is domain-specific. Since noticing students' thinking occurs in the context of evaluating student work, to the extent possible, we arrange the findings to first inform the "how" question about the process and then to inform the "what" question about noticing.

How Teachers Notice, Interpret, and Act: Formative Assessment Personalities

Our analysis allowed us to identify contrasting ways in which participating teachers engaged in noticing (*descriptive*, *inferential*), interpreting (*evaluative*, *sense-making*), and acting (*directive*, *responsive*) while assessing students' knowledge and ideas about chemical control expressed in written work. Although a single teacher's approaches to noticing, interpreting, or acting could vary during the assessment process, our data indicated that each participant followed a major approach (either dialogic or authoritative) in two of the dimensions: interpreting and acting.

Figure 4 distinguishes four main quadrants, each of them highlighting a different "formative assessment personality" that participating teachers adopted on the basis of their dialogic or authoritative approaches to interpreting and acting. Two of the eight possible combinations of noticing, interpreting, and acting (5 and 7 in Figure 4) were not observed in the data. This is likely because sense-making interpreting is not possible unless a teacher makes inferences about what is noticed. In the following paragraphs, we provide a more detailed analysis of the different FA personalities that were observed and characteristic ways in which they were enacted.

FA Personality A: Authoritative Interpreting (Evaluative) and Authoritative Acting (Directive)

Quadrant A includes two combinations of noticing, interpreting, and acting. Both are evaluative in interpreting and directive in acting, but either descriptive or inferential in noticing students' ideas. Characteristic behaviors of teachers that fell into these clusters are described in Boxes 1 and 2. FA personality A was expressed by 14 out of 41 teachers in our sample.

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

Box 1. Descriptive Noticing, Evaluative Interpreting, and Directive Acting (Combination 1)

Teachers adopting this combination tended to focus on and highlight when students used or did not use specific chemistry theories, principles, and vocabulary in their responses. These teachers used student work from the FA task to determine whether or not students were able to provide and support answers aligned with accepted scientific models and principles. Teachers used their evaluations of student understanding to propose strategies to direct students toward the proper use of scientific models and principles to clearly and accurately express scientific understanding.

Box 2. Inferential Noticing, Evaluative Interpreting, and Directive Acting (Combination 2)

Teachers in this group often built inferences that were evaluative in nature, describing student thinking as accurate or based on misconceptions that they anticipated and recognized. Their proposed actions focused on providing stepwise guidance for students to reach a desired learning goal. For example, many proposed actions took the form of recommending more scaffolding in the prompt, using guiding questions during a specific experiment chosen by the teacher, or helping students sequentially narrow their thinking in the correct direction.

Teachers in combination 1 (Box 1) were mostly descriptive in their noticing, highlighting what students said or did (or did not say or do) without building inferences about student understanding. Consider this example:

> *Also speaking of that same student, Notnhat, their first response was to heat up the test tube, and they talked about the correlation between the temperature increase and an increase in the pressure, but they didn't talk about closing the test tube. So I felt like they had some knowledge there, and that they were thinking creatively, because I think that the only other student who mentioned pressure was AyyVolcano. But they were missing the, if they were talking about the pressure, would be closing the tube. (G9-T2)*

This teacher paraphrased but did not infer any meaning in what Notnhat said and then provided an evaluative interpretation of it (having some knowledge, thinking creatively) without offering any thoughts on what Notnhat may have been thinking. The teacher continued to provide a similar evaluation of AyyVolcano's response, noting what this student did not do. In contrast, teachers in combination 2 (Box 2) tended to build inferences about student knowledge or thinking based on what was noticed, as illustrated by the following excerpt:

> *I didn't see any student pick up on the 1 to 3 ratio of reactants that was in the formula. Nobody called that out specifically. The one student who tried said it backwards, so I don't know if she misinterpreted the numbers and just reversed it. I think she looked at it and noticed there was a difference, cause she says, she only talked about changing one reactant, but she went the wrong way with it. (G6-T3)*

In this example, the teacher inferred what the student meant, saying that the student just "said it backwards" perhaps due to reversing the numbers. The teacher then provided an evaluative interpretation of this as going "the wrong way with it".

Teachers who adopted FA personality A primarily proposed actions focused on advancing (see Figure 1) to move students

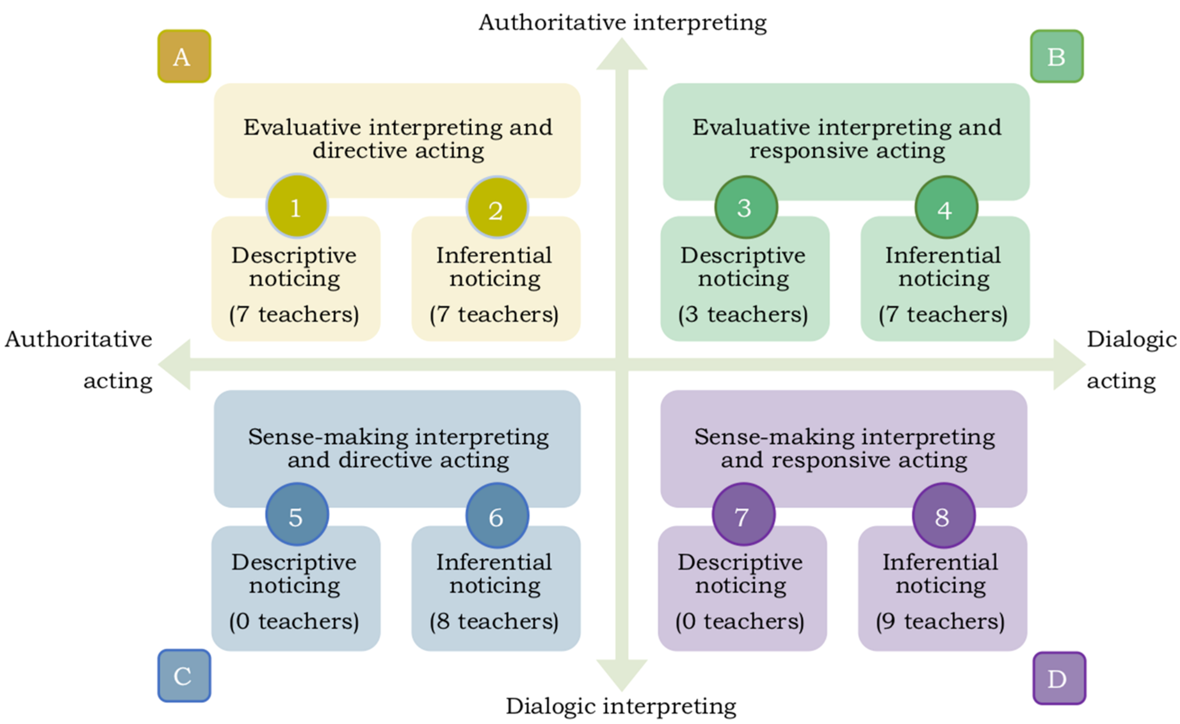

Figure 4. Combinations of teachers' noticing, interpreting, and acting observed in our study, organized around two axes characterizing the extent to which interpreting and acting align with authoritative or dialogic communicative approaches in interpreting and acting, and grouped as four "formative assessment personalities" (A through D) according to quadrant. Note that noticing is neither authoritative nor dialogic, authoritative interpreting is evaluative while dialogic interpreting focuses on sense-making, and authoritative acting is directive while dialogic acting is responsive.

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

toward the teachers' expected correct answer. The following excerpt illustrates this approach to acting:

So since we had made our own answers first before looking at the student answers, I tried to use sort of my own answers, so the quote—unquote correct answers as that sort of guiding rubric. And so if, the more things they got off of that internal rubric, then that sort of guided how much I guided them versus that I didn't need to guide them, I guess. (G6-T2)

This teacher relied on her own constructed rubric of "correct answers" to evaluate students' responses and proposed the use of guiding questions to align student thinking with the teacher's own thinking.

FA Personality B: Authoritative Interpreting (Evaluative) and Dialogic Acting (Responsive)

This quadrant includes combinations that are evaluative in interpreting and responsive in acting, while either descriptive or inferential in noticing. Characteristic behaviors in each of these clusters are summarized in Boxes 3 and 4. The major feature differentiating FA personality B from A is that teachers who adopted FA personality B (10 out of 41) primarily proposed laboratory activities, either to enhance student interest (combination 3) or to elicit more about students' ideas (combination 4), in contrast with teachers who adopted FA personality A, who mainly suggested reteaching or directly coaxing students toward specific content.

Box 3. Descriptive Noticing, Evaluative Interpreting, and Responsive Acting (Combination 3)

Teachers with this combination tended to focus on the level of specificity, the structure, or the style of students' responses, highlighting strengths or deficiencies. These teachers' actions were focused on increasing student engagement. For example, they proposed doing the volcano experiment with the students, as they might find it interesting and it could help students figure out how to make a bigger eruption. Their goal was often to develop general science skills such as experimentation and scientific writing.

Box 4. Inferential Noticing, Evaluative Interpreting, and Responsive Acting (Combination 4)

Teachers in this group often built inferences that then supported evaluations of the correctness of students' responses. However, they suggested actions focused on providing students with opportunities to express, explore, and evaluate their own ideas through methods such as experimentation, drawing, or peer review.

Teachers who adopted FA personality B tended to be authoritative in their interpretation of student work, focusing on the extent to which answers were correct or not, but were dialogic in their proposed actions, using students' ideas to make suggestions on how to move students forward. Within this FA personality, teachers in combination 3 often proposed actions directed at increasing students' engagement and interest in the task rather than further eliciting or advancing their thinking. The following excerpt illustrates this approach:

This would be so fun. Besides letting them debate, for starters. I think that the things that they said should be tried. Except for if they're dangerous. And that part, I don't know the chemistry, but, you know, exactly what they described. Add more, leave it open, close it up, heat it, and then explain if any of the solutions worked, and why. (G5-T5)

In this example, the teacher would encourage students to try their ideas, focusing more on exploration aspects than on chemical ideas. None of the combination 3 teachers discussed the chemical ideas that students expressed about controlling chemical reactions. Some participants in this category asked for assistance from other teachers in understanding the underlying chemistry in the selected FA task.

Teachers in combination 4 often proposed actions that created opportunities for students to express, explore, and evaluate their own ideas. Nevertheless, when these teachers proposed advancing moves (see Figure 1), they expressed a need for actions that carefully guided students in the right direction. Consider, for example, this suggestion:

Or you could have them analyze that reaction a little bit, like explain what this shows about why there's an explosion, or just describe in words what's happening in this reaction, or something like that, so that yeah, like they have to do something. And that could give you more information about how they're thinking about it. (G8-T2)

In this case, the teacher sought to narrow what students could do by asking them to analyze the chemical reaction given and to explain how it related to the chemical eruption. The proposed acting was responsive in that the teacher wanted students to think more deeply about the chemical process to both advance and gain further insight into student thinking.

FA Personality C: Dialogic Interpreting (Sense-Making) and Authoritative Acting (Directive)

This quadrant includes teachers (8 out of 41) who were mostly inferential in their noticing, sense-making in their interpreting, and directive in their acting (no teachers were descriptive in noticing while sense-making in interpreting). The characteristics of this FA personality are summarized in Box 5.

Box 5. Inferential Noticing, Sense-Making Interpreting, and Directive Acting (Combination 6)

Teachers adopting this combination shared the goal of unpacking student thinking to figure out what the student does or does not understand about particular chemistry topics. These teachers then used this information to develop next steps that focused on moving students forward toward a targeted scientific understanding.

Teachers who assumed FA personality C took a dialogic approach in interpreting student work, seeking to make sense of students' ideas. The following excerpt illustrates this interpretive approach:

I was thinking about what they probably have done in their own, with their own experience. Like the one student who talked about how vinegar is a known reactant with baking soda. And thinking about when the students were talking about having a smaller hole, like what maybe they had done before that led them to think that that would increase how the products came out. And then I also looked a lot at how viewing the reaction changed or didn't change their thinking about how to increase the reaction. (G8-T3)

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

In this example, the teacher was concerned with understanding the variety of different ways that students were thinking about the gas-producing reaction. She explored different interpretations of student actions and looked for trends across multiple students. This emphasis on diversity of voices and ideas illustrates a dialogic communicative approach in this teacher's interpretations.

Teachers with FA personality C proposed actions that directed students toward normative scientific understanding. These proposals often co-occurred with the expression of a desire to know the place of the FA task in the curriculum. Teachers stated that knowing what ideas they should be targeting with the activity was critical to proposing teaching actions. In the absence of this information, some participants assumed a particular content goal and then proposed how to act in response to students' ideas, as occurred in the following case:

> *They really need to be working on... on this. On the mole... the mole ratios and using that to figure out 'hey, what do I need to add to get nothing excess. To get everything used up. Maximize the reaction without basically wasting... wasting money, wasting chemicals. (G1-T4)*

This teacher described a directive advancing move (see Figure 1) that would provide students with carefully specific ways to move toward a particular scientific understanding. Teachers in this category often situated student thinking in the context of a specific topic in the chemistry curriculum rather than considering connections of ideas across different areas.

FA Personality D: Dialogic Interpreting (Sense-Making) and Dialogic Acting (Responsive)

The fourth quadrant included teachers (9 out of 41) whose practices were mainly a combination of inferential noticing, sense-making interpreting, and responsive acting. Major characteristics of this FA personality are summarized in Box 6.

Box 6. Inferential Noticing, Sense-Making Interpreting, and Responsive Acting (Combination 8)

Teachers with this combination used the FA to better understand how students were reasoning through problems in chemistry. They used what was uncovered about student reasoning to propose actions that pushed students to engage in deeper chemical thinking guided by their own ideas.

Teachers in this quadrant sought to make sense of students' ideas and proposed to allow students to use their ideas to complete the FA task. Consider the following excerpt:

> *Something I want to point out with Red4h's response, at first, I immediately, when I very first saw the prompt, I immediately was like, oh yeah, just replace it with sodium hydroxide. And then after like 30 seconds of thinking, I went, actually no, you need carbon dioxide. Like I know strong acid, strong base, they're going to react vigorously. But when you actually think, okay, what causes eruption, what you really want is bubbles. And they're, yeah, they'll bubble a little bit, but nowhere near like bicarbonate would. So I think that was interesting, that me and this student had like almost the same gut reaction, and then they clearly modified after seeing the reaction, whereas I kind of caught myself before seeing the reaction. (G10-T1)*

In this case, the teacher sought to make sense of how Red4h was trying to control the eruption by creating a different gas and did so by first recalling how he figured out himself that the eruption appearance is generated by a vigorous gas-forming reaction.

The acting suggestions that teachers in this category made were usually directed at either providing opportunities for students to build a stronger understanding of chemical ideas through experimentation and discussion (advancing student thinking in a dialogic manner), or opening ways to further uncover how the students thought about the problem (eliciting student thinking in a dialogic manner). Consider this example:

> *Looking at the thoughts and the idea about the hydrogen, maybe having them test the gases produced to see what happens with the flame, or allowing them to have certain tests to kind of have this sort of conceptual conflict. Like okay, you thought maybe that the hydrogen gas was produced, but when you put a flame there, it was extinguished. So they're up against this kind of conflict and friction between what they believe in their prior knowledge and what is actually happening in front of them in terms of the phenomena. (G11-T1)*

Here, the teacher proposed an advancing action (see Figure 1) based on the idea he saw in a student's response about hydrogen possibly being formed as a gas in the reaction. The action would give the student an opportunity to test out this idea in the lab but would also push the student to reconcile contradictions between what actually happened and what the student thought would occur. Teachers who employed FA personality D were the only ones who referred to opportunities for students to do their own sense-making. In addition, while middle school teachers were equally distributed among FA personalities A, B, and C, we found that FA personality D included only high school teachers. This may be an indication that the combination of dialogic interpreting and dialogic acting has a relationship with the educational level taught by the teacher or their chemistry content knowledge.

What Teachers Noticed

Our analysis of what teachers paid attention to in students' written work resulted in 17 codes organized into three categories: general noticing, topic-focused noticing, and noticing of chemical thinking (see Supporting Information). These three categories are described, followed by findings on what teachers who took different approaches (A, B, C, D in Figure 4) noticed.

General Noticing

All (N = 41) teachers engaged in general noticing that focused on figuring out how students operate when approaching a problem. For most teachers (N = 40), this involved a comparison. This included comparing students' answers (e.g., one student's answer is more specific than another's), noting whether a student's answer was the same or different from the teacher's own, matching answers to known misconceptions, or looking for self-consistency in a single student's answers. Teachers also looked for clues to ascertain how students may know something or what a student's educational situation was (N = 34). Most commonly, they expressed that it was important to know where students were in the chemistry curriculum, so they looked for signals of whether a student had previous exposure to gas laws or stoichiometry, for example, or clues about category assignments, e.g., a student who is "AP material" or an English language learner. Many teachers (N = 31) paid attention to more science-related indicators, such as the structure of students' arguments (e.g., whether they followed a claim−evidence−reasoning or a cause−effect pattern); the

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

specificity, sophistication, or quantity of chemistry vocabulary used; or whether or not a student showed calculations, used quantitative vs conceptual reasoning, or provided a procedure for how to carry out a proposed experiment. Some teachers (N = 8) focused on understanding how students would plan to use specific equipment, and whether it was appropriate, acceptable, or safe to use the equipment in these ways. About half (N = 20) of the teachers paid attention to features of the task and how those appeared to influence students to respond. For example, about one-third of teachers (N = 13) looked for evidence of whether students used ideas from the second page to revise answers on the first page.

Topic-Focused Noticing

Most (N = 39) teachers engaged in topic-focused noticing that centered on looking for evidence that students knew and could apply specific chemistry topics. The primary targeted topics of teachers' topic-focused noticing were gas behavior (N = 27), how particles behave (N = 26), amounts of reactants (N = 25), and stoichiometry (N = 25). The most common aspect of student responses noticed by teachers was that adding more reactants would generate a bigger "eruption". Many teachers also noticed when students recognized that increasing the gas pressure would increase the eruption and, primarily, looked for whether students applied a gas law argument to explain this. Teachers also focused on ratios of moles of reactants, limiting reagents, proportional yield, and stoichiometric calculations. Referring to particles was important to many teachers, who looked for evidence of reasoning based on kinetic molecular theory or collision theory and valued students mentioning arrangements of particles or how particles move. Many teachers (N = 14) also paid attention to whether students had misconceptions related to particles, as noted earlier.

Chemical Thinking Noticing

Most teachers (N = 37) also engaged in some noticing related to chemical thinking, but unlike topic-focused noticing where teachers paid attention to multiple topics, teachers primarily focused on chemical control thinking (N = 28), noticing how students proposed either: (a) changing the chemicals (N = 20), (b) changing the apparatus (N = 12), or (c) controlling the process (N = 11) in fundamentally different ways. Teachers' noticing of chemical control differed from the topic-focused noticing that was most often noted by teachers ("all the students got 'just add more'") in that teachers paid attention to whether a student's reasoning behind this was about controlling the reaction outcomes. When teachers focused on chemical control, they often also looked for multiple variables. For example:

> *Like it seemed like there were like four common, or like three to four like common themes. And if like we were talking about it in a whole class discussion, you got ideas, and then you hear like pressure, heat, amount of like products and reactants. (G7-T2)*

Some teachers (N = 20) noticed chemical causality thinking. These teachers mainly looked for whether students talked about the eruption being caused by a pressure build-up, and some teachers also looked for whether students reasoned about how a temperature increase causes the reaction to proceed faster. A few teachers also paid attention to which effects students considered important, e.g., faster reaction, more gas, or which gas. These are exemplified in the following teacher's chemical causality noticing:

> *What's causing the bubbles? And... realize that the CO_2 was what's going to cause that sodium citrate water solution to come out through the top. Or... Like those that switched the reactions, like the Red4H. And someone else, that SummerFanatic, mentioned adding acetic acid and more baking soda, they know that that's going to react. (G5-T4)*

Chemical mechanism thinking was also present in some teachers' noticing (N = 18). Half of these teachers paid attention to "the chemistry going on", which they clarified as meaning the class of reaction, e.g., gas-producing, acid−base, combustion. Some teachers focused on whether students differentiated CO_2-producing vs H_2-producing reactions. Others were interested in how students considered the role of water in the reaction. Chemical causality (what causes the change in outcome) and chemical mechanism (how does the change come about) noticing were sometimes difficult to discern because teachers often used the word "why" in ambiguous ways when discussing students. For example, G11-T4 discussed a student's ideas about "*why [heat] might change things*". It was not until several turns later that the teacher further explained that she noticed the student "*making the connection with heat and the way that changes the particle*". This clarified that the teacher was considering the student's thinking about the mechanism, i.e., how the outcome arises.

A little over one-third of teachers (N = 16) noticed chemical identity thinking. Most of these teachers focused on whether or how students identified or predicted the gaseous product of the reaction. Half of these teachers paid attention to compositional aspects, such as how students considered that elements in the reactants related to properties that products may have. The other half focused on the nature of different substances, such as strengths of different acids, and whether students considered aluminum as a reactant or as part of the equipment/materials.

What Teachers Who Assumed Different Personalities Noticed

Patterns emerged in a teacher's noticing according to which FA personality they assumed. All teachers engaged in general noticing, and only two differences stood out: all personality B and D teachers looked for whether consistency occurred across all students, and all personality B teachers additionally focused on whether students' answers were self-consistent. Figure 5 summarizes the other two categories of noticing demonstrated by 40% or more of teachers in each FA personality.

Teachers in FA personalities B and C exhibited the narrowest focuses in what they noticed. FA personality A teachers tended to focus more on whether an aspect was present in students' responses while personality D teachers noticed how students reasoned and talked about their ideas. Personality A teachers tended to look for students' use of stoichiometry or manipulation of external variables, such as pressure and temperature, and the relationships among variables. This noticing approach may have channeled teachers to propose more remediative actions, such as reteaching material that students had not sufficiently mastered. Teachers who assumed FA personality B had the narrowest focuses of the four groups, and their noticing centered on problems that often are practiced to a considerable extent in chemistry courses, e.g., predicting products, determining what gas would be produced in a given reaction, and recognizing that rate is proportional to temperature. The greater focus by personality B teachers on changes that students could make to reaction conditions, combined with whether students demonstrated similar responses, may have

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

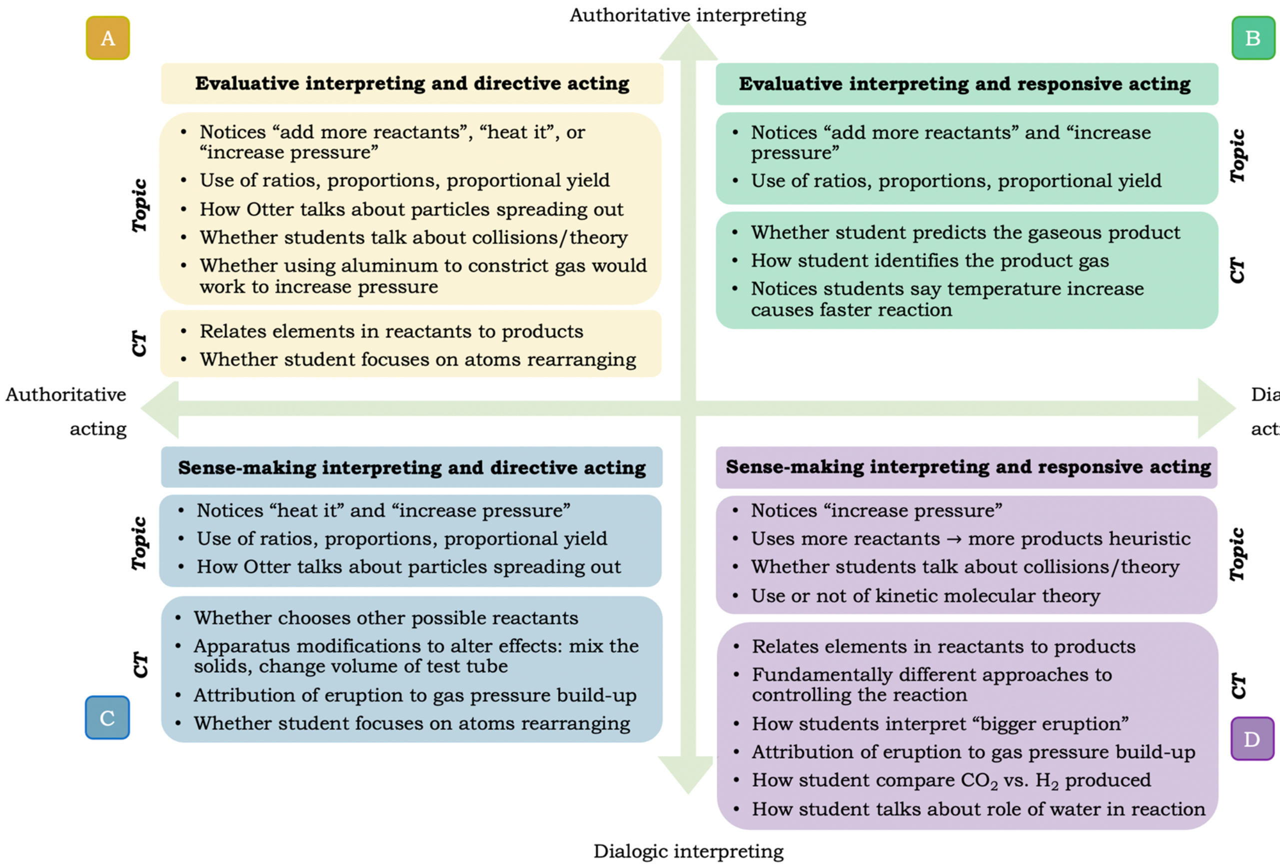

Figure 5. Topic-focused and chemical thinking (CT) focused noticing of teachers who assumed different FA personalities.

supported the teachers' responsive tendencies to propose trying out options in the lab. FA personality C teachers were less concerned with identifying mastery of specific chemistry topics and focused more on what students' ideas were. Nevertheless, their acting intended to carefully guide students to correct answers. The greater diversity of what teachers with FA personality D noticed, combined with their attention to whether students had similar or different ways of thinking, may help explain why they were more responsive in their acting.

Ambiguities and Other Limitations

The four FA personalities described in the previous sections can be seen as "hats" that teachers wear in their dynamic orchestration of FA activity, in this case when considering students' written work. In related research,[23] we have shown that experienced science teachers demonstrate versatility in moving back and forth between authoritative and dialogic teaching acts in response to in-the-moment purposes that guide their FA enactment (see Figure 1). It may be that our participants also were guided by in-the-moment purposes that they generated in relation to particular student responses, the context of the focus group discussion at that moment, and their own experiences. This could explain why a few teachers' FA personalities appeared to oscillate and therefore were not easy to categorize.

Besides some ambiguity, the methodology also imparted some limitations. The participants had a range of experiences and positions; however, a sample of 41 teachers is not necessarily representative of all chemistry teachers. In some cases, we had more demographic data than in other cases, which also limited our ability to draw findings across the entire sample. For example, we noticed a relationship between FA personality B approaches and formal preparation in chemistry or experience with content-focused professional development; however, we did not collect this information from all participants. Some participants brought this up during focus group discussions, but it also could have been relevant for others who did not bring it up. Furthermore, while the focus group methodology was selected because it conferred specific benefits, there are also known limitations to this method.[34] Sometimes a few individuals can dominate group talk while others feel sidelined; this may have happened with the two teachers who were removed from the sample due to their minimal talk. There also can be tendencies toward normative talk which can have an effect of discouraging diverse ideas to be raised and debated. We were aware of these limitations. We structured the protocol to reduce impacts, and the focus group facilitators in our team prepared strategies to minimize effects, but these may have been insufficient in some cases.

CONCLUSIONS AND IMPLICATIONS

On a domain-general level, our study allowed us to identify four main FA personalities that teachers adopted when noticing, interpreting, and acting in response to written student work generated by the probe used in our study. These FA personalities can be independently authoritative or dialogic in interpreting and acting. Teachers can focus on canonical correctness (evaluative) or can take a sense-making approach to interpreting. Proposed actions to address interpretations of students' thinking can narrow toward normative ideas or include students' ways of thinking in proposed follow-up. Each of the four FA personalities has utility and power. Our findings indicate that teachers who notice inferentially can do so in addition to

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

evaluating on the basis of canonical correctness, and teachers who propose more responsive acting can do so in addition to considering whether students need support in understanding difficult material. Nevertheless, interpreting more inferentially and proposing more responsive acting was not the norm and likely requires more targeted professional development.

As teachers build recognition of when they adopt a particular personality, they may find that some personalities are more or less productive depending on various conceptual, pedagogical, and contextual factors. For example, taking a more authoritative interpreting (evaluative) and acting (directive) stance may be the most productive when helping students develop specific practical skills in the laboratory, where evaluating students' abilities to manipulate equipment and directing their actions may be critical for safely completing a task. Adopting a more dialogic interpreting (sense-making) and acting (responsive) stance is likely to be beneficial when we want students to reflect on their intuitive ideas and meaningfully construct new understandings.

At the domain-specific level, most participants in our study engaged in both topic-focused and chemical thinking focused noticing, but they differed in the extent to which they attended to the presence or absence of specific ideas in student thinking versus recognizing and wondering about the different ideas students considered and the different ways they talked about them. Interestingly, whether teachers adopted an evaluative or a sense-making stance in the interpretation of student work, or a directive or responsive stance in the proposed acting, did not necessarily determine the diversity of students' expressed chemical ideas they paid attention to. Participants also demonstrated the ability to identify and assess relevant chemical thinking in students' answers to the assessment probe. This suggests that teachers can notice a variety of ideas in student thinking but need support in strengthening their capacity for dialogic manners of professional noticing, i.e., sense-making interpreting and responsive acting.

The findings from this study can be useful to teachers in gauging whether their own noticing tends to focus primarily on what students know and can do, or whether they also focus on the diverse manners in which students think. The coding categories and examples (see Supporting Information) can be used by teachers to compare against how they evaluate their own student work in the Volcano Probe or similarly rich FA tasks. Our results suggest that more diverse noticing may increase when teachers pay attention to whether answers are consistent across all students, and when they analyze the different variables students focus on in their analyses. Practicing these forms of noticing might lead to strengthened teaching practices.

The findings also have implications for professional development to support experienced chemistry teachers in continued diversification of their teaching practices and intentionality in their implementation. Rich FA tasks that are open-ended can create more opportunities to reveal student thinking when implemented in ways that maintain intellectual rigor.[4] These types of tasks open room for students to make different interpretations and to foreground different ways of thinking. These goals can be advanced through professional development that supports teachers in developing or adapting tasks to be richer in these ways, and also provides opportunities for teachers to examine which personalities they assume as they evaluate their students' written responses to these tasks. Given increased demands to develop students' content understanding while engaging in scientific practices and focusing on crosscutting concepts,[5] the versatility of chemistry teachers in attending and responding to students' chemical thinking is critical to support.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.9b01198.

Focus group interview protocol (PDF)

Coding categories and examples of noticing (PDF)

■ AUTHOR INFORMATION

Corresponding Author

Hannah Sevian – *Department of Chemistry, University of Massachusetts, Boston, Massachusetts 02125, United States;* orcid.org/0000-0001-7378-6786; Email: hannah.sevian@umb.edu

Authors

Stephanie A. Murray – *Department of Chemistry, University of Massachusetts, Boston, Massachusetts 02125, United States*

Robert Huie – *Boston Public Schools, Boston, Massachusetts 02108, United States*

Rebecca Lewis – *Hingham Public Schools, Hingham, Massachusetts 02043, United States*

Scott Balicki – *Boston Public Schools, Boston, Massachusetts 02108, United States*

Michael Clinchot – *Boston Public Schools, Boston, Massachusetts 02108, United States*

Gregory Banks – *Boston Public Schools, Boston, Massachusetts 02108, United States*

Vicente Talanquer – *Department of Chemistry and Biochemistry, University of Arizona, Tucson, Arizona 85721, United States;* orcid.org/0000-0002-5737-3313

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.jchemed.9b01198

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors acknowledge NSF Award DRL-1621228 which supported this work, and members of the Sevian research group for valuable discussions. We also acknowledge early contributions by Jennifer Lambertz, Courtney Ngai, Steven Cullipher, and Melissa Weinrich, who worked with the team during the initial design of the study. We are grateful to Pamela Pelletier and Marianne Dunne for their ongoing support of this work.

■ REFERENCES

(1) Bell, B.; Cowie, B. The Characteristics of Formative Assessment in Science Education. *Sci. Educ.* **2001**, *85* (5), 536–553.

(2) Sevian, H.; Talanquer, V. Rethinking Chemistry: A Learning Progression on Chemical Thinking. *Chem. Educ. Res. Pract.* **2014**, *15* (1), 10–23.

(3) Sevian, H.; Dini, V. A Design-Based Process in Characterizing Experienced Teachers' Formative Assessment Enactment in Science Classrooms. In McLoughlin, E., Finlayson, O. E., Erduran, S., Childs, P., Eds.; *Bridging Research and Practice in Science Education*; Sense Publishers: Rotterdam, The Netherlands, 2019; pp 325–337.

(4) Kang, H.; Windschitl, M.; Stroupe, D.; Thompson, J. Designing, Launching, and Implementing High Quality Learning Opportunities

for Students that Advance Scientific Thinking. *J. Res. Sci. Teach.* **2016**, *53* (9), 1316−1340.
(5) National Research Council. *A Framework for K-12 Science Education*; National Academies Press: Washington, DC, 2012.
(6) Goodwin, C. Professional Vision. *Am. Anthropologist* **1994**, *96*, 606−633.
(7) van Es, E. A.; Sherin, M. G. Learning to Notice: Scaffolding New Teachers' Interpretations of Classroom Interactions. *J. Technol. Teacher Educ.* **2002**, *10* (4), 571−596.
(8) Talanquer, V.; Bolger, M.; Tomanek, D. Exploring Prospective Teachers' Assessment Practices: Noticing and Interpreting Student Understanding in the Assessment of Written Work. *J. Res. Sci. Teach.* **2015**, *52* (5), 585−609.
(9) Jacobs, V. R.; Lamb, L. L. C.; Philipp, R. A. Professional Noticing of Children's Mathematical Thinking. *J. Res. Math. Educ.* **2010**, *41* (2), 169−202.
(10) Ogborn, J.; Kress, G.; Martins, I.; McGillicuddy, K. *Explaining Science in the Classroom*; Open University Press: Buckingham, 1996.
(11) Mortimer, E. F.; Scott, P. *Meaning Making in Secondary Science Classrooms*; Open University Press: Philadelphia, 2003.
(12) Chin, C. Classroom Interaction in Science: Teacher Questioning and Feedback to Students' Responses. *Int. J. Sci. Educ.* **2006**, *28* (11), 1315−1346.
(13) *Responsive Teaching in Science and Mathematics*; Robertson, A., Scherr, R. E., Hammer, D., Eds.; Routledge: New York, 2016.
(14) Coffey, J. E.; Hammer, D.; Levin, D. M.; Grant, T. The Missing Disciplinary Substance of Formative Assessment. *J. Res. Sci. Teach.* **2011**, *48* (10), 1109−1136.
(15) Lineback, J. E. The Redirection: An Indicator of How Teachers Respond to Student Thinking. *J. Learn. Sci.* **2015**, *24* (3), 419−460.
(16) Cowie, B.; Bell, B. A Model of Formative Assessment in Science Education. *Assess. Educ.: Princ., Polym. & Pract.* **1999**, *6* (1), 101−116.
(17) Colestock, A.; Sherin, M. G. What Teachers Notice When They Notice Student Thinking: Teacher-Identified Purposes for Attending to Student Thinking. In *Responsive Science Teaching*; Robertson, A., Scherr, R., Hammer, D., Eds.; Routledge: New York, 2015; pp 126−144.
(18) van Es, E. A.; Sherin, M. G. Mathematics Teachers' "Learning to Notice" in the Context of a Video Club. *Teach. Teacher Educ.* **2008**, *24* (2), 244−276.
(19) Windschitl, M.; Thompson, J.; Braaten, M. Ambitious Pedagogy by Novice Teachers: Who Benefits from Tool-Supported Collaborative Inquiry into Practice and Why? *Teachers Coll. Rec.* **2011**, *113* (7), 1311−1360.
(20) Windschitl, M.; Thompson, J.; Braaten, M. *Ambitious Science Teaching*; Harvard Education Pub Group: Cambridge, MA, 2018.
(21) Ruiz-Primo, M. A.; Furtak, E. M. Exploring Teachers' Informal Formative Assessment Practices and Students' Understanding in the Context of Scientific Inquiry. *J. Res. Sci. Teach.* **2007**, *44* (1), 57−84.
(22) Dini, V.; Sevian, H.; Caushi, K.; Orduña Picón, R. Characterizing the Formative Assessment Enactment of Experienced Science Teachers. *Sci. Educ.* **2020**, *104* (2), 290−325.
(23) Bereiter, C. Principled Practical Knowledge: Not a Bridge but a Ladder. *J. Learn. Sci.* **2014**, *23* (1), 4−17.
(24) Kang, H. Situating Teachers' Productive Responsiveness in Instructional Context. Paper presented at *NARST*; Atlanta, GA, 2018.
(25) Kind, V. *Beyond Appearances: Students' Misconceptions about Basic Chemical Ideas*, 2nd ed.; Royal Society of Chemistry: London, 2004.
(26) Johnson, P. Children's Understanding of Substances, Part 2: Explaining Chemical Change. *Int. J. Sci. Educ.* **2002**, *24* (10), 1037−1054.
(27) Talanquer, V. Commonsense Chemistry: A Model for Understanding Students' Alternative Conceptions. *J. Chem. Educ.* **2006**, *83* (5), 811−816.
(28) Taber, K. S.; García-Franco, A. Learning Processes in Chemistry: Drawing upon Cognitive Resources to Learn about the Particulate Structure of Matter. *J. Learn. Sci.* **2010**, *19* (1), 99−142.
(29) Goedhart, M. J.; Kaper, W. From Chemical Energetics to Chemical Thermodynamics. In *Chemical Education: Towards Research-based Practice*; Gilbert, J. K., De Jong, O., Justi, R., Treagust, D., van Driel, J., Eds.; Kluwer: Dordrecht, 2002; pp 339−362.
(30) Rabiee, F. Focus-group Interview and Data Analysis. *Proc. Nutr. Soc.* **2004**, *63* (4), 655−660.
(31) Dalgety, J.; Coll, R. K.; Jones, A. Development of Chemistry Attitudes and Experiences Questionnaire (CAEQ). *J. Res. Sci. Teach.* **2003**, *40* (7), 649−668.
(32) Clinchot, M.; Ngai, C.; Huie, R.; Talanquer, V.; Lambertz, J.; Banks, G.; Weinrich, M.; Lewis, R.; Pelletier, P.; Sevian, H. Better Formative Assessment: Making Formative Assessment Responsive to Student Needs. *Sci. Teacher* **2017**, *84* (3), 69−75.
(33) Krippendorff, K. Computing Krippendorff's Alpha-Reliability. Departmental Papers, Annenberg School for Communication, University of Pennsylvania, 2011. https://repository.upenn.edu/asc_papers/43/.
(34) Smithson, J. Using and Analysing Focus Groups: Limitations and Possibilities. *Int. J. Soc. Res.* **2000**, *3* (2), 103−119.

https://dx.doi.org/10.1021/acs.jchemed.9b01198
J. Chem. Educ. XXXX, XXX, XXX−XXX

Teacher Focus Group Interview Protocol

Before participating in the focus group, teachers will watch the same silent 3-minute video that students watched before answering the questionnaire, and then they will answer the student handout so that they are familiar with the questions the students answered. Teachers will not be asked to share their own answers. Then teachers are given the student answers and asked to silently jot down *feedback* to these students' answers (this will be collected).

#	Question Asked by Interviewer
1	I have specific questions I'm going to be asking you to just kind of prompt the discussion. I'll move on to different questions at different points so that we can get through all the questions. I just want to let you know right now that it's going to feel unsatisfying cause we won't get to talk about everything that everyone has thought of. (The other thing I'd like to ask is if you could please try and make sure that everybody gets to have some voice. – bring up if it becomes an issue) This should be more like a conversation instead of an interview. If someone says something common or dissimilar to what you were thinking bring it up. The first question that I want to ask about it is: **What did you pay attention to in the students' answers and why did you pay attention to those things?**
2	Please go around and also start talking about some of the things that you saw in the students' answers. **When you were paying attention to different things in different students' answers, what kinds of things jumped out at you?**
3	(When teachers seem to coalesce around a particular student's answers, then say) **You've talked about some of the things this student** [*identify by response number/code*] **wrote. How do you make sense of that?** *Some possible follow-up questions:* • What do you think is going on with the student? • How do you make sense of what the student said? • You noticed that this student said contradictory things (*repeat what teachers said*). What do you think the student was thinking? • What is your gut instinct about what this student is thinking? • What in the student's answer makes you think that's what the student is thinking?
4	**Let's talk about a different student. Please pick another student whose answers are different than the first one and talk about what you think is going on with the student.** *Repeat this with a few more students…*
5	**Can you talk a little about the patterns you saw in the student responses?**
6	**Imagine now that what you have seen in these student responses is a representative sample of a whole class of students. Please talk about what is your decision making process in order to figure out what you would do as a teacher in response to this set of students' answers.** *Rephrasing (if needed):* **Let's say you have all of these students in front of you, how do you make a decision about what's the best action to help the class?**
7	Now that you've talked about a lot of things that can be done, let's say you have this class, and you give them this probe and they give you these probes back and you look through them that night and you come back in tomorrow and, you don't have a whole lot of time to spend on this because you've got other stuff you also need to do. **What could you do that you would get the biggest bang for the buck? What's one thing?**
8	**How can the probe be improved to do a better job of finding out what students are thinking?**

Driving Question: What is the teacher searching for in the student work?

Category 1: General Noticing

Description: The main focus of the teacher is to figure out something about how the student operates. This can be about what the student may already have learned or where the student's class is within a year of chemistry. It might be about how the student has responded to the task, or how the task seems to have influenced the student to respond. Most indicators of this type of noticing are not related to specific chemistry ideas, but more about what the student is apt to do, or why the student is a particular way.

1 – Student or Curriculum
Description: The teacher is trying to find out how the student knows something, or whether the student is good at this subject.
Common examples: • Level of the student's chemistry background (middle or high school) • Relating to when different topics occur in the curriculum • Whether the student is using "chemical knowledge" (unspecified what knowledge) • Noting particular topics that student must have studied recently (gases, stoichiometry, mole concept, acids & bases, gas laws) • Indicators that the student is "AP material", or an English language learner, special education student, or like the teacher's own students in some ways • Identifying whether student X knows more or has a better answer than student Y

1 – General How
Description: The teacher is trying to find out how strategically or with what generally school-based ways the student approached answering the questions, including comparisons to other students and to the teacher's approach.
Common examples: • Student writes the same answer three times just rephrased, or the student has three different ideas • Whether the student's answers on page 2 differ from the answers given on page 1, or whether the student is consistent or contradicting self in answers on same page • Presence of thinking, understanding/lack of understanding, creativity, curiosity, confidence, careful consideration • Student tries to parrot back answers to the teacher or "doing school" • Able to make claims, defend them, explain well or not, justify appropriately or not • The student is capable of being specific, detailed or ambiguous, able to give a coherent complete account • The student has misunderstandings or typical misconceptions • Comparing or judging the student's answer against other students' answers or by the teacher's own answer

1 – Content How
Description: The teacher is trying to find out how the student is following (or not) generic chemistry or science ways of doing the problem.
Common examples: • The student uses chemistry vocabulary • Whether the student has explained the chemistry vs. justified the chemistry • Noting whether the student can do conceptual vs. quantitative reasoning/answering • Does the student use cause-effect reasoning, or do scientific claims-evidence reasoning properly • Is the student thinking mathematically • Are math calculations shown (in the stoichiometry question) • Is the procedure for how to do something explained, is it reasonable, does the student set up an experiment to test only one variable at a time, does the student specify the outcomes to watch, is a prediction made • Lament that the student did not draw a visualization (macroscopic lab setup or submicroscopic particles) • Is the student drawing from chemistry knowledge or some other knowledge (physics, engineering) to answer

Driving Question: What is the teacher searching for in the student work?

1 – Equipment/Lab Procedure How
Description: The teacher is trying to find out how the student plans laboratory procedures and how well the student can write a lab-based explanation or plan.
Common examples: • Whether the student specifies using other equipment options (e.g., hot plate, different test tubes), including proposing using equipment that was not on the list • Whether the student explains the procedure to be used, what would be measured, how much to use, what purpose to use the equipment for • Whether the student talks about using the equipment safely and/or intentionally

1 – Task Influence
Description: The teacher is trying to learn how the task may have directed the student to do something, including visuals in the video, specific words or cues in the task, and order and organization of information presented in the task.
Common examples: • Whether the student referred to the video or picked up on specific items shown in the video • Whether, and possibly which, ideas on the second page prompted the student to return to considering, and maybe revising, the ideas the student had written about on the first page • Whether properties of the prompt cue the student to structure the response in a claims-evidence-reasoning format • Whether the open-ended nature of the task caused students to open up (e.g., leading to diversity of ideas) or to shut down (e.g., leading to minimal answers) • How the task compares to tasks that the teacher often uses, with the purpose of then looking for ways that students could be responding to this type of task • Whether the student picked up on the words “explain” and “justify” and what this caused the student to do

Category 2: Topic-Focused Noticing

Description: The main focus of the teacher is to find out what chemistry content knowledge the student knows and can apply to this problem. This can include identifying topics in the curriculum that the student is using successfully or incorrectly, specific skills that a student must become good at in order to master the topic, or whether the student is making a mistake that is common when learning that topic.

2 – Amount of Reactants
Description: The teacher is noticing that students know that adding more reactants will make the eruption bigger.
Common examples: • Notes that students say "add more reactants" • Notices that a student did not say which reactant to add more of • Points out that a student did not say how much more of a reactant to add • Synthesizes that students are using a "more reactants $\rightarrow$ more products" heuristic

2 – Heating
Description: The teacher is noticing that students know that heating increases the reaction outcome.
Common examples: • Notes that students say "heat it" • Notices that students refer to an outcome of heating, typically that the reaction will be faster or greater • Notices ways that students propose to run the reaction at a hotter temperature, such as by heating the water before adding it • Notices when a student talks about how heating makes particles move faster or have more collisions

2 – Stoichiometry
Description: The teacher is trying to find out whether the student knows how to solve stoichiometry problems, including writing and balancing a reaction and knowing what the coefficients mean, understanding the idea of proportional yield, identifying the limiting or excess reagent, and doing calculations correctly.
Common examples: • Notices that the student used ratios or proportions correctly or not, or reasoned based on proportional yield • Whether the student identified which reactant to increase based on stoichiometry, or identified the limiting reagent • Notices that the student does or doesn't know how to do stoichiometry • Whether the student can balance a chemical equation or calculate molar mass

2 – Particles and Particle Theory
Description: The teacher is trying to find out whether the student can or does use a particulate model to explain a process.
Common examples: • Concentrates on how Otter talks about the particles spreading out and getting bigger, focusing on the misconceptions this student has about particles • Notices when students talk about particle motion as part of their explanation • Notes when students talk about collisions or collision theory • Pays attention to whether a student uses kinetic molecular theory, or reasons based on kinetic energy of particles

2 – Kinetics
Description: The teacher is looking for whether the student brings kinetics knowledge to solve the problem.
Common examples: • Notes that the student is using a rate equation • Notes that a student is referring to rate of reaction

Driving Question: What is the teacher searching for in the student work?

2 – Gas Behavior
Description: The teacher is trying to find out whether the student knows and can apply knowledge about gas behavior, including applying or failing to apply gas laws, understanding of P-V-T relationships, how modifying the apparatus to constrict the volume would affect the pressure, and whether or how the student distinguishes phases of matter.
Common examples: • Notices that students are talking about increasing pressure • Notices that students propose altering the apparatus to constrict the volume or increase the pressure (of the gas), such as using a smaller test tube or making the gas emerge through a smaller opening • Notes that students do or don't relate variables of a gas (P, V, and T), or that they account for these variables • Notices when students apply the gas law, or could use the gas law to better their explanations • Notices when a student has confusions about gas, such as thinking it is not visible, or not having a clear grasp on how particles are organized in solid, liquid, and gas phases

Category 3: Chemical Thinking Noticing

Description: The main focus of the teacher is to learn how the student thinks about major questions that chemistry enables answering. The teacher may be paying attention to which parameters a student thinks are important in controlling a reaction, what models of how a reaction happens are relevant, or what are different approaches students take to modifying the reaction. The teacher may be focusing on whether or how a student is or is not identifying which gas is being produced, or how one might determine this. The teacher may be focusing on how students are thinking about what is causing the reaction, or how the reaction is occurring.

3 – Substance identity
Description: The teacher is trying to find out whether or how the student is thinking about the identity of the gas produced or what types of chemicals the reactants are or could be.
Common examples: • Notices whether the student identifies or predicts what the gaseous product of the reaction is, and/or how the student identifies the products or reactants • Considers how the student is thinking about the different elements in the reactants and what properties those may lend to the products that contain those elements (e.g., hydrogen in the acid, or CO_2 in the bicarbonate, whether sodium is reactive) • Looks for whether the student is paying attention to which is the strongest acid or base to choose • Focuses on two different ways that the student could think of aluminum, as a possible reactant (since it is listed under the chemicals) or as a piece of equipment

3 – Control by changing the chemicals
Description: The teacher is trying to find out how the student thinks about modifying the chemicals to control the eruption.
Common examples: • Whether or not students choose other possible reactants, or whether they point out that changing a reactant would modify the outcome, or whether they explain why both (not one) reactants should be increased • Notices that students choose the “dangerous” chemicals to react because they think this would produce more spectacular outcomes • Notices that students propose mixing lots of chemicals together, or adding something to the products • Focus on risk in changing the reactants (usually as the teacher expressing concern that some combinations may be dangerous) • Notices that a student says to add more water

3 – Control by modifying the apparatus
Description: The teacher is trying to find out how the student thinks about ways that reaction can occur differently if physical changes are made to affect how the reaction takes place.
Common examples: • Pays attention to <u>how</u> students try to modify the apparatus to control the pressure, which equipment student opts to use and how that would modify how the reaction occurs, e.g., focusing on how a student talks about the way that using a smaller test tube or molding aluminum foil around the opening would constrict the volume or change the pressure • Notices that students think that mixing the solids (citric acid and baking soda) matters for the reaction • Notes that students say to shake the container or mix the gases • Notices that students are paying attention to which volume is being modified, the space that the solids or liquids occupy in the test tube or the space that the gas occupies, e.g., adding more solids decreases gas space • Pays attention to whether students propose using different equipment to for the purpose of altering the way the reaction occurs (e.g., use a different flask that has another hole in it which can be used for something)

3 – Different ways of controlling
Description: The teacher is trying to find out which different ways students think about controlling the eruption.
Common examples: • Notices that students have different approaches to modifying the reaction: heating it, changing the chemicals, changing the apparatus • Focuses on whether students' ideas for controlling the eruption are fundamentally different • Pays attention to different ways students interpret what "bigger eruption" means, e.g., more gas, gas comes out faster, change it to be explosive

3 – Cause of eruption
Description: The teacher is trying to find out what the student thinks causes the eruption.
Common examples: • Notices if a student says that the eruption is caused by a gas or by a pressure build-up, or notes if a student does not recognize this • Notices when a student focuses on heat causing a more energetic reaction • Notices when a student says that temperature causes the reaction to go faster • Pays attention to which causes a student thinks are important (faster reaction, more bubbles pushing up) • Whether a student understands that an eruption caused by pressure increase from gas is not the same as an explosion from a combustion reaction • Whether the student is noticing that the reactants in the chemical equation go from (aq) to (g) • Focuses on whether a student is paying attention to different drivers of outcomes: kinetics/rate of gas production vs. thermodynamics/how much gas is produced

3 – Mechanism of eruption
Description: The teacher is trying to find out how the student thinks about the way that the eruption is made.
Common examples: • Focuses on "the chemistry going on", referring to what the reaction is or what type of reaction it is (acid-base, gas producing, combustion) • Pays attention to whether student reasons based on a reaction which gas (e.g., CO_2 or H_2) would be produced by this reaction • Whether a student considers ways that atoms rearrange to form products that are different than reactants • Notices that a student talks about knowing that vinegar reacts with baking soda or wonders about what the student means by this, or that another student talks about knowing how bicarbonate reacts • Whether students recognize how the limiting reagent limits the rate • Whether students show how the rate equation leads to more reactants $\rightarrow$ more products for this reaction • Notices when a student talks about whether this reaction produces a gas quickly or not • Reflects on how student is comparing CO_2 vs H_2 producing reactions, or whether the student is describing a gas-generating reaction or an explosion mechanism • Talks about how the gas or the water plays a role in the reaction • Whether student understands how the system functions, e.g., P, V, and T relationships as part of the system • Whether the student narrates how the particles of specific substances collide