Characterizing a New Dimension of Change in Attending and Responding to the Substance of Student Thinking

Jennifer Richards, Andrew Elby, Ayush Gupta, University of Maryland, 2311 Benjamin Building, College Park, MD 20742
Email: jrich@umd.edu, elby@umd.edu, ayush@umd.edu

Abstract: "Responsive teaching," in which teachers attend and respond to the substance of students' ideas, is central to facilitating student learning through engagement in authentic disciplinary practices. In characterizing teachers' progress toward greater responsiveness, researchers typically code teachers' attention as shifting toward the intellectual content (substance) of students' ideas and away from other foci such as students' correctness. These schemes, however, do not distinguish between different aspects of the substance of students' ideas. In this paper, we argue that a science teacher, Mr. S, demonstrates progress not by shifting toward greater attention to "substance," but rather by shifting in the facet of student thinking to which he primarily attends and responds. He shifts toward attending to causal stories (mechanistic explanations) and away from causal factors (potentially relevant variables). We argue that such shifts toward more sophisticated epistemic practices should be targets of professional development and of the assessment of responsive teaching.

Introduction

When teachers attend and respond to students' ideas and seek to draw out or connect them with important aspects of the discipline, students demonstrate enhanced conceptual understanding (e.g., Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Pierson, 2008) and experience rich opportunities to engage in disciplinary practices, such as explanation-building and argumentation in science (e.g., Berland & Reiser, 2009; Duschl & Gitomer, 1997). Ball (1993) has described this sort of teaching as involving "twin imperatives of responsiveness and responsibility" (p. 374) – focusing on and grounding instruction in students' ideas, while helping them learn important disciplinary ideas and practices. In science, Hammer and van Zee (2006) highlight the importance of teachers focusing on various beginnings of science in what students are saying and doing. Take the following example they discussed: A student says it gets hotter in the summer because the earth is closer to the sun. Although this idea is incorrect and widely considered to be a common student misconception about the seasons, Hammer and van Zee emphasize the scientific features of the explanation – its mechanistic nature, tangibility, and consistency with other information the student knew. These are a few examples of scientific aspects teachers could note and promote in students' reasoning; Hammer and van Zee describe numerous others (e.g., anticipation of counterarguments, clarity of expression, etc.).

Characterizations of favorable change in attending and responding to the substance of student thinking, however, primarily emphasize how closely teachers focus on students' meanings with little attention to the sorts of discipline-specific features they notice. Researchers tend to focus on the specificity with which teachers attend to students' ideas (e.g., Jacobs, Lamb, Philipp, & Schappelle, 2011; van Es, 2011), the stance teachers take toward students' ideas (e.g., Crespo, 2000; Goldsmith & Seago, 2011), and/or the types of follow-up moves teachers make in response to students' ideas (e.g., Brodie, 2011; Pierson, 2008). These foci foreground teachers' treatment of students' ideas – in some cases, in the context of specific disciplinary domains, like elementary school students' mathematical problem-solving strategies – but do not clearly address the range of disciplinary aspects teachers may attend to in what they hear.

In this paper, our primary aim is to bring discipline-specific considerations into the discussion of change in attending and responding to the substance of student thinking. Drawing on two similar lessons taught by middle-school science teacher "Mr. S" in successive years, we argue that part of what constitutes the favorable change in Mr. S's attention and responsiveness to student thinking between April 2010 and March 2011 is the aspects of scientific reasoning and explanation Mr. S foregrounds with respect to students' ideas in each case.

Literature Review: Identified Dimensions of Favorable Change in Attending and Responding to Student Thinking

We begin by reviewing the dimensions along which researchers describe favorable change in attending and responding to student thinking, demonstrating that these dimensions are largely free of discipline-specific features.

A common consideration in evaluating responsiveness is whether teachers' descriptions of students' reasoning are a) general and draw on superficial aspects of the ideas or b) specific and draw on details and nuances within the ideas, with the latter considered more responsive (e.g., Crespo, 2000; Fennema et al., 1996;

Franke, Carpenter, Fennema, Ansell, & Behrend, 1998; Jacobs et al., 2011; Kazemi & Franke, 2004; Levin & Richards, 2011; van Es, 2011). For instance, in a teacher work group in which teachers were expected to share how their students approached a particular mathematics problem, Kazemi and Franke noted that early on, teachers focused on whether students' strategies were correct or not but paid little attention to the specifics of students' solutions. Similarly, Crespo noted that the preservice teachers in her study initially made claims about student understanding that were not grounded in much evidence, but later, teachers' "comments revealed greater attention towards the meaning of student's mathematical thinking rather than surface features" (p. 170). Similarly, in van Es's framework, part of what distinguishes Level 1 (baseline) from Levels 3 (focused) and 4 (extended) is that teachers in Level 1 "form general impressions of what occurred" and "provide little or no evidence to support analysis," whereas teachers in Level 3 or 4 "refer to specific events and interactions as evidence" (p. 139).

Another way in which researchers characterize favorable shifts in attending and responding to student thinking is in movement from an evaluative stance (looking only for correctness) to an interpretive stance (making sense of students' ideas) (e.g., Brodie, 2011; Crespo, 2000; Empson & Jacobs, 2008; Goldsmith & Seago, 2011; Levin & Richards, 2011; Pierson, 2008; van Es, 2011). In teacher work groups, researchers analyze the types of comments teachers make when looking at student artifacts. For instance, Goldsmith and Seago described how early mathematics teacher work groups interpreted student work in light of the correct answer, whereas later they looked for the logic in students' own solutions. Revisiting van Es's framework, stance is also integrated into the different levels. For example, in Level 2 (mixed), teachers "provide primarily evaluative with some interpretive comments" (van Es, p. 139), whereas in Levels 3 and 4 teachers shift to entirely interpretive comments.

In situ in the classroom, researchers interpret the teacher's stance based on the follow-up moves the teacher makes in response to students' ideas. For example, Empson and Jacobs (2008) define a progression in listening expertise that moves from directive listening (where the teacher focuses on alignment between a student's idea and an expected response and actively seeks to elicit the expected response) to observational listening (where the teacher passively listens to students' ideas without seeking to extend them) to responsive listening (where the teacher actively probes students' ideas and seeks to understand and build on the details). Similarly, Brodie (2011) and Pierson (2008) differentiate between follow-up moves that are corrective versus interpretive in nature. In these examples, the shift is in how teachers view and thus work with students' ideas and involves a change from seeking to evaluate students' ideas to seeking to understand them in more depth.

In summary, the shifts in attention/responsiveness described above depict movement from a) evaluating students' ideas, focusing on surface features to determine alignment with expected responses and making follow-up moves to push students in particular directions, to b) interpreting students' meaning, focusing on the details of students' ideas and making follow-up moves to elicit more information from students. While these are important aspects of responsive teaching, they do not shed much light on how teachers are attending and responding to specific disciplinary aspects of students' ideas. In this paper, we illustrate and tease apart two particular ways in which teachers' interpretive follow-ups to students' ideas can intersect with authentic disciplinary reasoning.

Data Sources and Analytical Approach

The data in this paper come from a professional development project aimed at helping fourth through eighth grade teachers promote inquiry teaching and learning in their science classrooms. Teachers voluntarily apply and may continue in the project for multiple years. As part of the project, teachers attend a two-week summer workshop in which they engage in their own minimally-guided inquiry, watch classroom video of students discussing scientific phenomena, and collaborate on other issues related to inquiry teaching and learning in the classroom (i.e., assessment, lesson planning, etc.). During the school year, teachers work one-on-one with members of our research team to facilitate scientific inquiry in their classrooms and attend bimonthly small group meetings with other teachers and members of the research team.

Our research team identified Mr. S – currently in his fourth year of participation in the project – as someone who came to consistently facilitate rich scientific discussions in his classroom, many of which we have videotaped. The two selected episodes in this paper come from Mr. S's seventh-grade classes at a Title I middle school in which 65% of the students identify as Hispanic, 30% as African American, and about 35% are classified as having limited English proficiency (1).

Specific features of this pair of episodes made them an ideal naturalistic setting for thinking about different scientific aspects teachers may attend to in students' ideas. In many respects, the episodes are similar – they feature the same teacher teaching the "same" lesson in consecutive years (April 2010 and March 2011). In both episodes, Mr. S posed the same basic question: If you're walking with keys, and you want to drop the keys into a container sitting on the floor, should you release the keys before the container, over the container, or after the container? Students posed sensible reasons for each option, and Mr. S entertained a range of possible answers. Yet what Mr. S foregrounded in students' explanations in each episode differed. Our research team had

previously noted that Mr. S's own explanations of scientific phenomena during the summer workshops varied in nature, at times identifying the causal factors responsible for the phenomena and at other times fleshing out more mechanistic explanations for how phenomena occurred. We noted that these different explanatory approaches seemed evident in his facilitation of this pair of episodes.

Our first analytical step was to fully transcribe the two videotaped episodes, each approximately fifteen minutes in length. The transcript captures pauses and emphases in participants' speech, drawing on transcriptional notations from Sacks, Schegloff, and Jefferson (1974): pauses in speech are indicated by long dashes (representing a beat) or (pause) (indicating a longer pause). Moments when a participant cuts himself off are represented by short dashes, and moments when a participant extends a word are represented by repeated colons in the middle of the word (e.g., "thi:::nk"). Emphases in speech are indicated by either underlined or capitalized words, with the latter representing increased volume specifically. Combinations of emphases and colons reflect pitch change in the course of a word, () indicates that the speech could not be deciphered, and actions are described inside double parentheses (( )).

We then compared Mr. S's attention and responsiveness to students' ideas in the two episodes in the following manner. We focused on exchanges in which common ideas came up in both episodes or in which Mr. S followed up with students extensively, because these sorts of exchanges were likely to provide useful points of comparison. We drew on three kinds of evidence to unpack what Mr. S was foregrounding during these exchanges:

- How Mr. S revoiced students' ideas (O'Connor & Michaels, 1993) – emphases in his summaries suggested what he primarily attended to (e.g., "Maybe GRA::vity. GRA::vity" [April 2010] vs. "Gravity's pulling it down" [March 2011])
- How and when Mr. S pressed on students' ideas (Brodie, 2011) – questions Mr. S asked students indicated what he wanted them to flesh out (e.g., "So you're saying some kind of forward motion based on what?" [April 2010] vs. "Why will the keys go fast too?" [March 2011])
- When Mr. S made verbal and nonverbal bids to close the conversation (Schegloff & Sacks, 1999; Stivers & Sidnell, 2005) – accepting students' ideas as sufficiently articulated demonstrated what he found satisfactory (e.g., moving to another idea after a student identified wind as influential vs. after a student explained *why* wind was influential)

Evidence from other data sources (e.g., debrief conversations with Mr. S, recollections from small group meetings, stimulated recall/reflection interviews) triangulated with our interpretation of what Mr. S was foregrounding in each episode. Due to space constraints, we only review evidence from the episodes themselves in this paper, but more information (including full episode transcripts) can be found in Richards' (2013) dissertation work.

Findings

Our analyses demonstrate that Mr. S foregrounded different aspects of students' scientific reasoning in his attention and responses in April 2010 versus March 2011. In the first episode, Mr. S foregrounded students identifying *causal factors* responsible for the motion they predicted. In the second episode, Mr. S foregrounded students articulating *causal stories* for the motion they predicted, fleshing out how and why the object would move the way it did. This shift in attention from causal factors to causal stories represents a favorable change in the sophistication of explanation Mr. S attended to and pressed students for in the context of the key drop question.

Mr. S Foregrounded Causal Factors in the First Episode

In the first key drop episode in April of 2010, Mr. S primarily attended and responded to a particular form of scientific knowledge in students' ideas – their identification of the causal factors or force-like entities responsible for the motion they predicted. In general, if the factor causing the motion was not apparent in a student's explanation, he pressed the student to articulate it; if the factor was apparent, he accepted the student's response. Here, we provide two in-depth examples to illustrate Mr. S's focus on causal factors and cite supporting evidence from other exchanges throughout the episode.

The following exchange occurred well into the discussion and was one of the longest continuous exchanges Mr. S had with an individual student during the episode. The student, Suri (all names are pseudonyms), provided his sense of when it would be best to drop the keys, if you're running fast:

1. Mr. S: Okay, Suri, you want to respond to that or add something to the discussion?
2. Suri: Yeah, I'm like, if you're running, you feel like the wind is pushing you back.
3. Mr. S: So you're saying as you're going fast, faster, you're also feeling some pressure, some air, pushing back against you.
4. Suri: So my drop, um, is from above or after.
5. Mr. S: Above or after because of what?

6. Suri: Because if the wind is working in a different direction than you, you're running and () ((moves one hand forward and the other in the opposite direction on top)).
7. Mr. S: So when you, when you're saying, when you're running fast, there's some pressure coming up against you, coming against you?
8. Suri: Mm-hmm.
9. Mr. S: What is that? (pause) What do you think that is? (pause) So you're saying there's a pressure, there's something pushing back against you. ((faces board, writes)) There's a push back. And, so that push back, when you release the keys, what is it going to do to the keys?
10. Suri: They're gonna drop backward.
11. Mr. S: They're going to drop back. Okay, okay. Um, now, what are some-

Throughout the exchange, Mr. S attended and responded to Suri's idea – he maintained his focus on Suri's idea and pressed Suri to say more. However, there are nuances in the ways Mr. S interacted with Suri that highlight Mr. S's emphasis on causal factors. For instance, after Suri provided his initial explanation and indicated that he would drop the keys above or after, Mr. S asked Suri, "Above or after because of what?" (line 5). The fact that Mr. S had already revoiced Suri's explanation in line 3 and the wording of the question in line 5 suggest that Mr. S may have been looking for Suri to further specify the particular factor he thought was in play. Instead, Suri reiterated his story of the wind "working in a different direction than you" (line 6), and Mr. S again acknowledged Suri's story but pressed for the responsible factor: "What is that?... What do you think that is?" (line 9). Note here that Mr. S attended to the causal story Suri provided about the wind working in a different direction and pushing back against you – this aspect was not completely absent. Yet what Mr. S pressed for was Suri's identification of the causal factor involved.

At several other times throughout the episode, Mr. S also pressed for or attempted to elicit specific factors or forces underlying the motion students described. For example, early in the discussion, one student, Jack, talked about the keys falling straight down because of their weight. Mr. S responded in part by asking, "What force will cause it to go straight down?" and excitedly accepted the response of gravity ("Maybe GRA::vity. GRA::vity"). Another example occurred when Katherine talked about the keys going backward if you're going fast. In response, Mr. S asked, "If I'm going fast, why would that cause the keys to go backwards? What, what force, what would cause the keys to go back?" His reframing of the question from *why* the keys would go backward to *what force* would cause the keys to go backward, and his subsequent summary that Katherine "said something about the wind," reflected his emphasis on causal factors.

Further evidence of Mr. S foregrounding causal factors in students' ideas comes from a close look at another exchange around an idea that came up in both key drop episodes – that the speed of the runner would make the keys move forward. In the first key drop episode, a student, Diane, related this scenario to what would happen if you were to jump out of a racecar:

12. Mr. S: Why before, Diane?
13. Diane: Because I thi:::nk that – well, let me try to give you an example, li:::::ke ((loudspeaker interruption)) I think, like, when you're racing? Like, you're in a racecar? And then, you know, let's say you have to () on fire or something? So when you're trying to land on the grass – because you're not going to get there right when you're at the grass or else you're gonna- because the car's fast, and you're going fast too. You gonna, like, get on the mud or something, so you're going to have to go before, so you know, you could, you know what I mean?
14. Mr. S: So what do you mean is that there's some kind of forward motion?
15. Diane: Yeah.
16. Mr. S: ((faces board, writes)) Okay. So you're saying some kind of forward motion based on what?
17. Diane: On the speed of the person who ().
18. Mr. S: So based on sp::eed, right?

Again, Mr. S attended and responded to what Diane was saying. In line 12, Mr. S's question ("Why before?") elicited a detailed causal story from Diane. His follow-ups, however, did not acknowledge Diane's specific example, but rather clarified the kind of motion she implied (line 14) and pressed Diane to identify the causal factor responsible for the motion (line 16). His verbal emphasis on Diane's identification of "sp::eed" as the relevant causal factor (line 18), followed by his moving on to another student, suggests this is the kind of explanation he was looking for.

Mr. S Foregrounded Causal Stories in the Second Episode

When Mr. S explored the same question with another group of students in March of 2011 during his second year in the project, he attended and responded to a different form of scientific knowledge in students' ideas – their causal stories of what they thought would happen. This foregrounding involved his continued pursuit of different stories and more mechanistic detail from students. We provide two illustrative examples.

As the discussion started, many students thought you should drop the keys over the container in order to get them in. Yet they offered multiple kinds of explanations, including restatements of their conclusions and problematic alternatives (e.g., "Because if we drop it before or after the container, it won't get in the container") and appeals to the skill of the person dropping the keys (e.g., "Some people have bad aim, so they can't even aim towards the trash can"). Among these explanations was the following causal story from a student, Cooper:

19. Mr. S: Um, Cooper?
20. Cooper: Um, above?
21. Mr. S: Above.
22. Cooper: Because like the gravity, like, when you put it up, it goes down.
23. Drake: It's heavy.
24. Mr. S: Cooper said that because it's heavy, what happens, Cooper, I have to, I have to drop it-
25. Cooper: No, gravity puts, like, pulls it down.
26. Mr. S: So, because gravity's pulling it down.

Here, Cooper offered both a causal factor and how it works – gravity as the factor that works by pulling things down (line 25). Even though Mr. S momentarily conflated Cooper's idea about gravity with Drake's idea about heaviness, note the follow-up question Mr. S asked – "what happens?" (line 24). Mr. S was not satisfied with the identification of the relevant causal factor; rather, he asked Cooper for more of a narrative and, after Cooper's response, verbally emphasized what gravity does (line 26, "gravity's pulling it down").

As students continued to offer different kinds of explanations, Mr. S returned to Cooper's explanation, emphasizing its causal nature: "So now let's, we want to get back to – why, why above? Cooper, you had some explanation why, what's the reason for it?" Mr. S recapped Cooper's response for a third time as he asked students for other reasons why you should drop the keys over the container: "Are there any other reasons why I should drop it above the container, other than Cooper said, the gravity's gonna pull it down. Why else might I drop it above the container?" This repeated emphasis on "why" and the causal story (what gravity does) instead of just the causal factor (gravity) suggest that Mr. S was looking for students to provide causal story-like explanations.

This push beyond causal factors became most apparent in an exchange with Chavez about the speed of the runner making the keys move forward:

27. Chavez: If you do it before, it'll go directly in? But if you do it like, like-
28. Mr. S: Why do we have to do it before again?
29. Chavez: Because it'll go, like, IN, like the keys will go in the trash can or the thing will go in the trash can.
30. Mr. S: What will cause it to go in the trash can if we drop it before as opposed to over, because earlier you said over?
31. Chavez: Like, like, like, like, like the speed of the keys also I guess coming off.
32. Mr. S: The speed of the- so the keys have speed?
33. Chavez: Because you're walking, no, because like you're walking? (pause) And like, and like since you're walking fast, like, I guess the keys will also go fast too?
34. Mr. S: The keys will go fast too?
35. Chavez: (pause) Yeah.
36. Mr. S: Why will the keys go fast too?
37. Chavez: I don't know!
38. Mr. S: I released the keys, wouldn't the keys just be there?

Recall how the exchange between Mr. S and Diane went the previous year when the idea of speed came up. Mr. S emphasized Diane's identification of speed and moved on to another student. Here, there are notable differences in Mr. S's response, despite the parallels between Diane's idea that "the car's fast, and you're going fast too" [April 2010] and Chavez's idea that "since you're walking fast… the keys will also go fast too" [March 2011]. First, Mr. S did not simply accept the idea of speed; he started to repeat it (line 32) but then reflected the idea back to Chavez with a questioning intonation (lines 32, 34). Second, Mr. S pushed Chavez to fill out an additional part of the story by asking, "Why will the keys go fast too?" (line 36). This question, followed by Mr. S's counterpoint that the keys might "just be there" once they're released (line 38), indicates that Mr. S was interested in more than the identification of speed as a causal factor. He was also interested in Chavez fleshing out a causal story for how the keys would still have speed after they'd been released.

Thus, although Mr. S attended to both causal factors and causal stories to some extent in both episodes, we can see that he foregrounded one or the other in each case. We now turn to a discussion of why Mr. S's foregrounding of causal stories represents a favorable change over his foregrounding of causal factors.

Discussion: Considerations of Explanatory Sophistication in Science

Work in science education (e.g., Chinn & Malhotra, 2002; Russ, Scherr, Hammer, & Mikeska, 2008; Sandoval, 2003; Windschitl, Thompson, Braaten, & Stroupe, 2012) emphasizes the importance of students constructing causal explanations for phenomena. For instance, Chinn and Malhotra drew on work from the psychology, sociology, philosophy, and history of science to argue that one aspect of authentic inquiry is "the development of theoretical mechanisms with entities that are not directly observable" (p. 186). Sandoval's analysis of causal coherence in students' scientific explanations also focused on causal mechanisms, how students chain causes and effects to create coherent explanations. In creating and developing causal stories of how or why something happened, students engage in a practice that is arguably at the core of science.

When possible, fleshing out causal stories is a more sophisticated form of scientific explanation than simply identifying relevant causal entities or factors (Russ et al., 2008; Windschitl et al., 2012) (2). For instance, Russ et al. developed a framework for analyzing students' mechanistic reasoning, adapted from philosophy of science studies on the work of scientists. In Russ et al.'s framework for analyzing mechanistic reasoning, identifying entities and properties and actions of entities relevant to the target phenomenon is one component, but more sophisticated mechanistic reasoning involves creating a coherent explanation of how these activities or properties bring about the target phenomenon. In other words, identifying causal factors contributes to but is less sophisticated than telling causal stories, which requires consideration of how the factors behave and interact with each other over time.

Moreover, in the key drop conversations, students demonstrated the ability to engage in causal storytelling that could have been capitalized on both years. Consider Diane's racecar example from the earlier episode. Although she offered details that could have been drawn out further, Mr. S summarized her idea as having to do with speed and forward motion. Although this summary was coherent with Diane's idea, it quickly slotted her idea as a certain kind of thing rather than permitting further exploration. Diane's idea might have played out differently in the second episode. Judging from the Chavez exchange, Diane might have been asked to explain why you would still be going fast once you jumped out of the car. Rather than assuming that the same mechanisms were in play in the key drop scenario and the racecar example, the relationship between the situations might have been interrogated. In short, various aspects of Diane's explanation might have received deeper attention, and productively so for students' learning through engagement in scientific inquiry.

Thus, the favorable change seen in Mr. S's attention and responsiveness can be characterized *not* simply as greater attention to the substance of students' reasoning, but rather, by which aspects of the substance of student reasoning he foregrounded in his attention and responses. This shift in foregrounding from *causal factors* to *causal stories* does align with a dimension of favorable change noted above, namely the specificity with which Mr. S attended to students' ideas. Foregrounding causal stories necessitates attention to details of students' explanations in a way not required by attention to causal factors. However, with respect to the stance Mr. S took toward the ideas he heard, as reflected in his follow-up moves, we do not see differences between the episodes. In neither case did Mr. S direct the conversation toward the correct answer, nor did he listen passively; he was engaged in interpreting students' ideas in both episodes. Similarly, drawing on Brodie's (2011) scheme, the most frequent types of follow-up moves in both episodes were the reform-type moves of maintaining focus on students' ideas and pressing for more information. What *was* distinct between the episodes was the kind of information Mr. S pressed *for*.

Conclusion and Implications

We demonstrated that the shift seen in Mr. S's attention and responsiveness to the substance of student thinking between the key drop episodes hinged on which aspects of scientific explanation he foregrounded in relation to students' ideas. In his first classroom implementation of the key drop inquiry, Mr. S foregrounded students' identification of the causal factors or force-like entities responsible for the motion they predicted, such as *gravity* moving the keys down, or *speed* resulting in the keys' forward motion. Mr. S's subsequent classroom implementation of the key drop inquiry the following year, though, involved a more sophisticated foregrounding – students' articulation of causal stories of what they thought would happen. Here, mechanism was more of an emphasis, e.g., gravity pulling the keys down, or a lingering question about how the keys still have speed once they're released.

We recognize the limitations inherent in a case analysis of a single teacher, and as such, we do not claim that the specific shift seen here extends beyond this case, nor that discipline-specific considerations are *always* relevant in characterizing teachers' attention and responsiveness to student thinking. Rather, we see this case as a proof of concept that in some cases, as in the case of Mr. S, there is a disciplinary dimension to responsive teaching that is not captured by current characterizations in the literature. Additionally, space constraints prevent us from exploring two related issues: the reasons behind Mr. S's shift, and evidence that the shift represented stable change in practice rather than a mere "fluctuation." In other work we explore these issues (Richards, 2013). However, the data and analysis we presented here are sufficient to support our main argument that nuanced considerations of disciplinary authenticity and productivity, when evident in the data,

should inform notions of what counts as progress in responsive teaching—specifically, that shifts in attention to more sophisticated aspects of the substance of student thinking should count as progress toward greater responsiveness.

To conclude, we consider the implications of this work for professional development and research in which students' ideas are at the core of teachers' attention.

Implications for Professional Development

When students' ideas are central to professional development efforts, a critical topic for ongoing discussion should be the various disciplinary aspects that participants (including professional developers) note with respect to student thinking. After spending time making sense of students' ideas, participants could be asked to reflect on what is scientific about what students are saying and doing. For instance, in this case, Mr. S's sense that mechanism came up more in the second summer workshop likely influenced what he paid attention to in students' explanations, and how and when he pressed students to fill in gaps. More explicit discussion of such disciplinary aspects could help teachers open up space for students to explore and develop a deeper sense of a given discipline and what it means to engage and participate in ways that disciplinary experts do, in a sense becoming local disciplinary experts themselves.

Moreover, more explicit discussion would promote metaawareness in teachers of what they are foregrounding in given moments. Throughout his participation in the project, Mr. S has tended to use the terms causal factors and causal stories interchangeably, suggesting that he may not have been aware of his different foregroundings in the episodes. Thus, it is important to note how pervasive his foregroundings were in both episodes *without* his explicit awareness, and to recognize how much *more* powerful and purposeful these foregroundings could be *with* his explicit awareness. Such awareness might also facilitate teachers' shifting among aspects more responsively in the course of authentic disciplinary practice with students, demonstrating a sort of flexibility that might represent another avenue of growth for Mr. S and others.

Implications for Research

In terms of research, it would be beneficial to understand more about the impact different disciplinary foregroundings have on what students come to see as authentic disciplinary activity. For instance, shortly after Mr. S recapped Diane's idea as having to do with speed in the first key drop episode, a visiting member of our research team asked, "Folks, did you hear that reasoning?" A student responded, "Yes, it's based on speed," suggesting that Mr. S's foregrounding of causal factors may have been picked up by students as a sufficient explanation. Exploring potential connections like this between teachers' foregroundings and students' senses of the discipline is a ripe area for future research, with important implications for what students learn through engagement in discussions at the intersection of their ideas and disciplinary practices.

Future research could also target how explicit professional development discussions of various disciplinary aspects impact teachers' classroom practice. Do teachers exhibit enhanced metaawareness about what they are attending and responding to within students' ideas? If so, do they demonstrate more or less flexibility in what they foreground, and to what ends? Such questions could be explored in continuing professional development projects aimed at enhancing teachers' attention and responsiveness to the substance of student thinking.

Endnotes

(1) These statistics come from publicly available 2009-2010 demographic data, not directly cited to protect the anonymity of the school.

(2) That said, there are certainly situations in which foregrounding the identification of relevant causal factors is appropriate, like when engaging in experimental design (e.g., Ford, 2005; Toth, Klahr, & Chen, 2000). The identification of relevant causal factors for a given phenomenon provides useful insights about the phenomenon and predictive power with respect to similar phenomena, and is a publishable finding in various scientific disciplines, such as ecology, epidemiology, etc.

References

Ball, D. L. (1993). With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics. *Elementary School Journal*, *93*(4), 373–397.

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*, 26–55.

Brodie, K. (2011). Working with learners' mathematical thinking: Towards a language of description for changing pedagogy. *Teaching and Teacher Education*, *27*, 174–186.

Carpenter, T. P., Fennema, E., Peterson, P. L., Chiang, C.-P., & Loef, M. (1989). Using knowledge of children's mathematics thinking in classroom teaching: An experimental study. *American Educational Research Journal*, *26*(4), 499–531.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*, 175–218.
Crespo, S. (2000). Seeing more than right and wrong answers: Prospective teachers' interpretations of students' mathematical work. *Journal of Mathematics Teacher Education*, *3*, 155–181.
Duschl, R. A., & Gitomer, D. H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment*, *4*(1), 37–73.
Empson, S. B., & Jacobs, V. R. (2008). Learning to listen to children's mathematics. In D. Tirosh & T. Wood (Eds.), *Tools and processes in mathematics teacher education* (pp. 257–281). Rotterdam, NL: Sense Publishers.
Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V. R., & Empson, S. B. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education*, *27*(4), 403–434.
Ford, M. J. (2005). The game, the pieces, and the players: Generative resources from two instructional portrayals of experimentation. *Journal of the Learning Sciences*, *14*(4), 449–487.
Franke, M. L., Carpenter, T., Fennema, E., Ansell, E., & Behrend, J. (1998). Understanding teachers' self-sustaining, generative change in the context of professional development. *Teaching and Teacher Education*, *14*(1), 67–80.
Goldsmith, L. T., & Seago, N. (2011). Using classroom artifacts to focus teachers' noticing. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 169–187). New York, NY: Routledge.
Hammer, D., & van Zee, E. (2006). *Seeing the science in children's thinking: Case studies of student inquiry in physical science*. Portsmouth, NH: Heinemann.
Jacobs, V. R., Lamb, L. L. C., Philipp, R. A., & Schappelle, B. P. (2011). Deciding how to respond on the basis of children's understandings. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 97–116). New York, NY: Routledge.
Kazemi, E., & Franke, M. L. (2004). Teacher learning in mathematics: Using student work to promote collective inquiry. *Journal of Mathematics Teacher Education*, *7*, 203–235.
Levin, D. M., & Richards, J. (2011). Learning to attend to the substance of students' thinking in science. *Science Educator*, *20*(2), 1-11.
O'Connor, M. C., & Michaels, S. (1993). Aligning academic task and participation status through revoicing: Analysis of a classroom discourse strategy. *Anthropology & Education Quarterly*, *24*(4), 318–335.
Pierson, J. L. (2008). *The relationship between patterns of classroom discourse and mathematics learning* (Doctoral dissertation). University of Texas at Austin.
Richards, J. (2013). *Exploring what stabilizes teachers' attention and responsiveness to the substance of students' scientific thinking in the classroom* (Doctoral dissertation). University of Maryland at College Park.
Russ, R. S., Scherr, R. E., Hammer, D., & Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education*, *92*(3), 499–525.
Sacks, H., Schegloff, E. A., & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language*, *50*(4, Part 1), 696–735.
Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences*, *12*(1), 5–51.
Schegloff, E. A., & Sacks, H. (1999). Opening up closings. In A. Jaworski & N. Coupland (Eds.), *The discourse reader* (pp. 263–274). London, England: Routledge.
Stivers, T., & Sidnell, J. (2005). Introduction: Multimodal interaction. *Semiotica*, *156*(1/4), 1–20.
Toth, E. E., Klahr, D., & Chen, Z. (2000). Bridging research and practice: A cognitively based classroom intervention for teaching experimentation skills to elementary school children. *Cognition and Instruction*, *18*(4), 423–459.
van Es, E. A. (2011). A framework for learning to notice student thinking. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 134–151). New York, NY: Routledge.
Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education*, *96*, 878–903.

Acknowledgments

This work was supported by funding from NSF DRL-0733613 and NSF EHR/DUE-0831970. All findings, opinions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation. Special thanks to David Hammer, Paul Hutchison, Eric Kuo, Amy Robertson, and ICLS reviewers for feedback on earlier versions of this work.