Chapter 2: A literature-based primer on responsive teaching in science and mathematics

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Introduction

In this chapter, we provide an overview of existing literature related to responsive teaching. We begin by emphasizing that responsive teaching is not a new idea -- it has roots in Dewey's [1] focus on educative experiences, in which the educator must scout ahead "to see in what direction an experience is heading" (p. 38), assessing its potential for growth toward particular ends in interaction with "what is actually going on in the minds of those who are learning" (p. 39). It resonates with Bruner's [2] notion that students have productive intuitions for disciplinary learning, such that any subject can be taught, in some authentic form, to any student at any age by working with both their intuitions and the fundamental structures of the discipline.

What is newer is the *amount* of literature that has amassed in science and mathematics education about teaching that foregrounds attention and responsiveness to student thinking -- what we describe in this book as "responsive teaching." This chapter explores several well-documented and frequently-cited subsets of literature that share a central focus on teachers' practices of attending to the substance of students' ideas and adapting instruction in light of what they notice. Looking across these subsets, certain commonalities emerge, as articulated in Chapter 1 (see that chapter for more discussion):

- Responsive teaching foregrounds attention to students' ideas.
- Responsive teaching recognizes disciplinary connections within those ideas.
- Responsive teaching adapts instruction on the basis of students' ideas.

Each subset of literature also has its own unique characteristics, however, which we turn our attention to here.

We begin by introducing and describing each subset of literature, with an eye toward what it reveals about the nature of responsive teaching and approaches to conceptualizing and studying such teaching. We then highlight posited benefits of responsive teaching that scholars have either argued for or empirically supported in their work. Finally, we look across the subsets of literature, this time to draw out distinctions and open questions that may shape the field's work on responsive teaching moving forward.

Depictions of "Responsive Teaching" in the Literature

In this section, we provide an overview of different subsets of literature that emphasize and explore teachers' practices of attending and responding to student thinking in science and mathematics in the ways described above. We do not claim that this review is exhaustive; rather, we intend for it to serve as an introduction to some of the better-documented and -cited efforts in the field. We begin with a close look at one of the earliest efforts to help teachers adapt their instruction in response to what students say and do, Cognitively Guided Instruction (CGI). We then review the "mathematics teacher noticing" literature and its connection to responsive teaching before turning to two distinct approaches that scholars have used in studying responsive teaching. We call the first of these approaches the "discourse" approach; these papers focus on the kind of talk that makes up responsive interactions between teachers and students. The second approach -- representing a substantive fraction of the work in responsive teaching to date -- uses in-depth case studies of responsive teaching to unpack its nature, including the tensions teachers experience in working to respect their students *and* be responsible to their disciplines.

Cognitively Guided Instruction (CGI)

One early and well-documented effort to help teachers ground their instruction in and build on the substance of students' mathematical thinking was the Cognitively Guided Instruction (CGI) program [3-10]. Drawing on research on children's conceptual development in specific content areas like addition and subtraction, researchers developed "an organized set of frameworks that delineated the key problems in the domain of mathematics and the strategies children would use to solve them" ([10], p. 103).[1] One of the primary goals of the program was to familiarize teachers with these principled frameworks and the progressions children often follow to develop more sophisticated understandings in particular mathematical domains [5]. As Carpenter *et al*.. [3] describe:

> The CGI analysis provides a basis for selecting critical problems and for understanding what students' responses imply about their mathematical understanding. Because the framework is highly principled, it is possible to select a few key problems that will show what a student knows, and responses to individual problems fit together to provide a coherent profile of the strategies a student uses (p. 14).

Researchers expected that teachers would use the frameworks as in-the-moment templates in working with individual students, both to figure out what students know and decide on problems that will progress their thinking [7, 8].

What researchers found was that CGI teachers conceptualized and took up the frameworks in different ways. Teachers classified as "Level 3" tended to apply the frameworks as provided, using them to assess where their students were and to select appropriate problems [4]. Level 4 teachers, on the other hand, focused on the deeper relationships among problems and strategies [9] and "continually reflect[ed] back on, modif[ied], adapt[ed], and expand[ed] their models in light of what they hear[d] from their students" ([4], p. 5). In other words, for Level 4 teachers, the frameworks were not static [6]; teachers adapted them as they listened to and learned from students in their own classrooms, which Franke *et al*.. [8] described as the basis of generative growth for teachers. Ms. J, an exemplar CGI teacher, describes her teaching in the following way:

> As a teacher you have to be a supreme listener to kids, and not only do you learn to just listen, but then you learn what to listen for and what might be some possible next steps you might want to take ([7], p. 580).

Teachers may thus draw on the principled, research-based frameworks provided by CGI to "learn what to listen for" and to responsively design instruction that builds on students' current understandings toward increasingly sophisticated mathematics.

Studies of the effectiveness of the CGI approach reveal positive outcomes. For example, an early study [5] found that CGI teachers listened more closely to the range of strategies students used to solve problems than did control teachers. They also more accurately predicted which problems their students would be able to do, as measured by "the match between [the teacher's] predictions for [which strategies] each target student [would use to solve particular problems] and that student's actual response" (p. 511).

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[1] These frameworks are detailed and domain-specific. For instance, addition and subtraction are broken down into four basic classes based on the action or relation that students need to complete or consider (Carpenter, Fennema, & Franke, 1996). Each class can be further decomposed on the basis of which quantity is unknown, and the quantities themselves can be changed in the moment to enhance or diminish the difficulty of the problem.

Mathematics teacher noticing

Other work in mathematics education has focused not on how teachers make sense of research-based frameworks of student thinking, but on how the teachers themselves distill key features from a chaotic, complex instructional environment [11-22]. In particular, mathematics teacher noticing involves (i) trying to understand the meaning that learners are making of mathematics in the moment, (ii) connecting learners' mathematical meanings to the discipline, and (iii) using the information to inform instructional next-moves [11-14, 18, 23, 24]. For example, Jacobs *et al.*. [23] describe the development of teachers' "algebra eyes and ears… identify[ing] the relational thinking *embedded* in students' strategies and… consider[ing] how different students' strategies made use of different types of relational thinking" (p. 271, emphasis added); these processes connect the meanings that students are making of mathematics to the discipline itself by discerning the relational thinking inherent in their ideas. Increased skill in noticing students' mathematical thinking is generally characterized by movement from superficial evaluation of students' ideas to detailed, evidence-based interpretation of their meanings and consideration of how their ideas connect to broader issues of mathematics learning and teaching (*e.g.,* [18, 20]).

Much of the existing literature on mathematics teacher noticing[2] has taken place in the context of professional development settings, in which teachers interact with classroom video [18-21, 25, 26] or student artifacts [12, 14]. Noticing students' mathematical thinking is regularly described as a skill or set of skills that can be learned; for instance, Jacobs *et al.* [13] reported differences in the noticing skills of teachers that seemed to be related to the number of years the teachers had spent in professional development that focused on noticing students' mathematical thinking -- teaching experience mattered but did not fully account for the trends in the data. Some recent work has moved into the classroom setting (*e.g.,* [19, 26]) and has noted a relationship between increased noticing in the professional development setting and increased noticing or responsiveness while teaching, suggesting some amount of transferability. However, the authors also highlight substantial variability in the classroom setting with teachers sometimes taking up students' ideas as objects of inquiry and sometimes not.

Researchers who study teacher noticing might not necessarily consider themselves to be studying responsive teaching, in part due to a debate about what noticing involves. They have generally divided noticing into three separate processes – noticing, interpreting, and/or responding – and argue about whether these processes are nested or separable [11, 13-16]. Some authors argue that noticing is the most fundamental process; others argue that noticing and interpreting are inseparably connected but that a response follows from these two, and others argue that the three are so deeply entangled that they cannot be meaningfully separated.[3] Regardless, the authors agree that noticing and making sense of student thinking are important precursors to teaching responsively and are a worthy aim of teacher development.

Additionally, researchers who study teacher noticing differ somewhat in what counts as evidence of noticing students' mathematical thinking. For example, Sherin and van Es [19] coded observations of classroom interactions on the basis of whether they displayed confirming or disconfirming evidence of teacher attention to student mathematical thinking. Confirming evidence

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[2] For the purposes of this literature review, we chose to focus on the noticing literature that draws particular attention to students' mathematical thinking. Other literature that characterizes the myriad foci of teachers' attention is not necessarily included.

[3] In fact, Jacobs *et al.* (2011) offer empirical support for the relationship between noticing and responding. In their study, K-12 teachers watched a video of a kindergartener solving a mathematics problem and then wrote down (a) how they might respond to the student, and (b) what the student actually did as he solved the problem. The authors found that almost all of the teachers whose hypothetical response [(a)] was tied to the students' mathematical understanding also provided evidence of attending to his problem solving strategy [(b)]. However, the reverse was not true: only a subset of the teachers who attended to his problem solving strategy [(b)] also decided how to respond on the basis of it [(a)]. Thus, responding was tied to noticing, but the reverse was not necessarily true.

included teachers noticing *that* students were presenting ideas or tagging ideas as interesting (*e.g.,* "That's interesting" (p. 30)), but it did not always require the teacher to put the mathematical substance of the ideas on display. In contrast, Jacobs *et al.*. [13] attended explicitly to whether teachers noticed the "mathematically significant details, such as how children counted, used tools or drawings to represent quantities, or decomposed numbers" (p. 183). This distinction may be due partly to the differing contexts in play (in-the-moment instruction in Sherin and van Es versus written reflection in Jacobs *et al.*.) and may also be linked to Jacobs and colleagues' prior involvement with the CGI project, which focused on the details of students' problem-solving strategies.

Discourse studies of responsive teaching

Similar to Sherin and van Es' [19] efforts to identify teacher noticing during instruction, several researchers studying responsive teaching take a discursive approach to defining and evaluating such teaching in classroom interactions [27-29]. This approach grows out of a larger body of literature on classroom discourse and the functions and meanings of particular markers in the flow of talk. For instance, the researchers cited build on previously defined discourse moves such as "revoicing" [30] and the "reflective toss" [31] in considering what teachers do to keep the focus on students' ideas in the classroom.

The detailed schemes laid out in Lineback's [28] and Pierson's [29] research shed light on how they think about what it means and looks like to teach responsively in the classroom. For instance, Pierson defined categories of discourse moves that represented low responsiveness, medium responsiveness, and two different kinds of high responsiveness. Low, Medium, and High I responsiveness differ in the extent to which teachers' responses connect to what students said, but all three focus (at least to an extent) on correctness and on the teacher's thinking. High II responsiveness, in contrast, shifts the focus to students' reasoning, and teachers' moves that work with students' reasoning rather than seeking to transform it into something else; this kind of responsiveness correlates closely with students' success on conceptual measures. Lineback's scheme highlights a particular kind of moment in the flow of classroom activity -- when the teacher redirects the students' activity or the focus of the conversation. Her scheme characterizes "redirections… according to the nature of their responsiveness" ([28], p. 18). Similar to Pierson's scheme, Lineback considered whether a given redirection was tied to students' ideas that came before (*i.e.,* whether the new activity is "grounded in, and therefore responsive to… students' comments" (p. 23)). She also considered *how* the redirection was tied to students' previous ideas -- the most responsive redirections are ones in which students are invited to consider one another's ideas in more depth. As seen in these two schemes, the discourse approach moves beyond whether a teacher is attending and responding to student thinking or not (*e.g.,* Sherin and van Es' [19] confirming or disconfirming evidence) to consider the nature of that responsiveness -- *how* the teacher is attending and responding to students' ideas, with implications for *how well* teachers are doing so.

There are several shared assumptions underlying this approach. First, there is a sense that learning occurs *through* discourse, so a critical part of supporting student learning is supporting students' opportunities to voice and interact around their own ideas. As Lineback [28] noted, "The more students talk about mathematics [and science], the more they are likely to learn about the nature and discipline of mathematics [and science]" (p. 3); Brodie's [27] notion of giving a learner "a chance to articulate and hence deepen her thinking" (p. 181) communicates a similar sense that thinking may become richer through expression. Second, the cited papers share an assumption that teachers' moves impact student talk and opportunities to learn -- that what students are saying and doing is directly linked to their teachers' prior moves -- in such discussions. Pierson [29] highlighted this relationship as follows:

> By encouraging students to verbalize their thinking and provide explanations of their ideas, discursive moves with high levels of responsiveness… can support coherence and clarity in thinking, help the speaker plan and regulate a course of action, encourage the organization and integration of new ideas into prior experience, and expose errors in reasoning" (p. 34).

In other words, moves high in responsiveness on the part of the teacher can support students in articulating and explaining their thinking, and learning through these processes.

There are also researchers who make use of the discourse markers described above to demarcate boundaries of cases of responsive teaching, but whose work does not necessarily align with the articulated assumptions of the discourse approach. For instance, in her dissertation work, Lau [32] defined discursive evidence of attending and not attending to student thinking. She used these categories of evidence to delineate instances of each in teachers' classroom practice, with the aim of studying the identified instances in more depth. Similarly, Richards' [33] dissertation drew on evidence from the cited discourse studies to define cases in which teachers were relatively stably focused on students' ideas, analyzing what stabilized this focus in each case. Such case study research foregrounds the nature and dynamics of responsive teaching -- what it entails, how it feels, what supports or constrains it, etc. -- and is the subject of the next section.

Case studies of responsive teaching

The responsive teaching case study literature can roughly be divided into two subsets -- (1) first-hand practitioner accounts of responsive teaching and (2) researchers' analyses of examples of responsive teaching. We begin by reviewing numerous first-hand accounts [34-40] that provide a detailed look inside responsive teaching from the perspective of the teacher. These accounts foreground important characteristics of the *nature* of responsive teaching, highlighting that it is (a) active and intentional, (b) highly contextual, and (c) tension-filled.

First, practitioner accounts of responsive teaching demonstrate that the teacher plays an active role in shaping the conversation that takes place [34, 35, 37-39]. Responsive teaching is filled with continual decision points in which teachers must decide how to move forward based on what they've heard and what they're hoping to support, disciplinarily, in students. For instance, Hutchison [38] describes a moment in his physics class in which students were considering what makes some objects float. The class had posed both weight and density as options, and one student, Katie, indicated that there might be a linear relationship between weight and density. Hutchison decided to introduce a mathematical definition of density as weight/volume and described why this choice seemed productive to him in the moment:

> The moment seemed instructionally ripe, both conceptually and epistemologically… In the discussion among students that immediately preceded this, many students were using the words "weight" and "heavy" when talking about the relevant features of objects with respect to floating and sinking. Just before I wrote down the equation, Katie argued that when "weight" is added to a floating cup its "density" must somehow increase. I meant to build from the students' reasoning, and so I chose to use the word they had been using. I also think of "weight" as a more everyday, commonsense word than "mass," and I thought using weight would help maintain the commonsense feel of the class discussion up to that point. ([38], p. 516)

As evidenced, Hutchison made an active move that was responsive to what students had been discussing and how he hoped to support their continued scientific work. His use of the term "weight" connected to the students' conversation and was more "commonsense" than mass, and Hutchison hoped that defining density in this way would allow students to retain a productive framing of their activity while adding precision. Lampert's [39] discussion of her role in a fifth-grade mathematics class depicts a similar level of active participation: "I assumed the role of manager of the discussion and sometimes participated in the argument, refuting a student's assertion" (p. 50), indicating that she not only facilitated, but added her own ideas to the conversation at key moments as well.

The example from Hutchison and Hammer (2010) also illustrates the second point -- responsive teaching is highly contextual [35-37]. Hutchison's decision to define density as weight/volume was made in a particular moment with particular features that Hutchison took into consideration. As he noted, his "choice of 'weight' rather than 'mass' was not premeditated; that is,

[he] did not walk into the class that day thinking [he] would define density in this way" ([38], p. 516). Rather, he considered the context and made a choice about how to move forward. Chazan and Ball [35] describe similar dynamics at play in their mathematics classrooms, ultimately arguing for a pragmatic approach to responsive teaching "in which teacher moves are selected and invented in response to the situation at hand, to the particulars of the child, group or class and to the needs of the mathematics" (p. 7). For example, Ball notes that she could press a particular student, Betsy, in ways that she couldn't press other students; Hammer's [37] responses in his high school physics class also took into consideration numerous aspects of the immediate context, including his interactional history with individual students.

Third, practitioner accounts often make explicit some of the tensions associated with responsive teaching [34, 36, 40]. Ball describes several dilemmas that arose as she attempted to teach third-grade mathematics in a way that "respects the integrity both of mathematics as a discipline *and* of children as mathematical thinkers" (p. 376), such as what to do with a student's mathematical creation that bucked conventional notions of even and odd numbers. Others raise similar concerns about how to manage these -- at least at times -- competing goals. For example, Schnepp [36] describes two ways of working with students' ideas in his advanced placement calculus course. In the first way of working, he primarily listened to and assessed students' thinking without contributing; in the second, he took a more active role by making suggestions, sharing mathematicians' ideas, etc. He articulated the tensions he felt with respect to both ways of working:

> When I am mainly listening and assessing, the process is extremely time consuming and students may not be learning the mathematical facts and methods that I am supposed to cover. But, students *are* being challenged to be intellectually independent and to think about why they believe something should be considered true in mathematics… When I am more active in discussions of student exploration, my contributions can bring their ideas closer to standard ideas in the curriculum. But, if I become too active, students will quickly apply pressure for me to just tell them how to do it ([36], p. 179).

These first-person examples highlight some of the considerations and difficulties that come into play as teachers attend and respond to the substance of student thinking.

Researchers have also used case studies to unpack what influences responsive teaching [32, 33, 41-46]. These findings in many ways parallel the findings above and connect responsive teaching to other constructs in the literature on teacher behavior. For instance, in Schnepp's [36] quote above, he highlights what he is "supposed to cover" as an important consideration in his teaching. Levin's dissertation work on responsive teaching in the science classroom [41] also highlights the salience of curricular coverage for teachers, along with other institutional priorities that serve to constrain responsiveness (*e.g.,* work environments that draw attention to other issues, like classroom management). Several case studies tie responsive teaching to the construct of *framing* [32, 41-43, 45], indicating that whether and how teachers attend and respond to student thinking is interrelated with what they think is "going on" in the classroom at any given time. Other cases tie responsive teaching to teachers' *content knowledge* in various ways [33, 46]. Wallach and Even [46] noted that a teacher, Ruth, heard her students' solutions through her own understanding of the posed math problem. Richards [33] noted a similar dynamic between one teacher's (Mr. S') (a) changing understandings of what constitutes a satisfactory scientific explanation and (b) what he pressed students for in class discussions. However, another teacher (Ms. L) was more likely to pursue students' ideas in a responsive manner when she did *not* know the answer to the question they were grappling with and could thus inquire alongside them.

In summary, the diverse body of case studies provides in-depth analyses of the nature and dynamics of responsive teaching. We see the insights from first-hand accounts of responsive teaching as a particularly important contribution from this subset of literature, adding to our understanding of responsive teaching from within.

Posited Benefits of Responsive Teaching

The subsets of literature described above, as well as other pieces related to responsive teaching, posit benefits that occur when teachers attend and respond to the substance of student thinking. In this section, we address several in turn.

Responsive teaching enacts formative assessment.

The literature on formative assessment (*e.g.,* [47, 48]) incites teachers to use the information that they glean from formal and informal classroom assessments to inform their instructional decisions. Responsive teaching thus enacts formative assessment (as argued by [29, 49, 50]) as it attends to student thinking and adapts instruction in both the short and long term to support and build on students' developing understandings. Responsive teaching is distinct from other forms of formative assessment in its particular attention to the substance of student thinking [51] -- the *meaning* that students are making of their disciplinary experiences -- and in its stance toward that thinking as productive and resourceful. Teachers listen to students in order to *build* on their thinking, rather than to correct it.

Responsive teaching treats student thinking as resourceful and is consistent with constructivist learning theory.

In responsive teaching, teachers start from the assumption that the ideas students bring to the table are *sensible* and *productive*, and they seek to engage with and refine these ideas [3, 34, 40, 52-54]. For instance, Hammer, Golberg, and Fargason [53] write:

> "…this approach presumes -- in fact it builds from -- a view that children are richly endowed with resources for understanding and learning about the physical world: Engage children in a generative activity, and there will be productive beginnings to discover and support." (pg. 55)

By valuing and seeking to build from students' existing knowledge, researchers have argued that responsive teaching is theoretically consistent with constructivism [29, 50]. (For further reading on constructivism, see [55]; [56]; [57]; or [58].)

Responsive teaching may promote more equitable participation.

Teaching that treats students as capable sense-makers, with productive resources to bring to bear in the classroom, can promote equitable participation (*e.g.,* [59-65]). The authors cited here specifically describe or call for teaching that attends to and builds on the resources that students from culturally, linguistically, and socioeconomically diverse communities bring to the classroom, and they demonstrate how these resources are continuous with disciplinary ideas and practices. For instance, Michaels [62] reflects on working-class children's narrative practices, which rely heavily on justifications derived from everyday experiences. She describes how these practices may be seen as

> "intellectual affordance[s] for working-class children in learning science -- their trust in their own experience as evidence and their willingness to rely on it in making sense out of abstract or counterintuitive scientific concepts" ([62], p. 140).

If teachers recognize and support such diverse entry points, they may provide an "in" for students who are often marginalized in traditional classroom discourse.

Responsive teaching fosters enhanced student conceptual understanding.

Likely related to its enactment of formative assessment (an empirically-established means of improving student understanding -- see [47]) and its alignment with constructivism, responsive teaching promotes enhanced student conceptual understanding [5-7, 29, 49, 66-69]. For example, Fennema *et al.* [6] found that gains in students' mathematics achievement co-occurred with shifts in teachers' responsiveness to their students' mathematical thinking. Studies have also compared student performance in responsive classrooms to those in more traditional classrooms and found higher gains in the former (*e.g.,* [29, 49, 66]).

Responsive teaching provides rich opportunities for students to engage in disciplinary thinking and practices.

In addition to conceptual understanding, researchers have demonstrated that responsive teaching opens space for students to engage in important kinds of disciplinary thinking and practices [24, 33, 34, 38, 51, 53]. This may happen when teachers attend to and take up the mathematical or scientific thinking and practices that emerge as students engage with their own and one another's questions, such as when Sean proposes that six is "both even and odd" [because it has three (odd) groups of two (even)] in Ball's [34] third-grade mathematics classroom. As described in Chapter 1, Sean's proposal instigates a discussion in which students offer multiple different (and sometimes competing) definitions for odd numbers, and Ball sees in this emergent debate – and in Sean's proposal – an opportunity for her students to explore the role of mathematical definitions and their "nature and purpose in mathematical activity and discourse" (p. 387). She encourages her students to investigate patterns in "Sean numbers" as they did the same for even and odd numbers.

Teachers may also provide opportunities to engage in disciplinary thinking and practices in the way that they plan for and organize classroom activity. For example, Schifter [24] describes how Ms. Kaye modifies a word problem that her students are solving to draw out and capitalize on her elementary school students' nascent sense of mathematical generalization. After her students have decided that the word problem – which reads that "Oscar had 90 stickers and decided to share some with his friends. He gave 40 stickers away. Becky also had 90 stickers. She gave away 35 stickers. Who has more stickers now?" (p. 207) – should be represented as 90 – 40 and 90 – 35, she asks her students to answer the question without performing the subtraction. Her students notice that Becky will have more "because she's giving away less" (p. 207), which is like "reversing" addition (p. 208). Schifter argues that Ms. Kaye saw in the word problem "an idea about the behavior of subtraction," and her students not only took this opportunity up but also contrasted this behavior with that of addition.

The explanation-building, argumentation, and assessment practices represented in these and the other studies cited are central aspects of what it means to do science or mathematics. Responsive teaching supports students in doing so (at least in part) by framing their classroom activity in terms of opportunities to generalize, argue, etc.; by noticing and responding to nascent scientific and mathematical practices as they emerge in the flow of classroom activity; and by distributing the authority for assessment of ideas and for the direction that classroom activity should take.

Responsive teaching promotes teacher learning and development.

Finally, studies report favorable shifts in teachers' knowledge, values, and practice as they engage with the substance of students' disciplinary ideas [5, 6, 8, 10, 19, 40, 49, 60, 70]. For instance, Fennema *et al.* [6] describe a feedback loop that regularly occurred as teachers in the CGI project increasingly attended to students' solution strategies for math problems:

> As the teachers saw that their students were capable of inventing strategies and doing more than they had anticipated, they increasingly made problem solving a greater part of their instruction; the children increasingly solved harder problems and reported their thinking; the teachers listened and understood children's thinking better; and so it continued. (p. 431)

Through listening to students, teachers learned that students were capable of sophisticated mathematics, gained knowledge about student thinking, and shifted their classroom practice to provide more opportunities for independent problem solving. Making sense of students' ideas can also help teachers enhance their own content understandings [40, 70].

Future Directions for Work on Responsive Teaching

Based on the content of reform-oriented science and mathematics education documents (*e.g.,* [71, 72]) and on the burgeoning discussion about ambitious teaching and high-leverage practices (*e.g.,* [73, 74]), we anticipate that responsive teaching will continue to be a focus of research and teacher development efforts in the field. Thus, in this final section, we look across the subsets of literature to draw out distinctions and open questions that may shape this future work. Some of the questions we raise are more clearly research questions, whereas others are more about matters of design and implementation with respect to learning environments for teachers. However, these sorts of questions tend to overlap and shed light on each other in practice, and as such, we do not make clear delineations between them in what follows. We simply point to them as areas and issues worth further consideration and pursuit. We also indicate, where relevant, how the chapters in the remainder of this edited collection further the discussion on several of these issues.

Are there particular moves that characterize responsive teaching?

The literature we have reviewed differs with respect to whether specific practices or moves are characteristic of responsive teaching, or whether responsive teaching (by its very nature) is more amorphous. Generally, the mathematics teacher noticing literature, the discourse studies, and some case studies (*e.g.,* [32, 33]) articulate teacher moves or stances that are indicative of responsive teaching and use these to identify and in some cases rank examples of responsive teaching. The noticing literature and the case studies draw on such moves and stances as probable evidence that a teacher is attending and responding to student thinking, and the discourse studies go even further in largely *defining* responsive teaching by these moves -- a teacher is being responsive when he or she is taking certain actions with respect to students' ideas.

However, other case studies of responsive teaching have called this approach into question. As highlighted above, Chazan and Ball [35] explicitly challenge the practice of defining responsive teaching as a specific set of teacher moves, arguing instead that teachers necessarily select and invent moves in response to the situation at hand when they are being responsive. Additionally, first-hand accounts of responsive teaching demonstrate that such teaching not only lives in the actions a teacher takes, but also in the relationship between those actions and the context, including the teacher's perceptions and intentions. For instance, Hutchison's [38] insertion of a mathematical expression for density would be considered a less responsive move according to the discourse frameworks, but his reflection indicates how it was responsive to his interpretation of students' ideas and framings at the time.

These variations pose a challenge for researchers -- where do we locate evidence of responsive teaching? Is the evidence primarily in the teacher's actions? In the teacher's intentions? Some combination thereof? And what does this mean for describing *progress* in responsive teaching? With respect to the latter, some researchers have highlighted shifts in the frequency or presence of certain moves or markers (*e.g.,* [19, 28, 29]), but this approach is complicated by the role of context noted above as well as the variability in teachers' responsiveness highlighted by several authors (*e.g.,* [32, 44]). Furthermore, Maskiewicz and Winters' case study of one teacher's classroom practice [44] describes the variability in her responsiveness as a function of differing contributions from students, highlighting an additional consideration that was the source of much discussion during our conference -- should we primarily consider the *teacher* in determining responsiveness, or should we focus on the *students*?

What role does classroom culture - in particular, peer responsiveness - play in responsive teaching?

The literature on teacher responsiveness has mostly focused on the teacher's role in attending and responding to students' ideas. However, on close inspection of the classroom dialogue reported in accounts of responsive teaching (*e.g.,* [28, 34, 37, 39]), we notice that *students* are also attending and responding to one another's ideas. It is this kind of authentic engagement between students that breaks the mold of the traditional IRE discourse pattern [75, 76] and motivates us to ask, "What role does classroom culture – and in particular, peer responsiveness – play in responsive teaching?"

The literature *hints* at an answer to this question. In order for a teacher to attend and respond to a student's thinking, the student must first make her thinking (or doing) visible to the teacher. Doing so requires courage on the part of the student [39, 40] and suggests that teacher responsiveness must be embedded in a *classroom culture* of responsiveness (*e.g.,* [7, 39, 44, 77]) that includes students responding to and taking up the meanings that others are making. Thus far, the thread of peer responsiveness has been the focus of few studies (see, for instance, [78], examining peer responsiveness among in-service K-12 teachers in a teaching seminar), and future work could examine the nature and impact of peer responsiveness as well as how teachers and students co-construct a responsive classroom culture. A related line of inquiry could be further exploration of how students experience responsive teaching and peer responsiveness; Chazan and Ball [35] call for "ways of probing the sense that different students make of varied teacher moves" (p. 9), and Sikorski ([79], this volume) explores this issue.

What are "ways in" to responsive teaching, and what sorts of supports help?

We take two different approaches to exploring this question. One way of thinking about "ways in" to the practices of responsive teaching is to look for the "seeds" of responsive teaching that recur across the literature; a second approach is to examine the ways in which researchers and teacher educators induct teachers into the practices of responsive teaching. With respect to the former, if we look at how different literatures define and describe expertise in responsive teaching, there are productive beginnings that could be noticed and supported. For example, expertise in CGI might begin with a teacher noticing patterns in the ways that children solve problems, or noticing varying degrees of sophistication within one strategy for solving addition problems. One "seed" of expert teacher noticing might be marshaling evidence to support generalizations about teaching and learning, and one "seed" of expert responsiveness, as defined by the discourse literature, may be acknowledging that teacher moves matter for student talk and learning. Expert responsiveness in the sense described by case studies may begin with teachers recognizing that one size does not fit all -- that responsive teaching must necessarily be tailored to specific aims, individuals, and settings.

If we look for the sorts of resources that are brought to bear in responsive teaching, as described by the literature, we notice that the literature repeatedly points to the content knowledge (including conceptual and epistemological knowledge), the dispositions, and the motivations entailed. In their reflections on their own (responsive) teaching, Ball [34], Hammer [37], Lampert [39], Paley [80], and Rodgers [81] express care for and curiosity about their students, in both disciplinary and holistic ways. Case studies (*e.g.,* [33, 34, 37, 39, 82, 83]) describe teachers who want to provide authentic disciplinary experiences for their students because of the joy they themselves feel when they engage in math or science. These implicit themes suggest "ways in" to the practices of responsive teaching: care and curiosity for students, disciplinary knowledge, and feelings of joy as teachers engage in disciplinary pursuits. One research direction that this lens on "ways in" to responsive teaching poses is the question of how we can connect these "seeds" to the practices of responsive teaching, in the way that responsive teaching connects the "seeds" of science or math to disciplinary ideas and practices.

Turning to the second approach -- the "ways in" suggested by teacher professional development efforts and frameworks for teaching -- we find that what counts as a "way in" depends in part on the kind of thing that one thinks responsive teaching *is* and what it requires: a set of skills requiring specialized training, a set of classroom moves, and/or the embodiment of particular orientations toward student thinking? For instance, to support teachers in framing students' ideas as sensible and productive, some researchers regularly use videotaped classroom interactions and invite teachers to focus on the meaning students are making and the disciplinary connections embedded in their contributions, assuming that teachers have productive resources for doing so [50, 54]. The noticing literature draws on videotaped classroom interactions to promote productive orientations toward student thinking as well, but describes teacher development less in terms of framing and more in terms of skill level [12, 14, 18-21, 25, 26]. These researchers generally characterize noticing as a specialized skill or set of skills that "is not a natural extension of being observant in everyday life" ([84], p. xx), nor a natural outgrowth of teaching experience [13]. As such, teachers practice noticing students' mathematical thinking in more controlled settings outside of the classroom, where they are not tasked with responding immediately or managing other classroom dynamics. Work on high-leverage practices in math education takes a similar approach, encouraging preservice teachers to rehearse certain routines (like eliciting and responding to student thinking) in preparation for enacting them in the classroom in real time [73, 85].

Researchers have also developed tools for teachers to use during instruction or as they plan for instruction -- again, matching their conceptualizations of what responsive teaching is and what teachers could use in such instruction. These range from the series of research-based frameworks on problems and solution strategies in CGI, to particular talk moves and strategies teachers can use to elicit and work with student thinking in the classroom [74, 86-89], to launching questions designed to spark scientific discussion and generate mechanistic thinking [53]. Generally, much work remains to be done in understanding how teachers take up or adapt the various "ways in" to responsive teaching described above. Part of this understanding may be gleaned from asking *teachers* what supports they feel they need to teach responsively, and unpacking the concerns and constraints they face in seeking to do so.

What constructs can enhance (or have enhanced) the study of responsive teaching?

Researchers have brought a variety of constructs to bear on their understandings of responsive teaching. The construct of framing -- a teacher's sense of "what is going on here" -- has been used to explain variation in teacher attention and responsiveness, both within and between teachers [32, 42, 43, 45]. The literature also repeatedly points to specific types of knowledge and dispositions brought to bear in responsive teaching, described as "ways in" above -- conceptual and epistemological knowledge, care for students as disciplinary learners and people, joy in mathematical and scientific inquiry, etc. Work in CGI also emphasizes the importance of what could be considered a specific form of pedagogical content knowledge -- knowledge about students' conceptual development in particular domains [5, 8]. We anticipate that further research will continue to flesh out the relationships between these constructs and responsive teaching, as well as identify other relevant constructs that can be brought to bear on our understanding of teacher responsiveness.

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