Responsive teaching and responsive coaching:

Opportunities to advance practice and foster student sensemaking

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Abstract

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This dissertation looks at how responsiveness towards students' science ideas and teachers' understanding of responsive teaching provides opportunities for sensemaking and learning. For this study, I served as the primary science instructional coach for three upper elementary teachers at different schools for at least one school year. We engaged in multiple coaching cycles as part of a larger job-embedded professional development model endorsed by the district and in partnership with a local University. With respect to responsiveness and students' opportunities for sensemaking, I analyzed 30 science lessons where teachers intended to engage students in whole-class sensemaking discussions. I examined how teachers' responsiveness to their students' science ideas worked in combination with other supportive conditions to foster rigorous whole-class discussion episodes. I found that higher rigor episodes were associated with the teacher's use of multiple conditions, often four or more used together. These conditions included combinations of specific talk moves (open-ended questions, follow-up prompts, invitations to others), scaffolds for idea development (pre-discussion tasks, references to activity or representations of activity), and scaffolds for using language to communicate in particular ways (e.g. invoking talk norms; explicit attention to the language demands of a given discussion purpose). With respect to responsiveness and teacher learning, I examined my responsive approach to instructional coaching to identify if or when this approach provided opportunities for teachers' pedagogical experimentation with teaching practices intended to help them become more responsive to their students' science ideas. I define what responsiveness means in a coaching context and propose five dimensions of responsive coaching. There are few examples in the literature that examine the nature of instructional coaching, particularly in one-on-one interactions with teachers. I address this gap by analyzing data from the coaching cycles with three upper elementary teachers to trace the pathways each teacher took in experimenting with these practices. I found that each teacher made productive progress towards fully enacting these practices and all teachers demonstrated an increasing or continued commitment to being responsive to their students' science ideas. In doing so, each teacher and I co-constructed unique learning pathways for each practice—at times, this experimentation gradually advanced their progress, maintained their progress, or stopped-then-restarted their work with a given practice.

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Dedication

To my husband, who encourages and supports me in pursuing my studies and passions.

Introduction

National science education reforms, such as the Next Generation Science Standards (NGSS), require that classroom instruction move away from portraying science as a set of "final form" facts and towards authentically engaging students in doing science (Duschl, 2008; Lead States, 2013). Even young elementary students are expected to evaluate scientific evidence, develop and revise models, explain phenomena, and apply their understanding to solve relevant, real-world problems. On one hand, we know students are capable of such intellectual work (Brown & Campione, 1996; Lehrer & Schauble, 2005). On the other, we must recognize that this shift requires elementary teachers to make significant changes to their current science teaching—which predominantly features disconnected, hands-on activities lacking connections to core science ideas and provides insufficient opportunities for student sensemaking (Roth, 2014).

One instructional approach shown to promote both rigor and equity in elementary classrooms—responsive teaching—supports *all* students in engaging in the authentic disciplinary work described in reforms. Responsiveness legitimizes contributions of traditionally marginalized students (Rosebery et al., 2010; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001), allows for increased student authority and agency over the construction of knowledge (Hammer, Goldberg, & Fargason, 2012; Stroupe, 2014; Windschitl & Barton, 2016), and intersects with creating rigorous learning opportunities (Colley & Windschitl, 2016; Pierson, 2008; Thompson et al., 2016; Windschitl & Barton, 2016). When teachers take a responsive stance, their students are re-positioned as epistemic agents (Engle & Conant, 2002; Stroupe, 2014; Warren et al., 2001) as students are encouraged and supported in articulating their beliefs and ideas about how and why events happen (Jim Minstrell, 1982) and engage in class investigations organized around their questions and ideas (Warren & Rosebery, 1993). This approach affords building upon and from students' initial ideas, partial understandings, lived experiences and linguistic resources (Thompson et al., 2016). Furthermore, responsiveness is positively related to student learning and serves to "level the playing field" between students who have traditionally-privileged background knowledge and those who do not (Pierson, 2008).

Being responsive requires that teachers have a degree of pedagogical nimbleness and a substantial understanding of science ideas, in order to: design and facilitate tasks that elicit students' resources, recognize and foreground the productive disciplinary substance of students' contributions, and proceed in ways that deepen students' conceptual understandings to move toward canonical ideas and practices (Hammer et al., 2012; Robertson, Scherr, & Hammer, 2016). To facilitate teachers' engagement in this pedagogical work, researchers have articulated sets of ambitious instructional practices which are grounded in responsiveness to support rigorous and equitable instruction (Ball & Forzani, 2011; Ball, Sleep, Boerst, Bass, & Ball, 2013; Kazemi, Franke, & Lampert, 2009; Lampert & Graziani, 2009; Windschitl, Thompson, Braaten, & Stroupe, 2012). Much of this work happens on the social plane of the classroom, in discursive interactions between students, which requires that teachers productively frame, scaffold, and facilitate students' participation during whole-class interactions. It is necessary, therefore, to build on prior studies to better understand how teachers mediate rigorous and responsive episodes of whole-class talk (see Colley & Windschitl, 2016; Thompson et al., 2016).

Currently, examples of responsive teaching in the literature feature math and science teachers with exceptionally refined or specialized expertise to illustrate what is possible in the classroom (Ball, 1993; Colley & Windschitl, 2016; Hammer et al., 2012; Maskiewicz & Winters, 2012; Rosebery et al., 2010). However, if responsive teaching is to become more commonplace given its associations with rigorous and equitable instruction, then it is important to understand how non-specialist teachers learn to take up such practices. My research addresses this gap by documenting the professional learning of three generalist (non-specialist) upper elementary teachers with students from diverse backgrounds. Two sets of questions framed this study:

1. *Rigor and responsiveness in students' sensemaking discussions:* Under what teacher-mediated conditions are students more likely to engage in rigorous science talk during whole-class sensemaking discussions? What patterns emerge over time for each teacher around intersections of responsiveness and rigor during these whole-class science discussions?
2. *Teacher learning and responsive coaching*: Is it possible for responsive coaching to support elementary teachers in taking up responsive instruction? If so, what dimensions of responsive coaching appear to support teachers' pedagogical experimentation aimed at being responsive to their students' science ideas?

Summary of Study Design

In this multi-case study, I investigated two levels of responsiveness, responsive teaching and responsive coaching, and their utility for providing sensemaking opportunities to students and teachers, respectively. Data for this dissertation were collected during a three-year, district-sponsored, job-embedded professional development model called STEM Academy. This model was aimed at improving upper elementary science teachers' instruction, and students' science learning. During STEM Academy, I served in the roles of curriculum writer, professional development facilitator, and instructional coach alongside the district's elementary science instructional coach. For this study, I analyzed data collected during coaching cycles with three teachers at different schools. These teachers represented a range of years of experience (from novice to experienced), they were all new to the practices and curriculum promoted in STEM

Academy, and each was willing and eager to have coaching support, particularly with an interest in improving whole-class science discussions.

Synopsis

My goal with this dissertation was to capture two distinct phenomena around responsiveness as a stance that (1) supports rigor in students' whole-class discussions and (2) encourages productive experimentation in teachers' practice. To tell a cohesive and focused story for each phenomenon, I have separated my dissertation into two stand-alone sections. Given that these studies happened within the same context, with the same teachers, there is some redundancy across sections. Also, there may be concepts noted briefly in one section that are more fully explained in the other. Your flexibility as a reader is appreciated. The structure of the dissertation is as follows:

Section 1: How teachers' responsiveness and other supportive conditions promote rigorous whole-class science discussions

For this section, I analyzed episodes of whole-class discussions from 30 lessons, where teachers intended to have sensemaking discussions with students, to uncover what conditions co-occurred with or preceded episodes of rigorous student talk. All participants expressed a desire to have rich, whole-class discussions around students' ideas. While setting-up and facilitating discussions, each teacher used talk moves and scaffolding in different ways. This study provided confirmation of prior studies about the supportive conditions for rigorous talk and insights that "everyday" (non-expert, non-coach) teachers can support high levels of rigor in whole-class discussions using different combinations of conditions.

Section 2: How responsive coaching mediates elementary teachers' enactments of responsive teaching practices

I document and explain the learning pathways that each of three upper elementary science teachers took during multiple instructional coaching cycles over one school-year as these teachers learned about and experimented with sets of science teaching practices aimed at being responsive to their students' ideas. In particular, I traced their development around three focal teaching practices that were likely to provide opportunities for these teachers to be responsive to their students' science thinking. These were: (a) developing and/or using explanatory models (modeling), (b) summarizing and recording student learning from classroom activities (summarizing), and (c) listing or revising student hypotheses.

In my role as the instructional coach, I made efforts to identify and leverage what I perceived as productive elements of individual teachers' professional experiences, current pedagogies, and instructional routines in order to support their professional learning and enactment of more ambitious forms of science instruction. This responsive approach in coaching to support teacher learning parallels, in some ways, how teachers who take a responsive stance support students' science learning. In this study, I characterized what a focus on responsiveness in professional learning settings looked like and explained how it mediates changes in teacher reasoning and/or instructional practice. I examined how responsive instructional coaching informs what these elementary science teachers chose to experiment with, abandon, or incorporate in their day-to-day science instruction.

SECTION 1

How teachers' responsiveness and other supportive conditions promote rigorous whole-class science discussions

Despite efforts over several decades to improve instruction, elementary students' science learning opportunities remain limited. In a recent U.S. survey, a majority of elementary science lessons were rated as low-quality based on factors such as inadequate time and structure for sensemaking, instruction not adapted to students' levels of understanding, and representing science as a static body of knowledge (Banilower et al., 2013). When teachers do make time for science, the centerpiece is hands-on activity largely lacking connections to core science ideas (Roth, 2014). At best, this fun, activity-centered approach develops student interest in science; however, it does not provide the opportunities students need to sense-make of new information and revise their conceptual understandings over time (Roth, 2014). To address these challenges, the Next Generation Science Standards (NGSS) promotes three-dimensional student performances intended to engage students in *doing* rather than just *knowing* science (Lead States, 2013). With the NGSS, students are expected to make progress on their understandings through opportunities to elaborate on, revise, critique, explain, and debate their scientific explanations using evidence. In order to do this work, students need teachers who provide meaningful tasks, sufficient time, and scaffolding to support them in gathering relevant evidence and information, and then who facilitate discussions in ways that help students to make changes to their own personally held theories (Duschl, 2008; Roth, 2002). However, neither the standards documents nor the K-12 Framework articulate instructional practices that would help elementary teachers design and facilitate the kind of science learning required of these standards.

In working with students, teachers must understand and attend to the conditions that support students' sensemaking over units of instruction. Furthermore, one approach that has been shown to support rigorous and equitable instruction is responsive teaching. For this study, I investigated the following research questions:

1. Under what teacher-mediated conditions are students more likely to engage in rigorous science talk during whole-class sensemaking discussions?
2. What patterns emerge over time for each teacher around intersections of responsiveness and rigor during these whole-class science discussions?

I begin by defining and unpacking responsiveness, as an orientation to supporting learning, as it underpins student-sensemaking focus of this study. Then, I summarize what we know about responsive teaching, patterns of classroom talk, and what conditions support students in participating in discussions with high levels of explanatory rigor.

Responsiveness in the Classroom

Current definitions of responsiveness refer to interactions between teachers and their students. Therefore, I begin by unpacking what we know about responsiveness towards students and what we know about conditions that support responsive and rigorous classroom discourse. Before proceeding, it is necessary to articulate the main assumption that grounds responsive teaching, namely that learners' ideas, experiences, and language are used as productive and legitimate resources not only for students themselves but for their peers (Hammer & Elby, 2002; Louca, Elby, Hammer, & Kagey, 2004). To be used as such, students' resources must be surfaced and made public (Michaels, O'Connor, & Resnick, 2008). Thus, responsive teachers operate with the assumption that student contributions are worthy of inquiry, frame these resources as generative for collective sensemaking, and provide opportunities for working with and on ideas publicly.

Defining responsiveness. Definitions of responsiveness and responsive teaching must take into account: (1) time-scales of responsiveness, (2) the intellectual work, cognitive demand or rigor, and (3) what teachers are responsive to.

Pierson (2008) defines responsiveness at a turn-of-talk level, taken up by students and teachers, describing it as, "attempts to understand what another is thinking, displayed in how a conversational partner builds, questions, probes, clarifies, or takes up that which another has said" (p. 25). This implies that in-the-moment decisions impact opportunities for students to build conceptual meaning. Pierson separates responsiveness from intellectual work in her analysis though she argues that teachers need to understand, in these moments-of-interaction, how to integrate responsiveness and intellectual work with core disciplinary content.

Other scholars expand the time-scale to include these in-the-moment moves as well as lesson-level and unit-level timescales of responsiveness. Robertson and colleagues (2016) define responsive teaching as foregrounding the substance of students' ideas, recognizing disciplinary connections within students' ideas, and taking up and pursuing the substance of student thinking. In these cases, responsive teachers use student ideas and questions to alter a discussion, lesson, and/or unit plans to authentically pursue their students' lines of reasoning. This happens over a longer time than turns-of-talk—though it is informed by these turn-of-talk level interactions. This view of responsiveness implicitly addresses intellectual demand. Similar to Pierson, the idea of taking up and pursuing student thinking is directly related to rigor or intellectual demand, even if it is not explicitly named as part of their definition of responsiveness.

Finally, with a focus on expanding what teachers are responsive to, a third definition of responsiveness provided by Thompson and colleagues (2016) is rooted in principles of culturally responsive teaching and equity-in-practice. They articulated and examined three aspects of responsiveness around students' individual and collective knowledge construction which were: responsiveness to building on students' scientific ideas, responsiveness to participation and building classroom community, and responsiveness to students' lived experiences. Like Pierson, Thompson and colleagues (2016) defined and analyzed rigor as conceptually separate from responsiveness though they acknowledged that rigor and responsiveness are merged and intertwined in "substance, practice, and in-the-moment dilemmas" (p. 29). Their findings illustrate this intersection, such that high levels of rigor were not possible without responsiveness; and that when multiple forms of responsiveness were present together, the unfolding episode was more likely to be higher rigor (Thompson et al., 2016).

Drawing upon these definitions, I define responsiveness as a teaching stance where teachers:

- Engage in concerted attempts to elicit and legitimize learners' resources.
- Recognize and highlight the disciplinary substance of these resources.
- Pursue this substance with students as a productive line of inquiry by providing students opportunities to engage with these resources in disciplinary ways.

This definition is further elaborated by recognizing the requirements for teachers who are learning how to be responsive to their students. Responsive teachers know how to: (1) provide opportunities that surface students' resources; (2) recognize both the substance of and relevance within these resources once they are made public; (3) design and facilitate tasks that support other students in working with and on the substance of these resources over time; and (4) manage the endemic tensions of when/how to respond to unanticipated student contributions at different time scales (in-the-moment, in a lesson, or at a unit level). This teaching stance demands developing particular sets of professional skills and practices in order to know how to productively position and utilize student resources to support all students in achieving disciplinary goals in ways that are responsive to students' ideas, experience, and language.

Demands of responsive teaching. In responsive learning environments, students need intentionally designed and facilitated opportunities to comprehend and utilize their peers' resources productively to co-construct and revise their understanding. These opportunities are largely predicated on how teachers, as instructional leaders, make sense of the on-going activity and decide how to respond in an effort to provide support for students' on-going sensemaking. Many factors contribute to a teacher's ability to do this. These include, but certainly are not limited to, the teachers' knowledge of the discipline and how to use talk moves for specific disciplinary purposes.

Sufficient content knowledge to notice the disciplinary substance of student contributions. We know that a teacher's ability to improvise responses in-the-moment is impacted by their own disciplinary content knowledge. Teachers must decide what piece within a student contribution to pursue and which to ignore or save for later (Ball, Thames, & Phelps, 2008; van Es & Sherin, 2006). Teachers can make purposeful use of student comments to advance students' disciplinary content understanding while still maintaining an atmosphere of student-centered discourse (Krussel, Springer, & Edwards, 2004). This is contingent upon what teachers notice and attend to within students' contributions and how they interpret its utility for other students' understanding during the moments of classroom discourse (van Es & Sherin, 2006). As they notice and interpret student contributions, teachers, particularly non-content specialists, such as elementary teachers, are confronted with the limitations of their content knowledge (Alexander, 2015; Ball et al., 2008; Krussel et al., 2004). This creates difficulties in identifying the more productive aspects of student contributions and uncertainty around how to prioritize one idea over another to support the on-going development of student understanding (Alexander, 2015; Krussel et al., 2004; Nystrand, Wu, Gamoran, Zeiser, & Long, 2003). Additionally, teachers, in their role as leaders of the learning communities, understand functional features of the disciplinary practices and provide students access to them by making tacit knowledge explicit and by providing resources to support interactions (Gee, 2008).

Students bring in unexpected ideas and experiences that are public bids for taking the discussion in unanticipated directions which can create tensions around supporting lines of student reasoning (Colley & Windschitl, 2016; Mehan & Cazden, 2015). Without sufficient content knowledge, teachers engage with particular dialogic principles (see Alexander, 2015) but are limited in how they can help students build ideas and create cumulative understandings. Therefore, it is important to support teacher's content knowledge development while also attending to teacher's repertoires of discursive practices.

Orchestrating student participation in purposeful talk. Once a responsive teacher decides on what aspect of the student contribution to explore, then the teacher must choose how to follow-up and pursue this idea. Teachers guide student's thinking in productive directions when they select and use particular talk moves in response to student contributions while also attending to ongoing classroom conditions that support productive talk (Engle & Conant, 2002; Mercer, Dawes, Wegerif, & Sams, 2004). Teachers must be able to recognize when and how to intentionally invoke particular communicative approaches to support students talk for specific purposes. Scott, Mortimer, and Aguiar (2006) note that "shifts between communicative approaches are an inevitable part of teaching whose purpose is to support meaningful learning of scientific knowledge" (p 605). The majority of this work happens through classroom discourse—Teachers facilitating, listening in on, and otherwise orchestrating discursive interactions with and between students. This becomes is the main vehicle to surface student ideas, experiences and questions, enhanced significantly when paired with tools and inscriptions, that then, the teacher can interpret and use. In the next two sections, I describe in more detail how classroom talk supports rigorous and collective student sensemaking culminating in my discourse framework for responsiveness.

Patterns of Classroom Talk: From Traditional to Responsive

Patterns in classroom discourse are unique compared to other professional or everyday exchanges (Hicks, 1996; Lemke, 1990). To students, these patterns of classroom talk reinforce what counts as valued forms of participation and message whose ideas and which ideas matter in a given classroom environment.

One common pattern is a triadic structure of classroom talk, initiate-respond-evaluate (Cazden, 2001; Lemke, 1990; Mehan, 1979; Wells, 1993), which happens when teachers initiate with a question or prompt, students respond, and teachers evaluate the response. This structure reinforces the teacher's role as the knowledge authority. And, in the context of a whole-class discussion, the teacher's closing turn simultaneously serves to "control the flow of interaction" and assess student knowledge while publicly confirming or affirming this knowledge to the class (Cazden, 2001). Another such unique pattern arises in how teachers use particular utterances to invoke participation. For example, classroom discourse involves patterns of exchanges between novices (students) and experts (teachers) in such a way that the expert often asks questions or uses "designedly incomplete utterances" to elicit answers which the expert already knows (Koshik, 2002). In non-school contexts, incomplete utterances are used to imply a question or legitimate request for additional information, but are not employed by someone who already has that information. In school, however, over time, students become accustomed to these unique patterns of talk as they learn to "play the game of school". An unintended consequence of such exchanges is that students may come to equate the goals of these patterns of talk with disciplinary goals (e.g. see 'guess-the-answer' in Ball & Forzani, 2011). In science, these patterns of traditional classroom talk reinforce a traditional transmission model of science learning (i.e. science is about *knowing*) which is problematic for the three-dimensional student performance expectations required in NGSS (i.e. science is about *doing*).

Compared to recall or recitation, a focus on reasoning requires students to do something more with an idea or multiple ideas, such as interpreting, explaining, justifying, revising, countering, comparing, and/or jointly constructing understanding (Mehan & Cazden, 2015; Mortimer & Scott, 2003). Here the IRE pattern can shift to IRF, where the third turn is feedback or follow-up rather than evaluation. Wells (1993) points out that IRE/F itself can serve different functions and should not be characterized as necessarily good or bad. Scott, Mortimer, & Aguiar (2006) expand on this claim by characterizing particular modes of communication as a cross between interactive or non-interactive and authoritative or dialogic—similarly these combinations are not good or bad but employed by teachers for particular purposes. These discursive interactions shape practice and illuminate the ongoing negotiations between participants which, often tacitly, reveals the roles and responsibilities for participation, 'what counts' as worthy of inquiry in a discussion, and the purpose of such talk (Gee, 2011).

The ways classroom communities engage in particular discursive activities can change over time through concerted efforts by any participants, but more often due to the teacher's actions. Teachers play a specialized role as the instructional leader of the learning community. Using the inherent power and authority of this position, teachers have influence over whose ideas are allowed and if/how students are positioned to interact with said ideas. Teachers draw upon the suite of tools and moves in their pedagogical repertoire and/or invoke historically established classroom norms that create and maintain accountability to the learning community, to disciplinary content ideas, and to standards of reasoning (Michaels, Connor, & Resnick, 2008). Teachers are simultaneously working to align students with each other and with the content of the academic work *while* socializing students into particular ways of speaking and thinking (Gee, 2008; Mehan & Cazden, 2015; O'Connor & Michaels, 1993). Students and teachers make bids to explicitly or tacitly negotiate what it means to "do science" in this classroom and what kinds of behaviors, arguments, stories, contributions, and interactions are allowed. These properties shift within moments of an activity because of the negotiated and improvisational nature of such exchanges, which is, in part, why facilitating responsive and rigorous whole-class discussions is challenging. First, with respect to ideas, teachers "help turn tacit knowledge in to explicit knowledge to be used to further developed" (Gee, 2008, 93). And, second, regarding participation, teachers control structures, norms, and routine managing what kinds of interactions are allowed and who is invited to participate. Therefore, it is useful to examine teachers' enacted decisions about managing and scaffolding participation as to when and how they invoke tools, norms, and resources and how these moves shape the ongoing activity. This is not to say teachers have a monopoly because students do make bids to negotiate tasks and provide contributions which influence the on-going activity; however, teachers, in their position of authority, generally have more control over the learning environment than students do, and for these reasons it is worth inquiring into how teachers use of particular conditions mediate sensemaking activity.

Teachers play an important role in establishing goals for talk and facilitating productive talk between students in their classrooms. Teachers need tools to help them continuously reflect and improve how they support and use talk as a thinking tool. Several researchers have developed frameworks and principles towards these goals. The framework for *productive disciplinary engagement* (Engle & Conant, 2002) outlines principles for designing a learning environment within which such discussions can take place. Engle and Conant's (2002) four guiding principles of productive disciplinary engagement engagement—(a) problematizing the content, (b) giving students authority, (c) accountability to others and the discipline, (d) resources to support students—inform the design of learning environments which support productive talk. Specific norms, scaffolds, and routines can live and change across time within a learning environment to align with the principles outlined above across all classroom activities. Teacher's talk moves (see Michaels & O'Connor, 2012) or particular teacher interventions (see Mortimer & Scott, 2003) can contribute to students engaging productively with each other and with disciplinary ideas. Peers as well as teachers provide behavioral models of what kind of talk is expected and accepted. Students try out their own thinking, hear how others reason, see how to generalize and make connections. Teachers support students in participating when they explicitly teach students how to use language as a reasoning tool (Mercer, Wegerif, & Dawes, 1999). Yet, students' engagement in productive talk is not guaranteed even with supportive conditions in place (Colley & Windschitl, 2016; Engle & Conant, 2002).

Supporting the Rigor in Collective Sensemaking

Learning happens over time when peers publicly share and revise ideas particularly when ideas are rooted in problematized, complex content which establishes a common purpose, aim, or object of this collective work (Brown & Campione, 1996; Engle & Conant, 2002; Greeno & MMAP, 1998). Students are responsible for participating in ways that assist in making ongoing progress on their collective understanding over time. To challenge students' own prior notions, they must have opportunities to surface their existing understanding, collect and/or review evidence, and explain for themselves how this evidence strengthens or refutes their current understanding and if/how they will modify their understanding. When done in public and collective ways, students identify their own understanding and compare it with their peers' as well as with information provided by other authorities such as scientific texts, data sets, informational videos, and their teacher. Collective discussions using particular forms of talk provide the primary mechanism for sensemaking—supporting students in developing understanding of complex concepts (Mercer, 1996; Michaels et al., 2008; Resnick & Michaels, 2010).

Defining rigor. The act of public sensemaking through talk is a rigorous and intellectually demanding process. Public sensemaking requires individuals to take in new information, process it, and compare it against their current understanding, and then offer a subsequent contribution that acts on the idea in-play. In science, the aims of such discourse is to use the idea to explain a phenomenon to others, understand that any explanation is one among many plausible alternatives, and assess the credibility of one's ideas or explanations based on evidence (Ford & Wargo, 2011). Rigor, then, is not an attribute of standards, curriculum, or lesson tasks, but rather, it emerges in the moment-by-moment co-construction and negotiations between participants during interactions (Thompson et al., 2016). In assessing levels of rigor, more rigorous discussions are dialogic and interactive (Mortimer & Scott, 2003), broadly characterized by: clarifying or challenging conceptions, attempting to link observable to unobservable events or processes, comparing and contrasting explanations, and using evidence to justify or refute an idea. Lower rigor interactions are marked by monologic discourse, such as sharing of a canonically accepted fact or truth (Bakhtin, 1981), recounting observable events or experiences, or telling a personal story without inviting connections or justifying its relevance to the ongoing conversation.

If we accept that *public* sensemaking—engaging with others to communicate, interrogate, debate, build-and-revise ideas—is valuable to learning (Michaels et al., 2008; Resnick & Michaels, 2010), then it is important to identify and examine conditions which are likely to foster rigorous-and-public student sensemaking talk. In looking at intersections of responsiveness and rigor, Thompson and colleagues (2016) found that high levels of rigor cannot be attained when teachers are not responsive to students' resources. Conversely, episodes featuring multiple forms of responsiveness—building on students ideas, lived experiences and participation in the classroom community—were more likely to have elevated rigor (Thompson et al., 2016). Alongside responsiveness, other teacher-controlled conditions, when used in combination, have shown promise in increasing the likelihood that students will engage in a rigorous discursive episode (Colley & Windschitl, 2016; Henningsen & Stein, 1997). These include conditions related to the task itself, such as, planning an inquiry-worthy sensemaking task that requires reasoning (Henningsen & Stein, 1997; Schoenfeld, 1994); framing the task to students in ways that foreground building on students' ideas and helping students to see connections to disciplinary concepts (Jackson et al., 2013); providing a clear academic purpose for the discussion (Michaels & Connor, 2012); and providing tasks where students represent and inspect one another's ideas through writing, drawing, and talk (Danish, Enyedy, Hall, & Angeles, 2006; Radinsky, Oliva, & Alamar, 2010). Other conditions relate to supporting talk: teachers using open-ended prompts and follow-up moves to elicit ideas, reasoning, and justification from students (Black & Wiliam, 1998; Nystrand et al., 2003; Roth, 2002); allowing and encouraging students' informal language (Warren et al., 2001); supporting students in taking up specific talk roles (Kawasaki, Herrenkohl, & Yeary, 2004); and explicitly teaching students to use language for specific disciplinary purposes (Manz, 2015; Mercer et al., 1999). In a learning community that foregrounds making progress on ideas and revising ideas, combinations of these conditions increase the likelihood for supporting students in engaging with each other in rigorous whole-class sensemaking discussions.

A discourse framework for responsiveness

Figure 1 illustrates my discourse framework for responsiveness. It compares two potential pathways of talk, where teachers either recognize student contributions or are responsive to them (Colley & Windschitl, 2016). The dotted-line path on the left illustrates an IRE pattern (Lemke, 1990) which is often authoritative in nature (Mortimer & Scott, 2003). This pathway, though at times purposeful, is not a common pattern characterizing sensemaking conversations. The goal of IRE is, at times, purposed productively at confirming information previously learned or known to the community, naming concepts, or, other times used less productively, to fish for correct answers (Mortimer & Scott, 2003). The solid-line pathway on the right, featuring an iterative loop, indicates a responsive pathway which opens the possibility for multiple exchanges of teacher and student reasoning to work collectively on idea(s) that are put into play through student or teacher contributions and kept in play through responsive prompts and students taking up these prompts. The more iterations within this loop, the more turns-at-talk are spent by students and teachers working on an idea or set of ideas together, which often, but not always, gives rise to a higher rigor sensemaking episode.

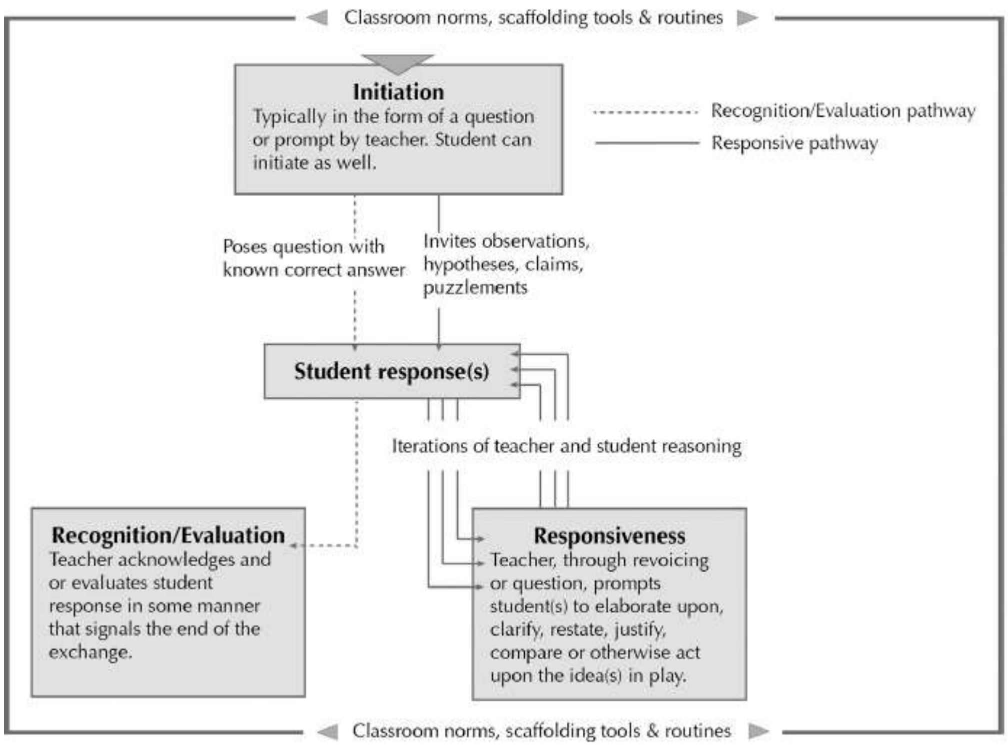


Figure 1. A discourse framework for responsiveness: Pathways for whole-class talk. (Colley & Windschitl, 2016)

In summary, if we accept public sensemaking—engaging with others to communicate, interrogate, debate, build-and-revise ideas—as valuable to learning (Alexander, 2015; Minstrell, 1982; Stroupe, 2014; Warren & Rosebery, 1993; Windschitl & Barton, 2016), then, it is important to identify and examine combinations of conditions which are most likely to foster rigorous-and-public sensemaking between students. Accordingly, my research adds to existing literature and extends my prior study (Colley & Windschitl, 2016) about what we know about supportive conditions for responsive and rigorous talk.

Methods

In this qualitative, multi-case study (Merriam, 2009), I examined whole-class sensemaking discussions with students from three different classrooms, at three schools. The data I analyzed for this study came from coaching work with individual teachers; yet understanding how my study is situated in a larger and collective professional learning context of the STEM Academy is important. Teachers participation in some of our collective activities impacted, in specific instances, what teachers decided to experiment with and take-up into their own science classrooms which, in some instances, influenced how they structured or framed whole-class discussions. I will share the context of STEM Academy and my role as participant observer before describing my participant sampling process, data collection, and analysis.

Study Context: Three-Year Job-Embedded Professional Development

The three-year STEM Academy (Fall 2013–Spring 2016) was designed to improve science instructional practice and support upper elementary teachers in implementing the Next Generation Science Standards (NGSS) as part of the district's transition plan. The STEM Academy model anchored professional learning around an NGSS-aligned set of high-leverage science teaching practices (see Ambitious Science Teaching Practices, www.AmbitiousScienceTeaching.org). The STEM Academy model had four main goals. First, for students, the district leadership hoped that teachers' participation would support students' science learning and raise test scores. Second, for teachers, the STEM Academy would provide classroom examples of practice that exemplified the District's strategic plan for teaching and leadership, captured by their "Four Pillars": (1) *Equitable Access* to rigorous, standards-based instruction, (2) *Results Focused* professional learning and collaboration, (3) *Strong Partnerships* with families and community, and (4) A *Culturally Responsive* organization. These pillars were referenced and included in a series of STEM Academy workshops. Third, the STEM Academy was designed to support teachers in building awareness of and transitioning science instruction to using the NGSS. Finally, the District intended for this three-year, intensive experience to develop a group of elementary science teacher leaders well-versed in NGSS and knowledgeable about high-leverage science teaching practices. These teachers were expected to take up leadership roles in future science workshops and with curriculum writing and revision iterations as the District fully transitioned to implementing NGSS in their elementary schools.

To achieve the District's goals, STEM Academy utilized a variety of coherent professional learning experiences with small cohort of teachers supported over three years. Year 1 was considered a "slow start" with just three full-day workshops on NGSS featuring the redesigned curriculum guides. Each of these workshops coincided with the start of a unit which for upper elementary, in this District, meant three science units per year, one per quarter. These workshops introduced teachers to the NGSS and ambitious teaching practices through the redesigned unit guide. Years 2 and 3 were more intensive. These years launched with a week-long summer institute where students attended each morning and experienced a mini-unit on sound energy which teachers observed, and at times, co-taught. After students went home, teachers debriefed in the afternoon, sharing observations of student ideas and co-plan upcoming lessons. Also, we added full-day Studio Days. These provided unique opportunities for teachers to visit each other's classrooms three times during the year to observe classroom routines, to collect and analyze data on student understanding, and to see a focal science teaching practice demonstrated each studio. Finally, the District expected teachers to take advantage of instructional coaching cycles offered. Table 1 summarizes the professional development activities during the 3-year STEM Academy.

Table 1.

STEM Academy overview of professional learning activities

Prof. Learning Activity	*Year 1 2013-2014 "Slow start"*	*Year 2 2014-2015*	*Year 3 2015-2016*
Curriculum revisions and workshops	3 full days, one per unit, 6 hours each	3 after-school workshops, one per unit, 3 hours each	3 after-school workshops, one per unit, 3 hours each
Science instructional coaching cycles	Provided, if requested	Highly encouraged, most regularly engaged	Highly encouraged, most regularly engaged
Week-long summer institute	n/a	5-days in August, Prior to Year 2	5-days in August, Prior to Year 3
Full-day Studios	n/a	3 full days per year, by grade level, one per unit	3 full days per year, by grade level, one per unit

My Role

To support this professional learning work, the District partnered with researchers at the local University who study science teacher learning. As a University partner, I designed and facilitated the professional development activities, taking up roles as a curriculum writer, instructional coach, and primary professional learning facilitator. I informed teachers and district staff about my role as a researcher, consented participants to data collection, and they understood my affiliation with the University. However, during the project, I prioritized my role as a facilitator/coach in the STEM Academy over my role as a researcher, taking a role of participant-observer (Merriam, 2009; Adler & Adler, 1998).

Participant Selection

To identify the cohort of STEM Academy science teachers, the District targeted fifth and sixth grade science teachers at five of their 18 elementary schools, resulting in an initial group of ten teachers. District leaders selected these five schools because of their historically low student performance on Grade 5 state science tests. The District required that participating schools departmentalize—meaning that these teachers would be required to teach 2-3 subjects (including science) rather than all subjects and that they would have multiple classes per day (two or three). This allowed participants to teach the same science lesson multiple times to different classes which provided an opportunity to practice, reflect, refine, and try-again which is not typical for self-contained elementary teachers. Notably, after year 1, the majority of teachers were not able to continue in the STEM Academy because they changed grade levels or schools (away from the five sites targeted by the STEM Academy) or changed districts. This meant that at the start of year 2, the majority of teachers in the STEM Academy were new to our work, NGSS, and the ambitious science teaching practices.

From the group of teachers participating in year 2, I selected three teachers to participate in my study using criterion-based sampling (Merriam, 2009). These teachers met the following criteria: agreed to fully participate in STEM Academy events, expressed a desire to improve on and include multiple student-to-student discourse opportunities during their science lessons, and committed to multiple cycles of one-on-one science instructional coaching cycles throughout at least one school year. Additionally, these three teachers, with a range of prior teaching experience (0-7 years), were new to learning about NGSS and the Ambitious Science Teaching Practices. These criteria allowed me to address the purposes of my research, namely, identifying the conditions that support rigorous whole-class science discussions.

Table 2 summarizes descriptions of my three teacher participants. Two taught fifth grade (Henry and Ellie), and one taught sixth grade (Amanda). Each had 2-3 classes of 24-28 students, taught science between one and four times a week, and their science lessons ranged from 45 and

75 minutes each lesson. Both Amanda and Henry joined in Year 2 and continued through Year 3. Ellie participated only during Year 2 because she moved out of the district before Year 3. Year 2 was Henry's first, Amanda's eighth, and Ellie's sixth year of teaching.

Table 2.

Participant Descriptions

Teacher	*K-6 Elementary School*	*Grade*	*Years of Teaching prior to STEM Acad.*	*Subjects taught*	*Frequency of science lessons*	*Science lesson duration*
Henry	Misty Creek	5th	0 years	Science, Math	1-2x per week	45-75 mins
Ellie	Barclay	5th	5 years	Science, Writing	3-4x per week	45-75 mins
Amanda	Madison	6th	7 years	Science, Writing, Social Studies	2x per week	60-75 mins

Data collection

My data for this study came from a total of 30 lesson observations during year 2 (and for Henry, part of year 3) of the STEM Academy. This timeframe allowed me to gather sufficient evidence of whole-class discussions to be able to discern typical discourse practices and track what teachers tried out and if/how it supported students' public and collective reasoning (Mercer, 2010). These 30 lessons were selected because the teacher communicated to me their intent to engage students in whole-class sensemaking discussion during that lesson.

Video recording lesson observations. Derry and colleagues (2010) recommend using the research interests to inform how video is collected. Given my interest in whole-class discussions as well as teacher actions to support discussion, I positioned the video camera to capture as much of the classroom as possible and directed towards the area of the classroom where the teacher spent most of his/her time during whole-class interactions to capture any work projected from the document camera or written/posted on the board that might be used during a discussion. The entirety of the lesson was video recorded to capture activities that preceded and followed these whole-class discussions to be able to identify supportive conditions at different timescales that may impact how these whole-class episodes unfold, a technique also recommended by Derry and colleagues (2010). One advantage to having this video record, in addition to other sources (photographs and coaching notes), was that I was able to revisit the video (Derry et al., 2010) to note visual presence of artifacts and how the teacher or students used them that I would not be able to capture using only audio recordings and photographs.

Missing data was infrequent due to malfunctions with recording equipment resulting in gaps or missing time during a lesson. In these few instances, my coaching notes and classroom photos filled in the gaps about what happened during that time and such gaps were noted in the transcripts as the lesson videos were transcribed.

Other lesson artifacts. During observations, I jotted notes about the lesson flow, sequence of activities, ideas or phrases I heard from students. I took photos of lesson artifacts; these were most often charts, lists, or tables that the teacher constructed with or for student use. Particularly, I was interested in artifacts that captured or addressed student ideas or questions. This provided a photo record of which kinds of ideas teachers were featuring, if/how teachers' use of these artifacts shifted over time. I also collected a sampling of actual physical artifacts to review later once the teacher and students were finished using them. These artifacts, along with photographs and my coaching notebook, enriches the data collected through video (Derry et al., 2010) and allow for triangulation across data sources to corroborate claims or identify inconsistencies to be explored (Miles, Huberman, & Saldana, 2014).

Data Analysis

Due to my primary role as a facilitator/coach the STEM Academy, I elected to analyze data after the completion of the STEM Academy to preserve my participant status.

Transcribed lesson observations. I started my data analysis by transcribing the video recordings of lesson observations, being sure to capture, in-full, any whole-group discussions between students, or between the teacher and students. In these transcripts, I included descriptive notes about any visual resources referenced or used in these whole group exchanges. I descriptively summarized other activity structures such as partner talk or individual or small group tasks. Next, I located photos from lesson observations and/or took screen captures of key moments from the video where having a visual record of that moment, as opposed to only a written description from a transcript, would be illustrative. Finally, at the top of each lesson transcript I added a lesson outline generated from my coaching notes and photos, and activity timeline. This lesson activity timeline was necessary in generating the activity structure row of the barcode representations I describe later and the photos and screenshots helped track key unit artifacts to see if/how teachers used them in ways that made students' ideas available to the class.

Analyzing lesson transcripts. After transcribing all of the lesson videos, my transcript analysis process consisted of the following steps: (1) reviewed the lesson transcripts to identify and bracket whole-class discussion episodes, (2) coded each episode for teacher-mediated conditions, (3) assigned each episode a rigor level, (4) identified the focus of each episode; (5) identified if teachers' reference to student ideas, generally or specifically; (6) noted when teachers referred to the nature or quality of talk, (7) reread the whole lesson transcript to look for specific practices and marked if/where/when evidence of those practices occurs, (7) built a visual representation, which I call barcodes, for each lesson observation that included information about episodes, rigor, student ideas, nature of talk, and focal practices; (8) looked across lesson barcodes to identify visual patterns to be able to make claims about the nature of whole-class discussions in each teacher's classroom over the year.

1. ***Identifying episodes within whole-class discussion activities.*** First, I read the transcript to locate whole-class discussion activities. I analyzed these discussions at the level of utterance—meaning an uninterrupted stretch of speaking by an individual (Rowe, 2011) to identify science ideas and/or student ideas discussed. Then I bracketed the entire sequence of topically-related utterances as one whole-class discussion episode. I defined episode as a set of related utterances, that included more than one person, and was focused on a particular student idea and/or science concept. Episodes could be initiated by a student or the teacher and included at least one other person (student or teacher) responding to the initiating prompt and providing at least one additional comment (by the initiator, or another person) though often episodes included multiple exchanges. The boundaries of where one whole-class discussion episode started and ended were determined by the ideas being discussed. Occasionally, there was a long span of whole-class discussion activity, but topics switched frequently. This meant the long span was bracketed into multiple shorter episodes. This meant that during a given span of time spent in whole-class discussion activity it might count as one long episode if the discussion stayed focused on one idea or set of ideas, or, if topics changed frequently, bracketed into multiple, consecutive episodes marking shift from one topic/idea to another.

2. ***Teacher-mediated conditions***. Then, within each episode, I coded for conditions around scaffolding and talk moves. These are defined with examples in Table 3. Some of these codes came from my prior study of teacher-mediated conditions (A-F) used during whole-class discussions (Colley & Windschitl, 2016). Others (G-I) emerged as patterns in teacher actions from this data around how teachers invoked talk norms or when they were explicit about the purposes of talk and use of language.

Table 3.

Teacher-mediated conditions

Condition	*Description*	*Examples*
A. Open question	The teacher (or student) poses a question for which there could be multiple legitimate responses or asks for a level of explanation.	What are some reasons that . . . ? What are some differences between...? How do you think X happens? Why do you think X happened in that way?
B. Pressing move as a follow-up	Teacher asks individual to clarify, elaborate, connect ideas that they expressed	Say more about . . . What do you mean by . . What evidence do you have for that idea?
C. Invite others to elaborate	Teacher asks others to elaborate, connect, agree/disagree with a statement by a peer	If you agree or disagree with what [student] just said about X, how come? How is your idea like [student]'s? What evidence can we use to support that claim?
D. Reference to recent activity	Talk episode initiated by the teacher that occurs directly after science activity	Students share observations and claims just after an activity is completed. Sketch of experimental set-up and list of observations created as public record.
E. Pre-discussion task	Individual, partner, or small group task to consider an [open-ended] question before bringing the ideas to the whole-class level	Task format such as think–pair–share or a quick write; sometimes used to compare two student-generated hypotheses, to decide which one they agree with, or to explain how or why they think process or event occurs.
F. Availability of a referent; either a recent activity or inscribed representation of it	The teacher or student gestures/ refers to an inscription of an idea. Materials are at hand for reference or manipulation.	Written conclusions for activity on public chart (reminder of learning). Class-created model or diagram (helps students explain ideas)
G. Language scaffold	The teacher provides guidance for how to use language	Word wall (vocabulary); Sentence frames provided to support a purpose (for example, justifying with evidence*: I know this because…;* asking questions about a model: *How did you show…?*)
H. Generic talk norms	Establishes or reminds students of generic norms about classroom talk	Remember to agree or disagree. Make sure you're listening. Remember we have our sentence stems up here (to agree, disagree, add-on)
I. Meta-talk	Teacher explicitly introduces, reinforces, reminds, or praises students' specific use of language for a purpose	When we ask questions about models, we can ask about what the symbols represent, like, 'What does that arrow mean?'

3. *Coding for rigor.* Once whole-class discussion episodes were identified and bracketed, each episode was assigned a rigor level using the definitions below (Table 4). If one goal of whole-class science discussions is to have students interacting publicly and making sense of an idea or set of ideas, then looking for the content of what students share and if/how other students take up, build, or do something with this idea is relevant. These code definitions for rigor were developed and utilized in my prior study (Colley & Windschitl, 2016). To clarify, a single utterance within the larger episode would not warrant a rigor level code for the entire episode; instead, I took the episode (which was about one topic or idea) and, for the majority of the episode, determined which rigor level code was the best fit for what was happening with ideas.

Table 4.

Coding for rigor in whole-group talk episodes

Code	*Level*	*Definition*
1	Low	Relevant descriptions of activity (observations) or sharing a related personal story/experience; some agreement and/or description (one-word answers, short phrases) without elaboration.
2	Medium	Includes partial sense making about a science idea, typically pairing an observation with an inference about an unobservable feature, or naming observable conditions under which a phenomenon is likely to occur; naming another students' idea but not building on it
3	High	Connects claims about observations to unobservable causal mechanisms; building on others' ideas; justifying claims using evidence or logic; comparing or contrasting ideas; conjecturing about relevant "what–if" scenarios in principled ways.

(From Colley & Windschitl, 2016)

4. *Coding for focus*. Next, I determined if the gist of the episode was focused primarily on (1) canonical science ideas (SCI) (e.g. discussing the concept of friction provided by a video or text), (2) a student idea or experience (STU) (e.g. a student describes an experience), or (3) if the ideas discussed merge science ideas and student ideas (MER) (e.g. student describes an experience and uses science ideas with it, in some way.) Knowing the episode focus, allowed me to identify if/when a shift in focus happened between episodes to see if this related to the rigor of subsequent episodes.

5. ***How teachers' reference student ideas***. Once student ideas had been elicited and/or acknowledged, I examined how teachers referenced students' science ideas. I reviewed the teacher talk in the lesson transcript looking for places the teacher explicitly addressed, invoked, or focused on student ideas. Table 5 defines the circle symbols I used to mark different ways teachers treated students' ideas. The shaded circle indicated a teacher referring to or naming a specific student idea for students to use in a subsequent task. The doughnut circle noted when teachers generally referenced student ideas to use in a subsequent task. The open circle showed where teachers made statements about the culture of working with ideas.

6. ***Attending to talk***. I made another pass of each episode looking at how the teacher attends to supporting students' talk and if it supported students in doing specific work with language for scientific purposes. A shaded triangle marks places where the teacher was specific and explicit about the purpose for talk in a lesson or episode and provided specific supports and directions to help students participate in that talk purpose. An open triangle marks places where the teacher made a reference to or general reminder of talk norms or moves that students could use. And finally, I used an X symbol to mark places where the teacher used a talk move or phrase that served to curtail or shut down subsequent talk. The triangles and Xs were added to the lesson barcode to visually reveal patterns between who talk is treated and what precedes, co-occurs, or follows with such moves, particularly looking for impacts on the unfolding rigor.

Table 5.

Coding for teacher's treatment of ideas

	Shaded Circle Reference specific student idea(s) for subsequent use	Doughnut Reference general student idea(s) for subsequent use	Open Circle Statement about classroom culture of working with ideas
Definition	Elevating specific student idea(s) and inviting others to use, comment, interact with for a period of time; Highlighting/using a specific student question to anchor a lesson;	Encourages students to work with ideas generally; ideas students will use are not specified; No specific student idea, theory, or hypothesis described or invoked	Teacher statements about how/why ideas are treated in this classroom; Often does not require any action on students' parts in that particular moment, however, it could also cue a routine during which students are trained to engage with each other around ideas without teacher intervention; Sets up or reinforces long-term norms about how ideas are positioned and treated; Could be explicit statement or inferential cue;
Implications /Function	Provides a common/shared focus for all students to work on/with same idea or set of ideas simultaneously; Supports public and collective sensemaking; reinforces class norm that this is what we do in science; concentrated intersubjective focus on a particular idea (joint-work);	Supports individual sensemaking because individuals select an idea to work with or interpret a general statement about ideas to consider their understanding of that general idea (not generally possible to have collective sensemaking if individual students are thinking about discrete and different ideas); reinforces class norm that this is what we do in science	When these statements match other actions to work on/with ideas, students learn the rules-of-the-game in this classroom are about revising their ideas over time in specific and principled ways, publicly and collectively

Table 6.

Coding for how teachers' address talk

Shaded Triangle Meta-talk	**Open Triangle** Generic talk norms	**Bolded X** Stifle or curtail student talk
Teacher explicitly introduces, reinforces, reminds, or praises a specific use of a talk move and when it can be used. This is often accompanied by some inscription (sentence stems, question starters, list of specific norms) to remind and scaffold student participation in using these talk moves. Talking to students about how to use discourse to get particular kinds of epistemic work done; talk for a particular purpose; discursive work that supports knowledge building – to tag with a triangle the teacher must describe the work that will be done with such talk (i.e. talk moves or questions that help critique or clarify a peer's model)	Teacher introduces or uses general talk moves; also reminds, reinforces, or praises the general use of talk moves. Can be accompanied with a reference to a list of talk norms or generic talk moves; not associated with using talk for a particular purpose rather more often associated with establishing and reinforcing turns-of-talk and talk behaviors;	Teacher moves intentionally or more often unintentionally used which serve to curtail, shorten, or subvert the intended or stated purpose for the talk; Marks a misalignment between teacher moves which may have resulting implications on subsequent or unfolding rigor of the episode (mixed message) Often these moves are used automatically and can be contradicting an aforementioned purpose or talk reminders by the teacher; The teacher must intentionally identify the purpose for talk and then have each talk move, prompt, task, and tool support students in this purpose, if not, even subtle cues can contradict/subvert the purpose;

7. ***Focal practices of responsive teaching***. Finally, I reviewed the transcripts once more and triangulated with lesson photos and my coaching notes to mark when/if teachers tried out or continuing working on any of the following practices: (A) developing, using, or revising models and/or engaging in modelling (modeling), (B) the development and/or use of the summary table (summarizing), and (C) listing or revising lists of students' ideas or hypotheses. These are practices through which students' ideas are made available to teachers and their peers. These practices make students' thinking public and visible often by inscribing them in models, tables, and lists for other students to reference and use over time (i.e. a few moments in a discussion, over a lesson, or over a unit.)

8. ***Creating a visual representation*: *Building the barcode***. Analyzing sensemaking in whole-class science discussions poses a representational challenge. Sensemaking means, in part, looking at when students participate to offer, take up, work on, and value each other's resources to do collective work of building understanding publicly. Such a display would need to allow for looking for patterns in practices, rigor-in-discussions, when teacher and students contribute, and activity structures both preceding and co-occurring within and across episodes and lessons. These patterns could reveal consequential findings and instructional implications in planning for and facilitating sensemaking discussions.

To identify patterns and changes over time in the discursive rigor of whole-class discussions, antecedent conditions for rigorous talk, and patterns in when teachers tried out the three focal indicator practices for responsive science teaching, I developed a color-coded barcode representation that I constructed for each lesson observation.

The barcode representation has five main elements: (1) *activity structure:* the colorful, horizontal activity structure bar where each color indicates a particular lesson activity; (2)

teacher and student talk: the relative amounts of teacher and student talk shown by the varying thicknesses of vertical black lines above and below the activity structure bar; (3) *number and rigor of each whole-group talk episode:* the number of whole group discussion episodes per lesson and rigor of each shown by the height of student talk bars; (4) *practices:* indicator practices of responsive teaching, when present in the lesson, are shown at the top; and (5) *ideas and talk:* shapes that show when teachers make explicit references to student ideas (circles) or science talk (triangles). The involvement of the coach, when present, is in gray compared to the teacher moves which are shown in black.

The example lesson shown in barcode form (Figure 2) lasted 54 minutes and focused on the practice of developing and using models (yellow). In the lesson, students had time to work independently (light blue), talk in partners (green), and then discuss whole group (red). There were 3 whole group episodes, two of low rigor, and the third of high rigor. The teacher was an equal, perhaps dominant, contributor in these episodes resulting in a barcode-like appearance with black and white stripes. The teacher invoked a specific idea at the start of the lesson (shaded circle) prior to the students' independent work time. The teacher had two moves of reminding students of general talk norms (open triangles) and two curtailing moves (X's) that stopped further conversation for that episode. The remainder of the lesson featured some content instruction (orange) and additional partner talk/task (green).

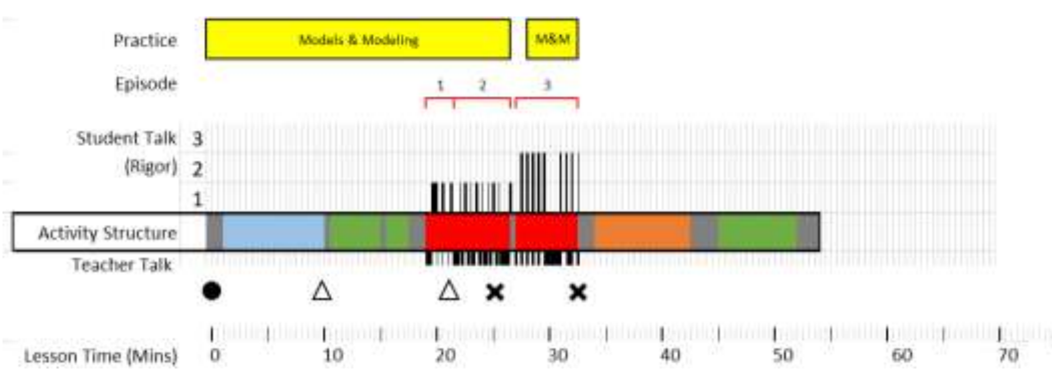


Figure 2. Example of a lesson shown using a barcode representation.

Findings

From the 30 lesson observations analyzed, I identified 127 episodes of whole-class discussions. In each of these 127 episodes, I looked at the co-occurrence of rigorous talk alongside combinations of teacher mediated conditions (TMCs). All teachers consistently engaged students in higher rigor talk (over half of their episodes were medium or high rigor). To support higher levels of rigor, teachers used multiple conditions, in combination. In looking, by teacher, at the conditions used, in low rigor episodes, their combinations were similar, yet for higher rigor conditions the teachers' selection and use of combinations varied. This implies that it is not the condition itself but the combination that is supportive of higher rigor. Also, teachers' elevation of specific student ideas and explicitly addressing how to use language both appeared to be consequential to the rigor of the episode.

I begin by showing the distribution of rigorous episodes (low, medium, high), and patterns in central focus (student idea, science idea, or merged-focus), and provide some example transcripts to illustrate what these foci sound like at different levels of rigor. Then, I describe trends from the data about which combinations of TMCs seem most likely to support higher rigor episodes of classroom talk. Finally, I share patterns in how teachers' attempts at responsiveness intersect with rigor in and across these episodes.

Distribution and Examples of Levels of Rigor and Focus in Whole-class Discourse

First, looking at rigor, across the 127 episodes, 36% of the episodes were low rigor, 39% medium rigor, and 25% were high rigor. Figure 3 shows the percentage of episodes from each teacher's class by rigor level. This figure shows that each teacher moderated episodes of talk at each rigor level and that all were capable of and facilitated high rigor episodes. For each teacher, over half of their episodes were medium-to-high rigor—54% of Amanda's, 62% of Ellie's, and nearly 80% of Henry's episodes. Even with sensemaking as a goal for these whole-class discussions, all teacher did have several low-rigor episodes. These ranged from 21% of episodes from Henry's classroom to up to 47% of episodes from Amanda's classroom. Figure 3 accounts for overall rigor levels across the data set and percentages of episodes by rigor and by teacher. However, this representation does not show patterns in episode rigor within lessons or across lessons. This analysis comes later using barcode representations of each lesson observation.

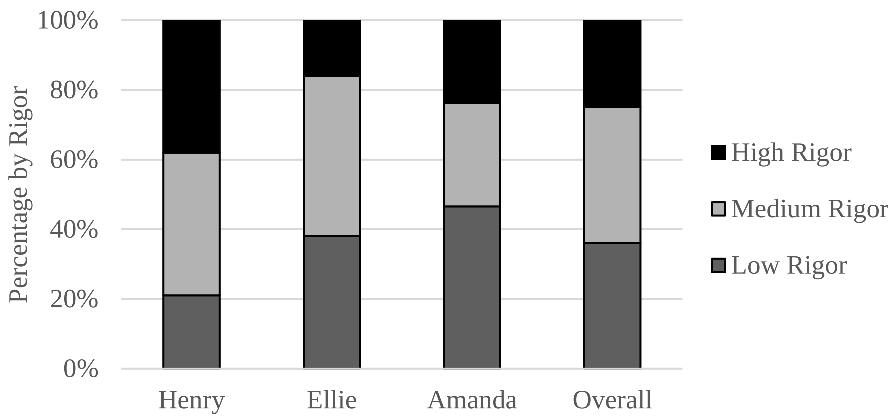


Figure 3. Percentage of episodes by rigor level for each teacher

In addition to a rigor rating for each episode, each episode had a rating based on the episode's dominant focus: science ideas, student ideas, or merged ideas. To briefly recap, a science focus (SCI) foregrounded science terms, concepts, relationships, with very little, if any acknowledgement or use of student resources. A student-resource focus (STU) foregrounded students' experiences, stories, examples, and language with very little, if any acknowledgement of science ideas. A merged focus (MER) demonstrated a balance between science ideas and student ideas. There were examples of each focus at each rigor level as indicated by the percentages in Figure 4. Figure 4 shows a pattern between focus and rigor—namely that as rigor increases so does the prevalence of merged and student-focused episodes. 20% of low rigor episodes had a merged focus. 48% of high rigor episodes had a merged focus.

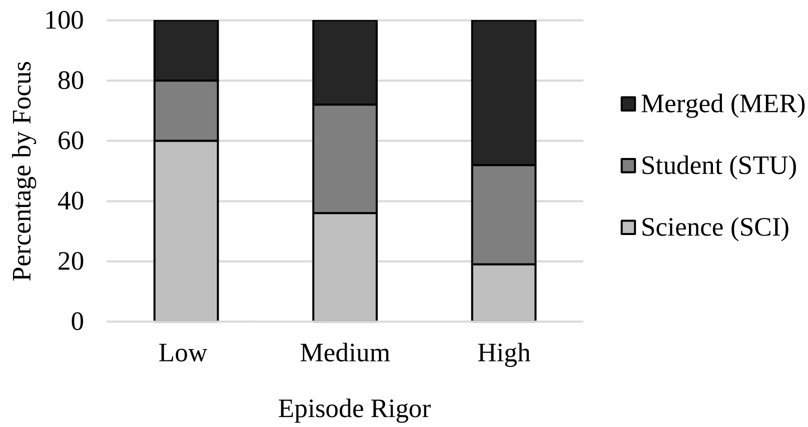


Figure 4. Comparing percentages of episodes by rigor and focus across all episodes

Breaking down this data from Figure 4 by teacher (see Figure 5), the trend holds that, as rigor increased, there was more of a focus on student and/or merged ideas for Ellie's and Henry's classes, but not for Amanda. 50% of Amanda's high rigor episodes had a science focus, where just 13% of Ellie's high rigor episodes had a science focus. None of Henry's high rigor episodes had a science focus. Looking at low rigor episodes, a majority of Ellie's low rigor episodes (84%) had a science focus, where only 57% of Henry's and 40% of Amanda's low rigor episodes had a science focus. Next, I provide examples of what different rigor level and episode focus sound like before analyzing these patterns in the data.

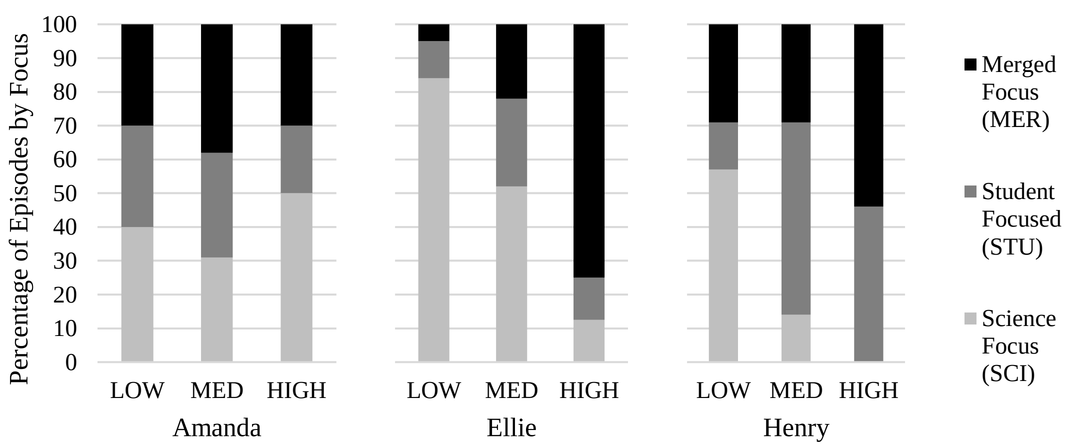


Figure 5. Percentage of episodes by teacher, rigor level, and focus

Example episodes by rigor and focus. To illustrate and compare low and high rigor episodes and to show difference in episode focus, I provide pair of examples from the same teacher, Ellie, to demonstrate that she can facilitate and support rigorous talk. Not all of her episodes were medium or high rigor, likely due to situational or contextual differences, mediated by conditions, that influenced the unfolding rigor. I have provided additional episode examples by rigor and focus in Appendix A.

Example 1: Low Rigor (LOW) – Science Focus (SCI). This example below (Figure 6) features low rigor (LOW) with a science focus (SCI). A science focus (SCI) in a low rigor episode (LOW) manifests itself through student's one-word or short phrase responses that usually focus on key science terms or repeated facts or definitions (related to the initiate-respond evaluate (IRE) pattern of classroom talk).

Example 1 comes from a 5th grade unit on forces and motion (phenomenon: Why did the boy's first jump succeed and his next jump fail?). In this the opening episode for the lesson the teacher, Ellie, asked students to remember back to an activity (a week prior) where they observed her on a scooter and they labeled a scooter diagram with key science terms (friction, gravity, and forms of energy). She opened this episode in a similar way, by sketching the diagram of herself on the scooter on the front whiteboard, and asked students to add to the model. This was the second time that students engaged in this naming/labeling task in this scooter story context.

This episode was coded as low rigor (LOW). The majority of Ellie's prompts in this episode required short choral or individual confirmatory responses (see lines 68, 88, 111, 117). At the start, Ellie vaguely prompts "So, okay, let's work on the scooter diagram" which, to an observer, would not imply anything about what student will be doing. However, due to experience with this diagram in a prior lesson, a student responds with, "Ooh! Ooh! I got this!"

(line 2) without being given further directions. This indicates that students knew what to say in an attempt to provide responses they believed Ellie expected. During this episode, students shouted out words to respond to questions and/or to finish Ellie's incomplete prompts (lines 29, 38, 72, 78, 88) by providing correct terms they had heard before in the unit. Because the main intellectual work students did through talk in this episode was, on the whole, providing vocabulary terms to fill-in-the-blanks of Ellie's prompts, so it was rated as a low rigor episode.

The episode is an example of a science focus (SCI) because of its predominant focus on content knowledge, in this case terminology. This means that students' resources are backgrounded in favor of a focus on canonically accepted science concepts. Student experiences, stories, language or examples are not largely present in this episode, which would have made it more student-focused. For example, Ellie's prompt in line 9 ("Talk to me about what you see up here") could have allowed students to share stories or experiences of them on scooters or riding bikes or skateboards, however, possibly due to experiences knowing what Ellie expects from having done this task before, Johi's response focused on terms (Johi: "…when you had your scooter and you were, you were talking about friction, gravity, and acceleration," lines 9-10). Further evidence that it is a science-focused episode is by looking at the kind of information Ellie requested. Ellie repeated a question until she got the concise, correct answer she was looking for (lines 38-70 with "Why is my hand getting hot?" and lines 48-59 with "What do we know about energy?"). At times, students briefly brought in their own language about friction (rubbing) instead of using the science term, however, Ellie continued prompting until a correct term was elicited, with Ellie adding each to the diagram on the board.

Low Rigor, Science Focus Episode from Ellie’s Classroom (EW102114-1)	*TMCs*
Ellie: Okay so let's work on the scooter diagram.	
Several Ss: Oooh! Oh! Oh! I got this! I got this!	
Ellie: So here I am... scooting along...*(sketching)* **Okay... here's the ground** *(pointing at diagram)*. **I'll use a different color for the ground** *(adds ground with a hill, then turns around to face the class.)...* **Oh! Look at all these scientists with their scientific ideas. We need to be in our seats, Catalina. Okay... Can you see? Okay, why don't you move up here with your notebook so you can see. Okay... Do you need to move so that you can see? You can sit on the floor right here. Okay, Johi, talk to me about what you see up here.**	Referent
Johi: Um, it was when you had your scooter and you were, you were talking about friction, gravity, and acceleration.	
Ellie: We were talking about friction, gravity, acceleration. Where do you see that on this diagram? Mr. Jacob.	
Jacob: When you were pumping your foot, you're creating, um, friction.	
Ellie: When I'm pumping my foot, I'm creating friction?	Press
Jacob: Yeah.	
Ellie: How?	
Jacob: Because... when... you... when you're pushing down and pushing out on the skateboard, I mean, ground.	
Ellie: When I'm pushing on the ground, my foot is creating friction with the ground?	Press
Jacob: Mm-hmm.	
Ellie: Okay. What else do you see up here? …Efren?	
Efren: Um... I see more frictions like... like by the scooter and the foot.	Press
Ellie: The scooter and my foot. So, where my foot is stuck on the scooter you see more friction? Why is that friction there?	
Efren: Because, um, you're putting your foot on something that you can rub against.	
Ellie: Absolutely. Who else sees something? Iman?	
Iman: Um, your hands on the scooter.	
Ellie: My hands on the scooter's doing what---?	
Iman: Friction?	Press
Ellie: Friction. Explain to me.	
Iman: Cuz, um, your hand is rubbing the place where you (inaudible)	
Other student whispering to Iman: The steering wheel	
Ellie: So, I'm holding on to my handle bars really tight, how does my hand feel?	
Iman: Kinda hot.	Press
Ellie: Why does my hand feel kinda hot?	Press
Iman: Cuz... you're... rubbing it on the... handle bars?	(repeated)
Ellie: Okay, so what is that an example of…? What's it doing? Why is it getting hot? Samaya.	Press (repeated)
Samaya: I see friction?	
Ellie: Okay, let's stick on this and then we'll come back to you. Why is my hand getting hot? Jacob.	
Jacob: Because when two objects rub together, they get hot.	
Ellie: Why?	
Jacob: Umm....(3 sec pause) because... I don't know.	
Ellie: Johi?	
Johi: The, um, they get hot because, like, they're rubbing.	
Ellie: Because-- okay, it could be because I'm rubbing. What do we know about energy? Katya.	
Katya: I think if it's rubbing against the metal it gets kind of like hot.	
Ellie: Why is my hand getting hot? What do we know about energy? Why is my hand getting hot when they're rubbing together? Aiden.	
Aiden: Because you're creating friction.	

Ellie: It's creating friction. Okay... what else? Alex.
Alex: Gravity? Press
Ellie: Gravity. Well, you brought up gravity. So, what do we know about energy? Friction is a kind of energy. And what do we know about energy?
Students shout out: It never disappears, it always changes forms.
Ellie: It never disappears, right? So, if I have friction, and friction is a kind of energy between my hands and the handle bars, why is it getting hot? … Why is it getting hot? Mr. Darvil?
Darvil: Um, because... you are holding it tightly.
Ellie: Uh-huh. Elena?
Elena: And you're rubbing it.
Ellie: And I'm rubbing. Efren.
Efren: Um, and, um and since you have a nice grip, your hands get warm by holding it on for a long time.
Ellie: Yeah, yeah. Iman.
Iman: Cuz you're making friction.
Ellie: Cuz I'm making friction and friction is a kind of energy, right?
Iman: Mm-hmm.
Ellie: And energy can sometimes---what?
Iman: Go away.
Ellie: Does it go away?
Several Ss: NO!
Ellie: What does it do, Aiden?
Aiden: It stores everything up.
Ellie: It stores everything up, or sometimes, it...?
Ss smattering of talk: It, um... Sometimes, it...(inaudible)
Ellie: Jacob?
Jacob: Sometimes it, um... (3 sec pause)
Ellie: Lakeesha?
Lakeesha: Kinetic ener-gy?
Ellie: Well, we know about kinetic energy...um, Caitlyn?
Caitlyn: It (inaudible)?
Ellie: Ahhh… Jacob?
Jacob: It transfers.
Ellie: It transfer and becomes, what? If it was friction and now it becomes...?
Ss shout out: Energy! Force! FORCE! Heat. HEAT!
Ellie: What does it become?
All Ss chorally: HEAT!
Ellie: Heat, right? Is heat a kind of energy?
A few students: Yes.
Ellie: Okay, so now we know that there's friction between my foot on the board, my foot on the ground, my hand on the handle bars, does anyone else see friction? Yahir?
Yahir: Uh the wheels and the ground.
Ellie: Why? *(Traces pink areas on diagram for friction, on the foot-ground interface.)*
Yahir: Because they're rubbing against each other.
Ellie: They're rubbing against each other? Or the ground?
Yahir: The ground.
Ellie: Okay, what else do I see in this picture? What else helps me to move in this picture? Mr. Darvil.
Darvil: Your foot.
Ellie: My foot. What's my foot doing? *(Picks up a whiteboard marker)*
Darvil: It's um fric-- it's pushing the scooter um, um...
Ellie: My foot is pushing the scooter. And what am I using?
Darvil: Um... uh...
Ellie: Katya.

Katya: Friction?

Ellie: Well, we know that there's friction here *(pointing at diagram between foot and ground)* **in these places that are pink, right? So, friction certainly plays a role. But right now we're talking about my leg pumping, right? …Aiden.**

Aiden: Um, like, force. You're putting force.

Ellie: What kind of force? So, my leg is moving--- *(pumps leg and arms)*

Ss eruption in talking and hands up, overlapping shouting of 'Kinetic' and 'Energy'

Ellie: Kinetic, what? Jacob?

Jacob: Kinetic energy!

Ellie*: (turns to write on board)* **So, I'm using energy, right?**

Ss smattering of talk: I said it first. I said energy.

Ellie: Where's this energy coming from? Hands up.

Some Ss shouting out, excited, and hands up: Oooh! Oooh! Your body! The body!

Ellie: Where did my body get that energy?

Ss chorally: FOOD!

Ellie: Awesome! Okay so now I know my foot's pumping and we're using energy from my food, right? For my foot to pump and propel me forward. Okay. And then the wheels have friction on the ground which are helping me to go forward.

Figure 6. Whole-class discussion episode example: Low rigor, science-focused

Example 2: High Rigor (HIGH) – Merged Focus (MER). The example of a high rigor episode (figure 7) happened with the same teacher, Ellie, earlier in the unit. The purpose of this lesson was to introduce students to the science concept of friction and to begin thinking about what role friction plays in getting objects to start moving, stay moving, or stop moving. Earlier in this lesson, prior to the episode, students observed a demonstration of a cart moving across a smooth table and compared its motion to one moving on a blanket. They time for partner talk about explaining their observations (TMC: proximity to activity (D/F)). Then, students watched a short video of a dog running around a house, over tile in the kitchen and then on carpet. Students talked with a partner about these observations with respect to the term *friction* (TMC: pre-discussion task (E)). Following from that, the episode featured in figure 7 occurred.

This episode was coded as high rigor because of what students were doing with ideas. Students were making comparisons to help them reason (see line 7, "…if the car was the dog and the blanket is the carpet"; line 12, "I'm gonna pretend like that's the dog and that's the kitchen floor"; lines 60-62, comparing a student running/slipping with the dog from the video running/slipping; line 78-79, "the kitchen floor […] is like the table"). Students conjectured about conditions under which events would happen (line 29 "he reached a point where he had enough friction"; line 43-44 "he was trying to get friction but (when) he got friction…"). Also, students justified their ideas (line 53-54 where Lakeesha brought an idea she and Michelle had partner talked about to the whole group to justify her assertions). Student contributions were generally longer than one-word or a short phrase, and provided lengthier reasoning for their ideas through comparing, conjecturing, and justifying, which met the criteria for a high-rigor episode.

The following episode illustrates a merged focus (MER) between science and student ideas. Students pulled together examples from science class (e.g. demonstration of car moving on table versus blanket, video of dogs running on carpet versus tile) alongside their personal experiences (getting stuck in the snow, slipping in the hallway). Ellie provided accessible opportunities for students to make connections by pairing the science demonstration with the relatable video, since many of her students had pets. She also revisited an experience that a student shared earlier in the lesson about her mother getting the car stuck in the snow. Students used science terms (friction, acceleration, balance) alongside their own language (rubbing, slippery, getting control). But it was not just about student language and student experiences, there was also the science concept of friction present as a thread in the discussion. Ellie focused students on the science concept of friction yet also used pressing moves to request more explanation and frequently asked students to share their thinking, ("I want to hear your ideas"; "Talk to me about that."; "Explain to me your ideas about that") not just a focus on what they know about science concepts (which was the focus in Example 1). In this transcript, students (Aiden, Lakeesha, and Johi) used and layered the science concept of friction onto their own ideas and experiences. Therefore, this episode was coded as having a merged focus between science and student ideas.

High Rigor, Merged Focus Episode from Ellie's Classroom (EW100914-6)	*TMCs*
Ellie: So, we need to circle up. *(Partners stop talking and turn back to the class)* **I want to hear your ideas about the dog and what was going on with the dog... Lakeesha, you seem super excited.**	Open-ended
Lakeesha: Okay.	
Ellie: Okay, okay, everybody. Listen.	
Lakeesha: Uh, the dog, he was out of control on the uh, on the slippery part--	Press
Ellie: --He was in control or he wasn't in control?	
Lakeesha: Wasn't.	
Ellie: So, he wasn't in control in the slippery part of the floor. Go on.	
Lakeesha: So, I, um, am thinking about if the car was the dog and the blanket is the carpet.	Referent/ Activity
Ellie: Okay	
Lakeesha: So, when he was running on it, he was in control but doesn't move as fast as he did on the kitchen floor so now I'm gonna pretend like that's *(pointing to car on desk set-up)* the dog and that's the kitchen floor. And when he was running it kinda looked like his legs were just going everywhere and he wasn't sure if he was gonna trip and his foot went out.	
Ellie: Okay.	
Lakeesha: Cuz it was more slippery--	
Ellie: --Talk to me about that. So, his leg went out because it was more slippery. Was he moving on the slippery floor? Or was he staying in one spot?	Press
Several students: He was moving.	
Ellie: Was he moving at first?	
Several students: Yeah!	
Ellie: Let's watch it again. *[Queues up and replays video clip of dogs running in the house]*	
Coach: So, we're looking to see if he's actually moving a lot on the kitchen floor.	
Ellie: Watch his feet. Okay, so Alex, you can freeze it? *(Alex, next to the computer, pauses video)***. So, what happened in the slow-mo? Was he moving forward? or was he in one spot?**	
Several students start talking out, overlapping, unintelligible.	
Ellie: Oh, oh. Aiden.	
Aiden: Oh, um, he was moving forward and our observation was that he was going so fast that when he reached the point where he had enough friction it made him lean backwards.	
Ellie: Oh, it made him lean backwards? So, then you're talking about balance. Let's start about... *(laughs, looks at Coach)* **I know... so, let's talk about when he started moving…um, Iman.**	
Iman: Um, when he started to move um he went a little slow and his feet were just going back and forth *(gesturing with hands)* and back-and-forth--	
Ellie: --Wait, wait, wait... freeze. Why were his feet going back-and-forth, back-and-forth?	Press
Iman: Cuz the um... the kitchen floor was slippery and that's what made him like *(gesturing)* when his legs were like going *(gesturing)*	
Ellie: Why does it matter that the kitchen floor was slippery?	
Multiple students (shout out): Cuz it's slippery	
Ellie: Cuz I'm thinking about what Samaya said about her, her wheel in the snow, how it was going, how the wheel was spinning but the car wasn't going. And I noticed that his feet *(pointing to dog on screen)* **were moving but he really wasn't moving and you said something about the floor being slippery so I just... Explain to me your ideas about that…Johi.**	Press
Johi: Um... on the floor he had like when he started he was trying to um get friction but he got friction, he (inaudible) when he got acceleration to increase but (inaudible) so he goes so fast.	
Ellie: Okay, everybody, freeze. Eyes on Johi. She made an important comment. Johi, say it again.	

Johi: Um... when the dog, when his paws were trying or starting to stop so he-- it was friction and acceleration when he wasn't moving, he started with friction and in the middle, he had, um, acceleration with the friction. [Press]

Ellie: Okay, so did he have friction when he started moving? He was going like this *(gesturing)* **and not moving anywhere, did he-- there was friction there?**

Johi: No.

Ellie: No, why? *(Johi looks around, Lakeesha raises hand).* **Talk to me Lakeesha.** [Referent/Activity]

Lakeesha: There wasn't friction because uh we *(gesturing to Michelle)* were talking about how the things rub together. His feet weren't on the ground but he wasn't moving, like when Alex was running *(previous accident in the hallway)*, and how he tried to stop hisself [sic], um, the dog, it was going, it wasn't really moving as much as-- Well, his feet were moving, but not him. [Press]

Ellie: Okay. And, so he did, or didn't have friction when his feet were moving but not him?

Lakeesha: I don't think he did.

Ellie: Alma.

Alma: So, when Alex was running and he slipped *(previous accident in the hallway)*, it was kind of like the dog when he slipped like, when he was slippin' on the kitchen floor so that kind of, like, it could-- like, he couldn't get control of it.

Ellie: So, he didn't have control.

Alma: Yeah.

Ellie: So, what's your idea about friction? Do you think when he started moving his legs but not his body, do you think that he had friction? *(7 sec pause)*

Alma shakes head no.

Ellie: No?

Coach: It's interesting cuz we were talking or she was telling me earlier, cuz I asked her if there was friction right now on that car right now, is there friction, and it's not moving. And you said no, cuz it's only when things are rubbing. So, then I'm like well, his paws were rubbing on the kitchen floor but he wasn't really getting anywhere, like he kept trying to rub them. But then when he hit the carpet, they were rubbing, paws to carpet and he was able to go. So, is the rubbing different? on the slippery versus the carpet?

Ellie: Iman.

Iman: Um, yeah, because um, when he was on the carpet, on the carpet, um, he was like-- he could walk. But when he was on the, um, kitchen floor, it was like more... it was... like , it's like the table *(pointing to the cart on the table set-up)*. And then when... it's like the table. And then when he was trying to move, he couldn't cuz it was slippery and cuz that um, and cuz that he was... making friction.

Figure 7. Whole-class discussion episode example: High rigor, merged focus

Combinations of Teacher-Mediated Conditions that Facilitate Rigorous Talk

In the two prior transcripts, there are contrasts between the low-rigor, science-focused episode and a high-rigor, merged-focus episode. For the low-rigor episode, there were two teacher-mediated conditions: referent/proximity to activity (D/F) and pressing (B). For the high-rigor episode, there were four teacher-mediated conditions present: open-ended prompt (A), pressing (B), pre-discussion task (E), and referent/proximity to activity (D/F). Again, all three teachers had examples of episodes at each rigor level and each focus. Next, I looked for patterns in the data between which teacher-mediated conditions (TMCs) were present at each rigor level.

Overall patterns in presence of teacher-mediated conditions alongside rigor. In my analysis of 127 episodes of whole-class talk, I identified which of 8 specific teacher-mediated conditions (TMCs) were present per episode. I looked for patterns between the combinations of these TMCs and episode rigor. Figure 8 shows a box-and-whisker plot with the range in the number of conditions present and how many conditions were present in 50% of episodes (gray boxes). Out of the 8 TMCs I coded for, the range of conditions present per episode was between 1 and 7 TMCs. Half of the low rigor episodes had 1 to 4 conditions with a mean of 2.9. Half of medium rigor episodes had 3 to 5 conditions with a mean of 3.9, and half of the high rigor episodes at 4 to 6 conditions with a mean of 4.4, out of the 8 possible. This suggests that having a combination of multiple conditions, around four or more, supports higher rigor student talk.

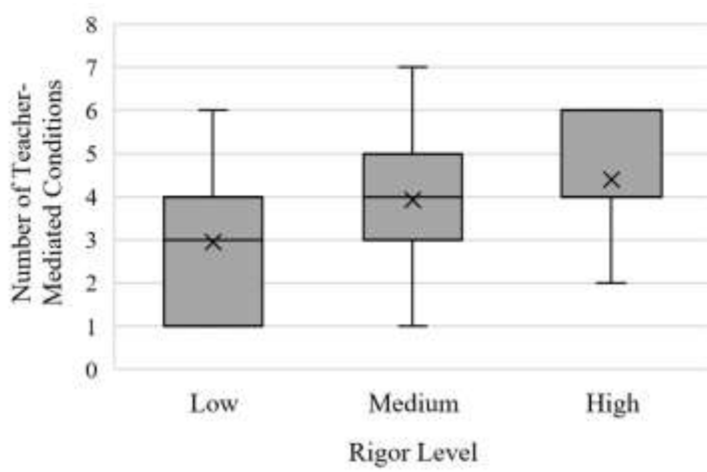


Figure 8. Box-and-whisker plot of teacher mediated conditions present by rigor level

Figure 9 shows the range of conditions with percentages by rigor level. Additionally, Figure 9 visually shows a downward trend for low-rigor episodes as in the number of TMCs increases. Figures 8 and 9 helped me identify four as a number of TMCs worth exploring further (less than four compared with four or more TMCs). With few examples of seven TMCs present together and no examples of all eight conditions, I cannot make claims either way about higher numbers of combinations.

The trends from figures 8 and 9 support my claim that multiple TMCs increased the likelihood of higher rigor student talk, yet did not guarantee it. Some episodes had fewer TMCs (less than 4) yet high rigor. Or, vice versa, there were episodes in which many TMCs were present (3 or more), yet the talk was low rigor. To explore this finding further, I examined each condition individually and in combination with others to see what additional patterns, if any, existed between TMCs and rigor level.

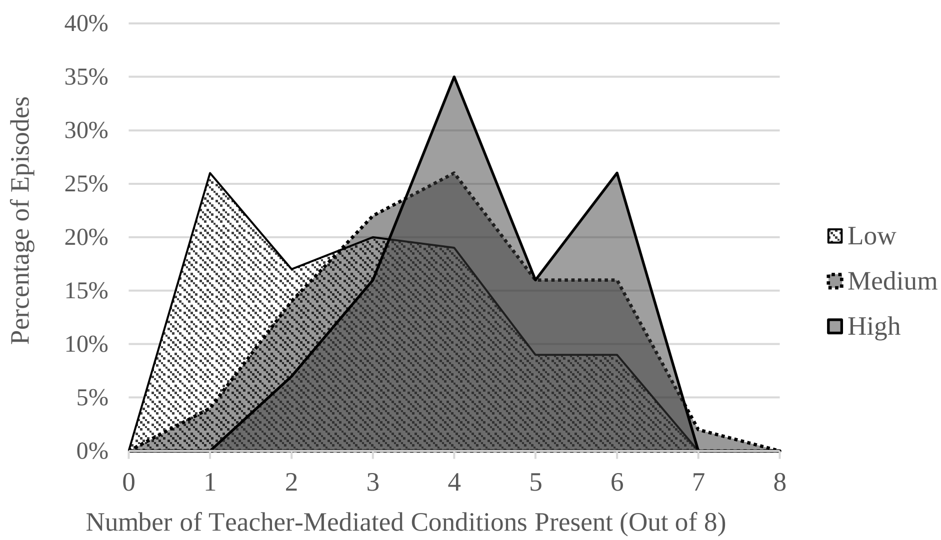


Figure 9. Percentages of episodes containing one or more conditions by rigor level. (e.g. For high rigor episodes, the range was between 2 and 6 conditions with 35% of high rigor episodes having 4 teacher-mediated conditions present.)

Presence of conditions by rigor level. The 8 TMCs were present across the 127 episodes of whole class talk in various combinations. Figures 8 and 9 above indicate that, although some episodes did have single conditions, the majority of episodes contained 2 or more TMCs. Table 7 below shows how frequently each condition appeared, by percentage, compared to rigor. These percentages do not add up to 100 as the majority of episodes contained 2 or more conditions.

Looking overall at the patterns between these 8 TMCs and rigor (see table 7), there is an increasing presence of particular conditions as rigor increases from low to high: open-ended prompts (A) were present in 59% of low-rigor which increased to being present in 94% of high-rigor episodes; follow-up moves (B) from 50% to 65%; inviting others (C) from 15% to 45%; pre-discussion task (E) from 42% to 61%; language scaffold (G) from 15% to 33%; verbal reminders of generic talk norms (H) from 33% to 48%,; and meta-talk (I) from 4% to 19%. The use of referents to or proximity to a recent activity (D/F) appeared regularly across all rigor levels (around 75% of all episodes at each rigor level).

The most frequent TMC was the use of open-ended prompts (A), present in 78% of episodes, overall. Open-ended prompts seemed necessary for higher rigor levels as 85% of medium rigor episodes and 94% of high rigor episodes contained open-ended prompts compared with 59% of low rigor episodes. In looking more closely at the 59% of low rigor episodes with open-ended prompts, 40% of these episodes had a curtailing move. This move, despite the open-ended prompt with other conditions in-place, seemed to stunt the potential for rigorous talk (I will unpack curtailing moves in the next section).

The second most frequently employed TMC was a reference to or proximity to activity (D/F), present in 75% of total episodes. This percentage held consistently across each rigor level. Looking at this condition on its own across this data set, it is not clear that a referent or proximity to activity necessarily relates to levels of rigor. However, concluding that this condition is not supportive of rigor may be misleading. Teachers consistently used this condition, even in low rigor, because our professional development focused, in part, on developing and using public records to help students recall and then make sense of activity. Teachers tried out ways to facilitate talk around creating and using these records of science activities in productive ways.

Therefore, for this data set, because these teachers experimented with ways to create and use public records of activity, this particular condition may associate with low rigor here because teachers are trying out new practices. That said, I decided to keep this TMC in my analysis due to my findings in my prior study, where, for students at one school but not the other, this condition was necessary to achieve high levels of discursive rigor (Colley & Windschitl, 2016).

Table 7.

Percentage of episodes that contain each teacher-mediated condition (TMC)

Teacher-Mediated Condition (TMC)	Overall % of all episodes with each condition	**% by Rigor Level**			**% by Teacher/Classroom**		
		Low	Med	High	Amanda	Henry	Ellie
A. Open-ended prompt	78	59	85	94	67	91	80
B. Follow-up press	63	50	72	65	63	44	67
C. Invitation to others	31	15	36	45	28	35	30
D/F. Reference or Proximity to activity	75	74	76	74	76	76	72
E. Pre-discussion Task	52	43	52	61	49	68	42
G. Language scaffold	24	15	26	33	28	24	20
H. Talk norms, generic	39	33	38	48	44	41	32
I. Meta-talk	8	4	4	19	17	12	2

Another TMC, follow-ups (B), happened in 63% of episodes—50% of low rigor episodes, 65% of high rigor episodes, 72% of medium rigor episodes—suggesting that teachers' follow-up moves support rigorous student talk (supported by Colley & Windschitl, 2016).

In my prior study of these conditions, two TMCs were insufficiently present to draw conclusions about their utility to support rigorous talk. These were pre-discussion task (E) and inviting others to contribute around a particular idea (C). The current data provides enough instances to make some claims. In this data set, pre-discussion tasks (E) occurred in 52% of all episodes, from 43% of low rigor episodes increasing to having a presence in 61% of high rigor episodes. Inviting others (C) happened in 31% of episodes overall, and increasingly prevalent as rigor increased (from 15% of low rigor episodes to 45% of high rigor episodes). This suggests pre-discussion tasks (E) and inviting others (C) supported higher levels of discursive rigor.

The next figure features visual maps by teacher and frequency for the presence of the 8 TMCs (A-I) where each octagon marks an increment of 20%. Figure 10 displays the numerical data from the “Teacher/Classroom” columns in Table 7. This representation shows similar distributions of TMC-use by Amanda and Ellie (similar shape on this map). Henry’s map looks a bit different with fewer follow-up prompts (B) and more pre-discussion tasks (E).

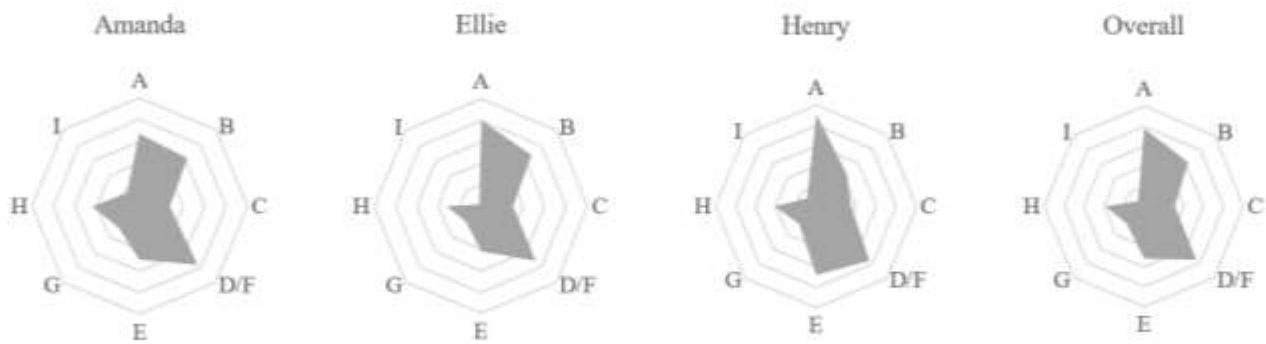


Figure 10. Visual maps of each teacher’s use of teacher-mediated conditions. Each octagon is 20% of episodes and A. Open-ended prompt; B. Follow-up press; C. Invitation to others; D/F. ReferenceProx. to activity; E. Pre-discussion Task, G. Language scaffold, H. Talk norms, generic; I. Meta-talk.

Figure 10 does not show the relationship between conditions and rigor. Therefore, Figure 11 takes the data from Figure 10 and breaks it down by rigor level to create a visual that layers on rigor, frequency by percentage of TMCs, and by teacher. As with figure 10, percentages in Figure 11, do not add up to 100% as the majority of episodes had at least two conditions present.

Figure 13 confirms a pattern shown in several prior figures that the number of conditions present increases as rigor level increases. Looking at the low rigor display only (left), the pattern of TMCs for each teacher was remarkably similar. However, as rigor level increases there is more variation in the pattern of conditions used by teacher. One similarity across teachers was an increase in the number of conditions present (larger shape area). Looking at the high rigor display only, all three teachers had high rigor episodes but each had a unique distribution of conditions. For Henry, he more often used pre-discussion tasks (E) than Amanda or Ellie. Amanda had more meta-talk (I) than Ellie or Henry. Also, Amanda referred back to activities (D/F) less often than Henry or Ellie in these high rigor episodes.

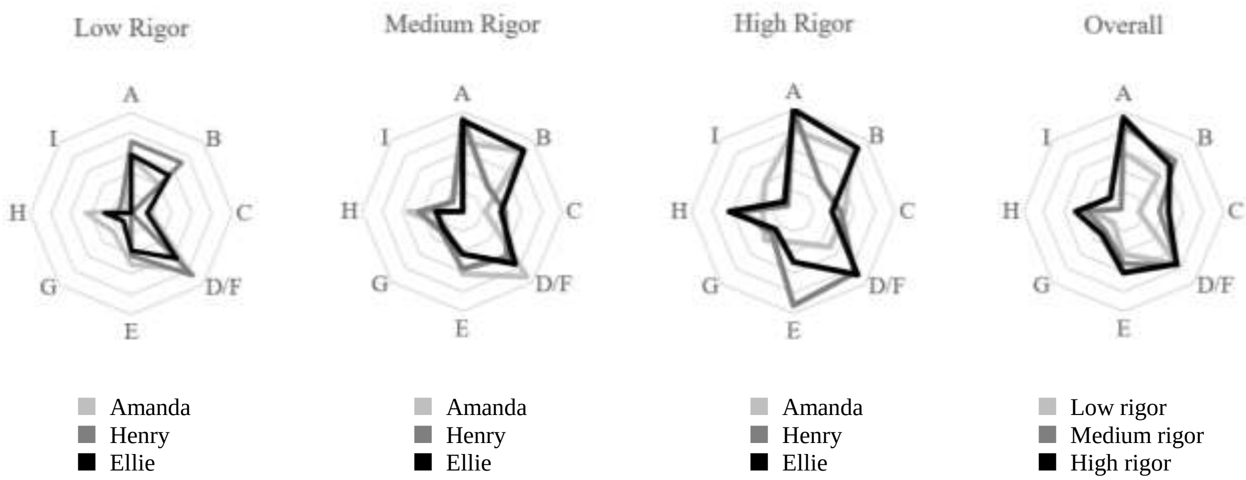


Figure 11. Visual maps of each teacher's use of teacher-mediated condition by rigor. (TMC: A. Open-ended prompt; B. Follow-up press; C. Invitation to others; D/F. Referent/Proximity to activity; E. Pre-discussion Task, G. Language scaffold, H. Talk norms, generic; I. Meta-talk).

Collapsing data into overall trends (right images, figures 10 and 11) masked trends by rigor level and by condition-use by teacher. One key finding from this analysis is that all teachers supported high rigor talk with variable combinations of conditions (different distribution shapes in figure 11, high rigor) and that all teachers had remarkably similar uses of conditions at low rigor levels (similar shapes in figure 11, low rigor).

Combinations of conditions. As I have previously established, combinations of multiple TMCs were associated with episodes of higher discursive rigor. Table 8 elaborates on this finding by focusing only on the episodes which contained 4 or more TMCs. Overall, 77% of high rigor episodes, 60% of medium rigor episodes, and 37% of low rigor episodes had 4 or more TMCs present. This suggests that combinations for 4 or more TMCs may increase the likelihood of a rigorous discussion, yet rigor is not guaranteed. Some combinations of teacher-mediated conditions occurred more often than others. In nearly half of the high rigor (48%) and medium rigor (44%) episodes, there were combinations of four or five of these TMCs: open-ended prompt (A), follow-up press (B), invitation to others (C), referent/proximity to activity (D/F), and pre-discussion task (E).

Table 8.

Percentage of episodes that contain four or more TMC by rigor.

Combinations of Teacher-Mediated Conditions (TMCs) Present	Low Rigor	Medium Rigor	High Rigor
4+ of any of the 8 TMCs from Table 7	37%	60%	77%
5+ of any of the 8 TMCs from Table 7	17%	34%	42%
4+ of these 5 TMCs from Table 7: A. Open-ended prompt; B. Follow-up press; C. Invitation to others; D/F Ref/Prox. to activity; E. Pre-discussion Task	24%	44%	48%

Next, I took the data from table 8 and examined it by classroom which revealed additional patterns (see figure 12). For Ellie and Henry, there was clear trend that as rigor increased there increasing percentages of episodes with four or more TMCs. For Amanda, however, her episodes do not mirror this trend. Instead, 50% of her low rigor and 50% of her high rigor episodes contained four or more conditions. This warranted looking more closely at what was happening with the 50% of low rigor episodes that had four or more conditions as this seemed unusual given the patterns with the other teachers.

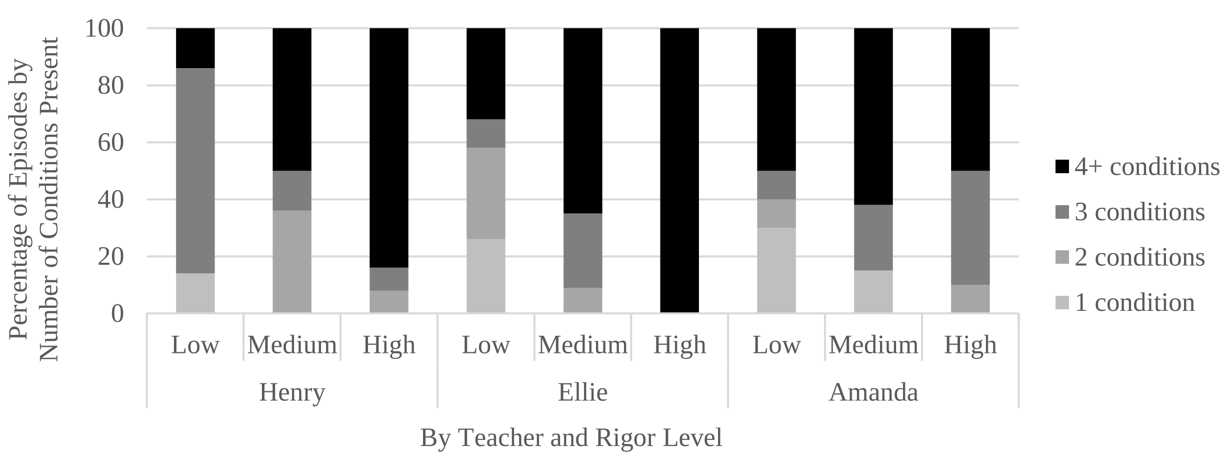


Figure 12. Percentages of episodes containing one or more TMCs present, by rigor level, teacher

I examined Amanda’s low-rigor episodes further to ascertain why her episodes did not follow this pattern. Of the 50% of her low rigor episodes which contained four or more TMCs, 90% of these contained a curtailing move. Recall that a curtailing move stunts the potential for a rigorous student talk. This means that, despite having potentially productive combinations of conditions in place, students did not participate in rigorous talk. I hypothesize that this was due to her use of a curtailing move. These TMC combinations likely would have been supportive of rigorous discussions, yet, in the presence of this curtailing move, they were not. These curtailing moves were rarely present in any of Amanda’s medium or high rigor episodes, but seemingly helps to explain why she had so many low-rigor episodes with four or more TMCs.

For Amanda, curtailing moves in these low-rigor episodes happened in two ways. First, if Amanda framed or reinforced the purpose of the discussion as *sharing out* or *presenting*, then the episode was low rigor (e.g. “Thank you for sharing. You guys can just start sharing after somebody is done,” AV100214-2). Sometimes she invited further discussion during the share-out before going to the next group/student that went unanswered (e.g. “Thank you for sharing. You guys have any questions for them? *(3 second pause, no response)* Alright, Jordan and James, you guys come up,” AV052015-1.) Sharing-out resulted in verbal lists of ideas or popcorning out contributions without students connecting, building, justifying, or elaborating on these ideas. Second, curtailing also happened when Amanda publicly announced, at the start of an episode, the order in which she wanted groups/students to share out. This announcement often preceded a low rigor episode (e.g. “I will do Jaime, then Leilani, then Jose,” AV101414-3; “Alright, let’s have Adriana, Natty, Samantha,” AV1007142-2). With both moves, she reinforced the *share-out* as the purpose for science talk either at the start, by announcing the order of the sharing, or during the episode by thanking those who shared before moving to the next group/student. These moves functioned to curtail rigorous talk from her students.

Despite the evidence from Amanda's class that these moves appeared to curtail rigor, the same statements in Henry's class did *not* associate with low rigor. Both Amanda's students and Henry's students clapped or silently cheered to show appreciation for the peer who shared an idea to the class (reinforced a presentation frame), yet in Henry's class the episodes more often continued beyond the applause or praise to work on/with an idea beyond just sharing-out (whereas, in Amanda's class, the episode ended as the next student/group came up to present). Though Henry took fewer turns-at-talk during whole-class discussions compared to either Ellie or Amanda, when he did, his moves such as, "Let's have one more" or "Let's have Madeeha share next," did *not* seem to function as a curtailing move as it had with Amanda's students. Therefore, it is not that these moves or conditions, on their own, that are responsible for increasing the likelihood of rigorous talk, or, with curtailing moves, decreasing the potential for rigorous talk. There are other contextual elements like classroom norms and routines that are at play that seem to override or to reinforce a curtailing move.

Patterns in Teacher Participation and Practices: Analyzing Lesson Barcodes

I created and compared barcode representations for each of the 30 lessons I analyzed (see Appendix B). In looking across all the barcode representations alongside my coaching notes, a few patterns emerged around *opportunity*— when teachers provided whole-class sensemaking opportunities (see *activity structure* and *practice* rows on the barcodes)—and *teacher participation*—how involved was the teacher in each episode in terms of airtime (black vertical strips in the *teacher talk* rows).

Teacher participation. There were differences across episodes in how much teachers contributed during whole-class discussion episodes. At times, teachers took a peripheral facilitator role, only interjecting occasionally or not at all (15% of all episodes). In the majority of the episodes, teachers had equal if not slightly more airtime than students in their whole-class discursive episodes (85% of all episodes). Next, I used the visual patterns from *teacher talk* on each barcode to examine teacher participation related to *rigor* to see if there were any patterns between teacher participation and rigor (see Figure 13). Higher rigor episodes were possible, whether or not the teacher was actively participation in the whole-class episode, or not contributing at all (14% of medium and 26% of high rigor episodes contained few or no teacher contributions). This suggests that there are other factors in play besides teachers' verbal moves (prompts, follow-ups, and invitations) that can sustain or support rigorous talk.

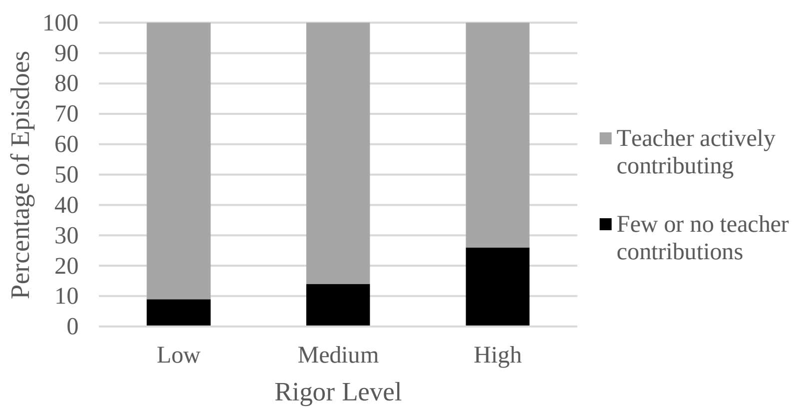


Figure 13. Teacher participation during whole-class discussion episodes by rigor level (e.g. 26% of high rigor episodes had few or no teacher contributions.)

Opportunity. Overall, students had substantial time provided for whole-class discussion activities which took up approximately one-third of all lesson time (27% for Henry, 30% for Amanda, and 42% of Ellie's lesson time was spent in the whole-group activity structures). To analyze where opportunities for whole-class talk occurred, I looked at two attributes on the lesson barcodes, the *practice* present and the *activity structure* sequence. As these teachers were learning about responsive science teaching practices and trying-out new practices, there were three practices I tracked. These practices had the potential to provide opportunities to surface student thinking (one necessary component of responsive teaching) and these practices were ones frequently featured in our professional development activities (summer institute, after-school workshops, studio days). These practices were: models and modeling, developing or using summary tables, and creating or revising lists of student ideas. Figure 14 shows the distribution, by percentage, of each focal practice that were present during whole-class episodes by rigor level. Percentages do not add up to 100% as the remainder of episodes did not contain any recognizable attempts at these three practices.

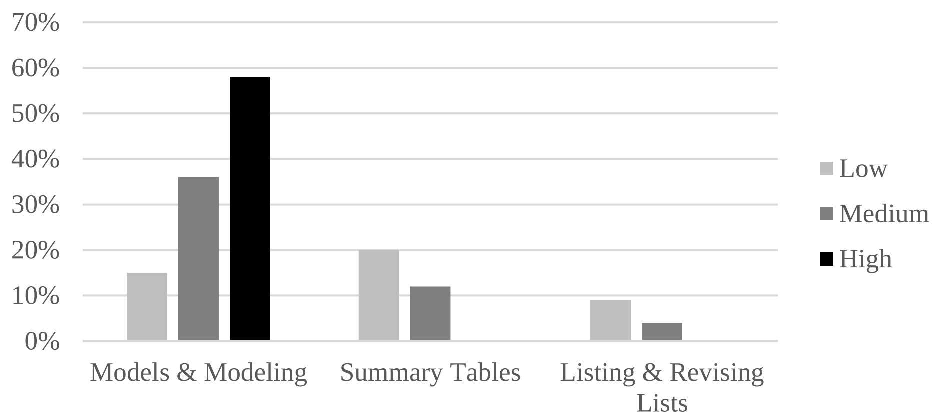


Figure 14. Percentage of total episodes containing each focal practice by rigor level (e.g. 58% of high rigor episodes and just 15% of low rigor episodes co-occurred with the practice of developing and using modeling.)

There were no examples of high rigor episodes which featured developing or using summary tables or listing/revising lists of student ideas. However, 58% of high rigor episodes and 36% of medium rigor episodes contained the practice of developing and using models during the episode. This invites additional exploration of how students use models or engage in the process of developing or revising a model as having the potential for supporting rigorous whole-group student talk. There were fewer instances of summary tables co-occurring with whole-class discussion episodes. This was, in-part, is due to the fact that some teachers had students work on summary tables with partners or small groups and did not bring the sensemaking work to a whole-class discussion. When this conversation was brought back whole-group, it was often sharing what each group figured out and moving to the next group (so often, low rigor).

To illustrate these trends in more detail and explain more about the barcode representations, I use the following two lesson barcodes, one from Henry's class (Figure 15) and one from Ellie's class (Figure 16). These example lessons had low, medium, and high rigor episodes, both have opportunities for partner or small group talk (green bars, a pre-discussion task (E)) throughout the lesson and each had multiple episodes of whole-class discussion (red bars, bracketed and numbered). Also, both Henry and Ellie provided generic reminders of talk norms (open triangles) and referred non-specifically to students' ideas (donut shape).

Henry's barcode example. Henry's example (Figure 15) was from a 5th grade unit on cells and body systems where students were working to explain the unit phenomenon about why a boy got sick from eating undercooked chicken and how he got better. This lesson focused students on learning about cells (What are they? Why are they important to us?), was 65 minutes long, contained 9 episodes of whole-class talk, had video clips to provide information to students about cells (orange bars) and a hands-on activity of where students observed onion cells under a microscope and made observation from photo cards of different kinds of cells (lavender bar).

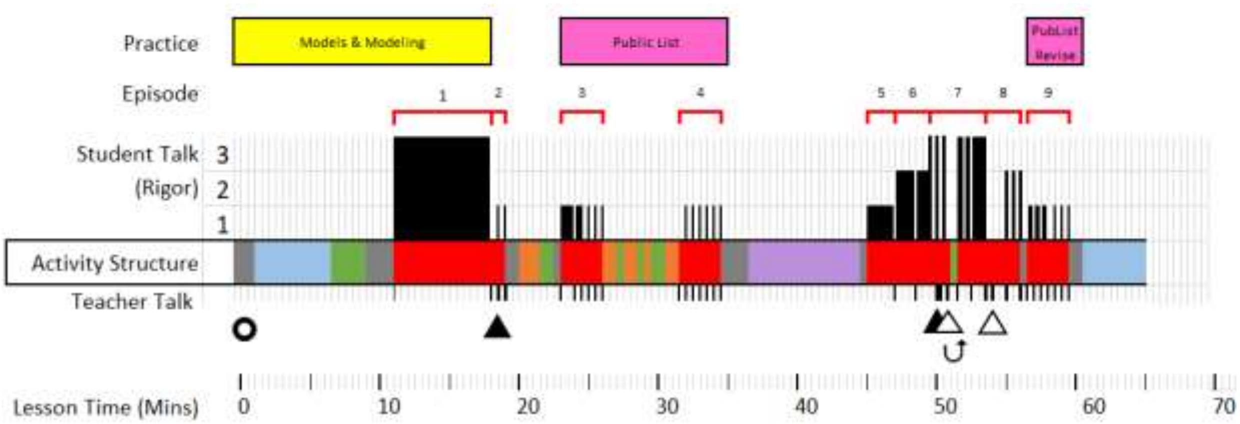


Figure 15. Barcode from Henry's example lesson (HP021816)

In terms of *teacher participation,* Henry generally had two kinds of whole-class discussions across his 10 analyzed lessons, student-facilitated and teacher-facilitated. During student-facilitated episodes, students knew their roles and what they needed to do with talk, and took up typical teacher roles such as turn-allocation, follow-up presses, or inviting others. Student-facilitated whole-class discussions contained few if any interjections by Henry (visually, this appears as a large black rectangle of continuous student talk, see episode 1 for seven minutes of uninterrupted whole-class student talk). Episodes 1, 5, 6, and 7 were student-facilitated so Henry was not involved or had few interjections (lack of black stripes for 'teacher talk' with these episodes). In episodes 5 and 6, Henry interjected a few times briefly for an appreciation move for the student-facilitator (*Can we give Ariana a hand?*) or to invite the facilitating-student's partner to share before going to a class discussion (*Jaleel, do you want to add something?*) or to allocate pacing (*One more*) followed by nearly a minute of student talk (so this move did not function as a curtailing move).

In episode 7, the right-handed U-turn symbol indicates a place where Henry interjected in the episode because a student posed a question he wanted students to discuss (Student: *"I have a question. In the video that we saw, it says cells move, but when we see onions [cells under the microscope] they didn't move"*). He asked her to repeat her question three times to the class so everyone showed they were listening and heard it and then Henry had students turn-and-talk (green) before discussing the student's question (red). Teacher contributions in episode 7 were only to mark a student's question as important, to ask the student to repeat her question, to prompt a turn-and-talk, to allocate a student to start, and to give a time warning.

On the other hand, episodes 2, 3, 4, 8, and 9 were teacher-facilitated, with back-and-forth between students and the teacher illustrated by more black stripes under these episodes for ‘teacher talk’. In this lesson example, none of the teacher-facilitated episodes reached high rigor; however, across Henry’s set of analyzed lessons, there was teacher-participation in one-third of high rigor episodes, and the remainder of high-rigor episodes in Henry’s class were facilitated by students.

Relating to *opportunities* for whole-class talk, this lesson had generous opportunities (nearly 28 minutes of the 65-minute lesson). Across his data set, Henry’s lessons ranged from just one episode of whole-class talk, to up to 9 episodes per lesson which composed 27% of all of total lesson time. He often opened with his entry task routine (present in 9 of the 10 lessons barcoded) that took up the first 13 to 28 minutes of the lesson and often (in 8 of these cases) prompted students to engage in the practice of developing and using models. Overall, it seemed that this entry task routine embedded the practice of developing and using models in order for students to explain or justify reasoning. Also, in this lesson, Henry used the practice of listing student ideas and revisiting to revise the list based on evidence from the activity. The pink boxes in the *practice* row show that Henry facilitated a share-out to generate a whole class list in episode 3, added to it with information form video (orange) in episode 4, and then revisited to confirm or revise ideas in episode 9. This was not a practice that Henry had tried out before (according to coach notes and prior analyzed lessons).

Ellie’s barcode example. Ellie’s example lesson was from the same 5th grade unit on cells and body systems as Henry’s, but was a different lesson topic which focused students on learning about environmental conditions that affect cell growth and reproduction. Students were tasked with interpreting and making sense of a graph provided as second-hand data.

In terms of *teacher participation*, Ellie actively facilitated whole-class discussion episodes, with turns of talk going through her. This is illustrated in the black vertical strips in the teacher talk and student talk parts of the barcode display to the top and bottom of the red whole-group activity structure. A signature talk move for Ellie, that she employed more often than either Amanda or Henry, was a repeating move. This is indicated in her barcodes by the left-handed U-turn symbols to indicate this repeating of specific student contributions. In this lesson, she repeated specific student contributions five times.

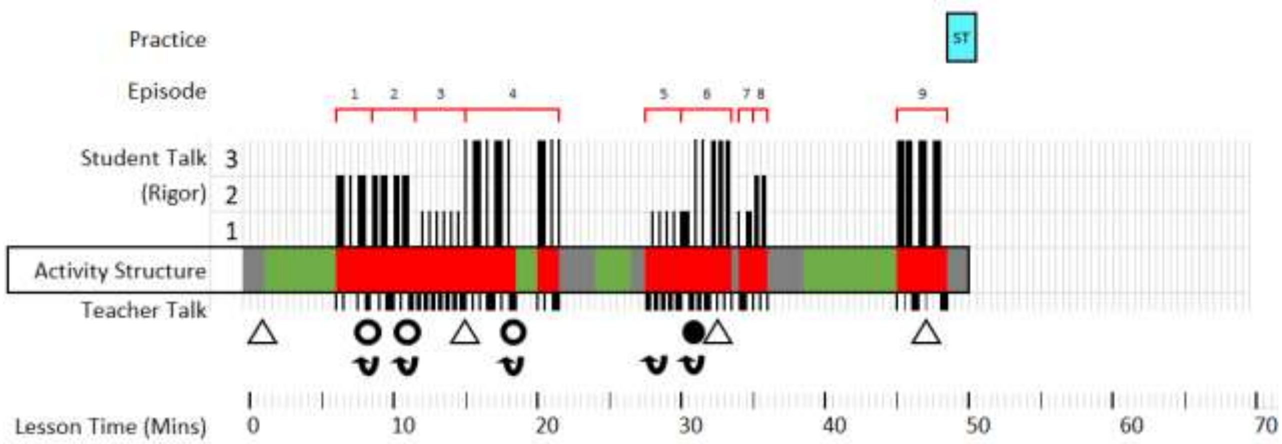


Figure 16. Barcode from Ellie's example lesson (EW012715)

With regard to *opportunity*, overall, 42% of lesson time was spent in whole-class discussions in Ellie's nine lessons analyzed for this study. For this lesson, nearly 23 minutes of the 50 minute lesson was spent in whole-class discussion activity (red bars next to *activity structure*). In terms of looking at the *practice* present in this lesson, she acknowledged summary tables at the end of the lesson (blue 'ST' rectangle at the end of the lesson) but was not involving students in any of the three practices I tracked in any recognizable ways. She had a blank summary table chart prepared with columns and headings displayed on the front board ready-to-use, yet did not acknowledge or tell student about it until the very end of the lesson. Here Ellie previewed where they would pick up in the next lesson: "So we're gonna keep our thoughts about that in our heads for right now because tomorrow we're gonna come back and we're going to discuss that. And then we're gonna take your observations and we're going to write them down on this chart. And then, if you guys learned something, or if you're making connections, *(pointing at columns on the chart)* we're gonna write that down also," EW012715, lines 492-498*).*

So far, I have shared findings with respect to the first part of my research question: *Under what teacher-mediated conditions are students more likely to engage in rigorous science talk during whole-class sensemaking discussions?* In summary, high rigor episodes most frequently co-occurred with combinations of four or more of the eight teacher-mediated conditions tracked in this study. In terms of specific conditions, combinations of these five TMCs were most frequently associated with episodes of medium or high rigor talk: open-ended prompt (A), follow-up move (B), invitation to others (C), presence of a referent to or proximity to activity (D/F), and providing a related pre-discussion task (E). Also, 80% of high rigor episodes had a student-focus or a merged-focus for the content of the episode. This indicated that in those episodes there was some elicitation, utilization, and/or attention to students' language, ideas, and/or experiences as part of these episodes. Next, I further examine the focus of episodes and how ideas are treated as I address the second part of my research question: *What patterns emerge around intersections of responsiveness and rigor and whole-class science discussions?*

Intersections of Rigor and Responsiveness: Student contributions are worthy of inquiry

One way that teachers demonstrated being responsive to their students' ideas was to take student contributions as legitimate resources, worthy of inquiry, and made them available and/or used them to support collective reasoning. Episodes coded with a merged (MER) or student (STU) focus indicate that student ideas were part of that episode. The data show that 80% of high rigor episodes had either a student focus or a merged focus. Another way I looked at how teachers made space for student ideas was marking instances that messaged how teachers viewed and treated ideas. On the barcode representations, I used a circle to mark places when teachers talked explicitly about ideas. As described earlier, an open circle (○) indicated a statement about a classroom culture of working with ideas, a donut shape (⭘) was referring non-specifically to student ideas. A solid circle (●) denoted the teacher referencing a specific student idea. Each teacher demonstrated each of these kinds of statements about student contributions (examples from various lessons are displayed in Table 9). I used the barcode representations to locate temporal patterns in when teachers referenced the treatment of ideas preceding whole-class discussion activities and then referenced transcripts at these time points to see how teachers referenced ideas and what happened in the subsequent discussion. Next, I provide descriptions and examples of each of these three codes for how teachers treated working with and on ideas.

Table 9.

Teachers' Treatment of Ideas: Examples

○ Culture of working with ideas *Reinforced working with/on our ideas*	⭘ Non-specific idea *Invoked for use in an immediate task*	● Specific student idea *Invoked for use in an immediate task*
Amanda: This is the best way that we're working our brain. Our brain is a muscle and we're working it. We're trying to make it so it's bigger and that you guys keep building all your information on top of each other. (105-109, AV120414B3)	**Amanda**: I was hearing some really good conversations involving air molecules and vibrations. […] Somebody said that sound makes air dots bump or hit each other. Um, somebody else said that force can stop or slow down the air. […] So just be thinking and we're going to share out here. What do you guys think is happening to the air if we're using hockey pucks to represent air molecules?" (289-298 AV101414B3)	**Amanda**: Did you guys all hear—Did you hear that question Samantha asked? Samantha: What [sic] did he did it at a distance? **Amanda**: So, she's saying well, what if he stepped further back, right if this is the glass *(gestures with fist)* and he was holding it like this *(close)* or if was holding it back here *(extends arms)*, okay? *(Gesturing close and far)* Is that gonna be a difference with him? Is he going to be able to break the glass? … Why don't you guys turn-and-talk and discuss, what do you guys think?" (187-198, AV100714B2)
Amanda: I'll compile a list of all the different classes so you can see everybody's ideas and you guys can refer back as we're continuing on. (AV100214B3, lines 364-366)	**Amanda**: So, try and take everybody's ideas (pointing to a list). Which ones make sense to you? And try to represent that. (461-462, AV101414B3)	Casey: Uh I think there's a difference cuz if there's like one magnet and one magnet right here I think it will be more stronger because there's more magnets and could be more force. **Amanda**: What do you mean by force? Casey: I don't know […] I don't know about force. I don't know how to... **Amanda**: Anybody else help? What do you think he means by force? (85-99, AV050615)

Henry: […] So, keep it up, okay. And keep this conversation going cuz I think it's very important, okay. It will help us understand something about the center of mass. (HP111814, lines 58-60)	**Henry**: *(After a student shared her initial explanation to the class)* Okay compliments, questions, add-ons? Cuz I'm sure, when we were walking around, we saw the same um ideas about the boy and what's happening inside his digestive system. Does anyone want to add onto that? (39-42, HP022615)	Madeeha: I have a question. In the video that we saw, it says cells move but when we see onions they didn't move. **Henry**: Wait, wow! That was a genuine question. That's what I would have asked. Okay, I want everyone to just track her. That's how we know you are listening. It's a very valid question to ask. Madeeha could you please repeat that out loud? Madeeha: In the video we saw that cells does [sic] move but when we saw on the on the uh it didn't. […] **Henry**: Quickly, just turn to your neighbor, what do you think? (395-411, HP021816)
Ellie: If you want someone to help you build on your idea, you can certainly ask someone. (327-328, EW100914) **Ellie**: So, it's not about being right or wrong, it's about finding the truth. So, sometimes, my ideas are wrong, but it's not about being wrong, it's about finding the truth. And that's what science class is. (244-246, EW011315).	**Ellie**: Okay, so I'm hearing a concept from several of you. […] I'm hearing the concept that if you have a fever your temperature rises, your body temperature rises, and the bacteria like that so they multiply more and they spread around more? […] What's the purpose of your body's temperature to go up if that's good for the bacteria that makes you sicker? […] Why don't you talk to your partners? About your ideas. Take that idea about why would your body temp rise if it's trying to fight bacteria? (181-192, EW012715)	Aiden: But if you wash your chicken, doesn't that take out the germs? Cuz you're running it under water? […] **Ellie**: Okay so Aiden had a really interesting question. So, the video said, 'Don't wash your chicken because the germs will spread everywhere.' And then Aiden's question was, 'Hey, but wait a second, if you're washing your chicken, doesn't that mean you're cleaning it?' Multiple students: Yeah! Yes! **Ellie**: So... so... raise your hands. […] What do you guys think? Why did they say-- What's going on with that? Iman. Iman: I agree with Lakeesha and Aiden. **Ellie**: Okay. Why? (129-153, EW0113151)

Invoking specific student ideas. For invoking a specific idea (●) to use in a task, there were 24 instances prior to whole-class discussion episodes. Of those, 13 preceded a high rigor episode, 8 preceded a medium rigor episode, and 3 preceded a low-rigor episode. The examples provided in Table 9 feature the *in-the-moment* examples when the teachers seized upon a student contribution and posed it back to the class. I expand on one of these examples from Henry’s class to illustrate how this in-the-moment responsiveness supports higher rigor talk. Then I describe ways that being responsive to specific student ideas happened across lessons at a different timescale.

In-the-moment responsiveness. Any in-the-moment moves teachers made informed by student contributions, counted as examples of in-the-moment responsiveness as long as teachers were legitimizing students' resources, or framing and/or using them in attempts to further students' sensemaking. In this next example (a high-rigor, merged-focus example from Henry's class), students were in the middle of a sequence of lessons focused on forces (such as gravity and normal force) and center of mass to explain why things fall. In this lesson, students observed a discrepant event demonstration where the teacher slowly pushed a secretly-weighted cereal box off the edge of a table (see Figure 17, left). Students were perplexed when the box did not fall when they expected it to, and hung over the edge of the table seemingly defying gravity. Students talked and created models to explain why this happened (see Figure 17, right). This whole-class discussion episode began with Henry selecting a student, Elsa, to share her model and facilitate a discussion about it (Figure 18). This routine of selecting students as they work on models to share their work and facilitate a discussion was a consistent part of his classroom routine and lesson plans. However, these student-facilitated discussions come with uncertainty about what students might say or ask, leaving the exact nature of the discussion uncertain. In this episode, Henry intervened in the student-facilitated discussion, which he did not often do, to seize upon Edgar's question about Elsa's model and tossed it back to the class.

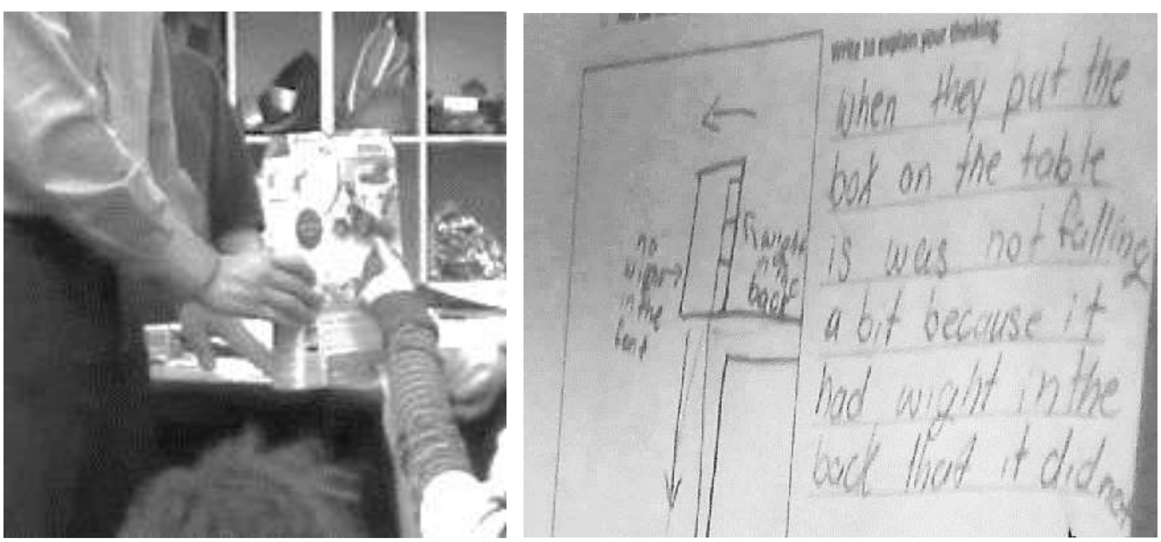


Figure 17. Photo of cereal box discrepant event (at left) and student's explanation (at right).

Example of in-the-moment responsiveness in Henry's class *(Excerpted from HP111814A-2, High Rigor, Merged Focus)*	*Notes*
Elsa: *(Displayed her model and explanation under the document camera so everyone could see it.)* Um, I wrote I put a table and the arrow means that they were pushing it um over and backward and there was blocks and there was weight in the back but not in the front so the weight was all in the back. That's what I put. And when they put the --And they… when they put the weight, it had to be in the back because I was holding it and it felt heavy. *(Looks up from her paper to the class. 7 second pause. Edgar's hand goes up)* Edgar?	Student projected her work (**pre-discussion task, E**)
Edgar: Uh... Uh, what happens if you put the *(something about 3 blocks on the other side, inaudible phrase)* does it fall?	Student poses an unanticipated 'what-if' question.
Elsa: I think it will because there's like, only *(inaudible phrase).*	Teacher intervenes to highlight and praise the student's question.
Henry: Hmm, you know what? That was a great question.	
Coach: Can you say it again? Cuz it was hard to hear.	
Henry: So, Edgar, when you're saying even, are you thinking about the blocks? *(Henry walks up to screen and points at Elsa's drawing).* **Like putting one here, one here, and one in the middle?**	Teacher asks clarifying questions to understand the student's question.
Edgar: No, like... yeah, putting three on the both sides, like when she put, uh, the blocks inside, uh where she put more on the other side--	
Henry: Like on this side *(pointing on the side)***?**	
Edgar: Yeah, I'd say-- if you could do it more farther, or if it might fall?	
Henry: Great question. So, here's the question, class. Let me just make-- *(Pointing to James)* **You're going to answer it James? I'm going to give you the opportunity. But let me just make sure that everyone understands what Edgar is asking. If your eyes are up here, you'll know what he's asking. He's asking…There are three blocks on this side** *(pointing on the right side of the box, over the desk)* **which is causing this box...to stay balanced. But, what happens that if we put three more on this side right here** *(pointing to the left side, over the air)***?**	Teacher poses the student's question to the class to consider. Teacher gives time to the class to consider the students' question.
Student shouts out: It would fall down!	
Henry: Can you just quickly, just talk to your neighbor, what would happen? and Why?	Teacher has the class discuss the student's question.
(Quick 30 second turn-and-talk about Edgar's prediction).	
Henry: *(Rings bell to get students' attention)* **There's the bell.** *(5 second pause as students turn back to the front)* **Guys... okay, I just need two people to share out because we don't have a lot of time. I asked, I promised James he will and I'm going to look for someone who has not shared today. Okay…**	
Students shouting out: Me! I haven't!	
Henry: Alright so let's have James. And let's have Mirriam.	
James: It will fall because-- it will fall in a way because even though they're both even as soon as the weight gets on the other side so it's even, so it's a balanced scale, and you put it and it moves too fast and the other side's gonna tip because the side that's on the thing has nowhere to (inaudible) down, but the one that has more weight has somewhere to move down so it's gonna just fall.	**Invite others (C)**
Henry: Any comments on what James said? *(3 second pause, then Anthony, student next to James, turns to respond)*	
Anthony: I would like to add on to what James said because I think it would fall right away because on the side that you add three blocks to...um, the gravity is also-- is, uh, helping the side that's, um, not on the table.	**Follow-up (B)**
Coach: Gravity's helping the side-- the one that's over kind of the air?	
Anthony: Yeah, cuz it's pulling it.	
James: Yeah, it's pulling it down.	
Coach: Is it -- I thought it would also be pulling down on the side that's--	
James: Yeah, but that side's getting supported by the table!	
Anthony: It's *already* down.	
James: So, friction has nothing to do with it!	

Coach: Now you brought a whole 'nother thing into it! *(Boys laugh)* **We are running out of time! So, did you** *(looking at Henry)* **want to have her** (Mirriam) **share?**	
Henry: So Mirriam, can you just share what you were thinking about?	
Mirriam: I was thinkin' that if you put uh three uh one box over here and one over there, the blocks, there probably would make it fall. It can make it fall, if it was inside. If the blocks was inside and then you can put them at the end of the table probably the blocks inside would make it fall.	**Follow-up (B)**
Coach: Differently than if we just had blocks on one side?	
Mirriam: Yeah	**Follow-up (B)**
Coach: It would be different... you think.	
Mirriam: Yeah. But if it was on the other side, if there were blocks over here (pointing) and blocks on the other side then it would make it fall.	
Coach: Hmm.. can you say why you think it would make it fall? Cuz if there are blocks on this side and I'm putting it over the edge like that?	
Mirriam: Yeah	
Coach: Why do you think?	
Mirriam: It will fall cuz there is pressure of the blocks will make it even uh it will probably fall because it will pull it, the blocks on that side will pull it down cuz there's no blocks, cuz it's not even, and there's no blocks in the middle of the box.	
Coach: So, I heard you talking about pressure pushing down on the inside of the box and since there's nothing to push back you said it would start to fall.	
Mirriam: Yeah.	

Figure 18. Example of in-the-moment responsiveness to a student's question about another student's model

This example legitimizes students' ideas in two ways: (1) student explanations were publicly shared, not just to recognize or acknowledge ideas but with the intention of serving as the basis for a discussion, and (2) students ideas were taken seriously, clarified, and discussed by peers to further reasoning. Henry's student-facilitated discussion routine was a planned activity sequence that allowed for student ideas to be a central focus and provided opportunity for the teacher to surface students' ideas and connections. These discussions were not always high rigor and sometimes went in tangential directions without teacher intervention. But in this example of in-the-moment responsiveness, Henry's intervention showed he recognized the substance and relevance of the student's question about the other student's model. Then he provided a task to help other students make sense of this contribution by providing time to think and partner talk before talking to peers whole group.

Responsiveness across lessons. Other attempts to be responsive to a specific student idea happens between lessons, when a teacher included a specific student idea from a prior lesson in a future lesson plans to anchor a task. Henry commented on this timescale of responsiveness in one of our coaching conversations: “I'm learning a lot. You know? The funny thing is, these things that we are doing now is not necessarily very particular to the lessons we have (in the guide/kit), but it is actually responding to what kids need. It's responding to kids' current learning and what they need to, uh, need to know and learn to move onto the next objective, the next lesson, so I think it's great,” (HP103014, debrief).

I have selected one example from Amanda’s class to show this lesson-by-lesson responsiveness. Amanda used a student’s representation from one lesson to anchor a task the next lesson. She re-sketched his drawing to enlarge it for the class to see how he showed the differences between humming and yelling as squiggles with different heights (Figure 19).

In our planning meeting after-school, she told me she noticed Anthony’s model and thought it could be part of the lesson plan the next day. Here are excerpts from the planning conversation and subsequent lesson enactment.

From after-school planning, Amanda talking to me:

> “Um, you know, I did hear (today) some kids talk about that and like Anthony, he's like, 'When you whisper it's like a flat line...' And, so, I was going to have him come to the board… and draw that. And I forgot, well, we ran out of time. But he did like the first, when it's a whisper it's just a little flat line, like the vibration is a straight line and then a whisper it's a little bit more bumpy and then it gets bigger as you get louder. […] So, we're doing Anthony's thing first. […] So, entry task, and then I'm gonna do the lesson (intro), and talk about the waves... um, so this sound representation, so how do you represent sound.” (AV100214, planning)

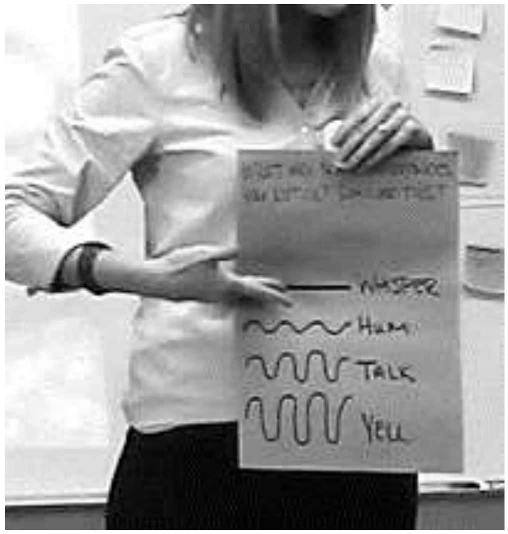


Figure 19. Student's wiggly line model of whisper, hum, talk, and yell.

During the lesson, Amanda framed the task to the class using Anthony's representation:

> "So, on Thursday at the end of the lesson, Anthony was like, you know these, it's like these lines and if we had a whisper it'd be a straight line cuz if you are whispering, can't feel those vibrations, so it would be kind of like a straight line. And when you hum *(pointing at chart, figure 19)*, it would be a little bit more. And then talk and then yell. So, what I want you guys to do...I'm going to give you a few seconds to think about this. Private think time. About this question: What are some differences you notice? What are some similarities that you might see with these different waves? *(Posts chart of different waves for whisper, hum, talk, yell on the board)* So let's take a moment to think to yourself... […] Alright, let's turn and talk, you can talk with your partner or you can talk with your pod. Go ahead...and then we're going to quickly share out so make sure you're listening to everybody else, what they're saying." (AV100714, observation)

After partner talk, each table group shared one idea or connection they discussed about this way of representing sound (e.g. the wave shows the strength of the vibration by going up and down more; the waves would be bigger each time from whisper, hum, talk, then yell; connection to heartrate machine displays at hospitals). This episode had potential to be high rigor, however, this was one of the instances with curtailing moves. So, the rigor of the subsequent whole-class episode was coded as low. However, based on what each group shared-out there was sensemaking happening during the partner talk. But, whole-group, students repeated what they discussed in their partner/pods and Amanda used curtailing moves to reinforce sharing rather than encouraging a discussion, moving quickly from group-to-group with no discussion ("Good. Next pod. Thank you," and "Thank you for sharing. Did every group share out?").

Ellie also made attempts at taking student ideas from one lesson and using them in the next lesson as. In her astronomy unit, we analyzed student work analysis from the prior lesson and noticed different ways students had explained about the tilt and rotation of the Earth. For the entry task in the subsequent lesson, Ellie introduced a few student ideas on list to have students review them and agree or disagree. She did not specifically attribute these ideas to particular students, however, the specific phrasing of these statements came directly from student work in the prior lesson, so it counted as referencing and using specific student ideas.

After-school debrief, analyzing student work, Ellie remarked:

> Um... I feel like... a good chunk of the class has a really good like idea about direct and indirect light and how it causes seasons. Some of the kids that were struggling, they're mixing up the idea of, um, seasons, like tilt versus rotation, so like… day-night versus winter-summer. Like they're starting to sort-of confuse that a little bit...[…]…that's kind of what I'm noticing. (EW042115, debrief; coach followed up with an email)

Follow-up email, I sent to Ellie:

> One idea (for Thursday) could be to select some ideas off Tuesday's entry task and see if students agree/disagree or want to combine to make a more complete response about

why we have seasons or about your mid-lesson question from today about do we have different seasons in the northern and southern hemispheres? For example, here are some ideas I see across the tasks. I’ve selected 4 so students aren’t having to read a ton of ideas. They are having to say whether they agree or disagree. See next page. (email attachment with lesson plan suggestion and entry task handout (Figure 20), 04-21-15)

From next lesson observation, Ellie introduced these ideas to the class by saying:

> “Remember what I said earlier this year about alternate understandings? That we all make sense of the world in different ways and we all kind of think about, we make sense of things differently, so we all might look at the same thing, like the Sun in the sky and we all might have a different explanation. And that's not necessarily, I mean, that's not a bad thing at all, cuz we're all making sense of our world, but we all have different ideas. We all have alternate understandings. So. We're gonna look at these 4 different understandings… about what causes the seasons and I want you guys to pick which one you agree with and add to it. Which one comes the closest to what you think is going on? And then explain it.” (EW042315, observation)

THURSDAY ENTRY TASK

On Tuesday, you all wrote your ideas about what causes the seasons. Below are four student ideas from the entry task paper.

- What do you think of these ideas?
- Which idea do you agree with?
- Which Idea do you respectfully disagree with?
- Would you want to combine more than one idea to make a complete explanation of seasons?

Choose 1 or more of these student ideas and write your response to these ideas:

A. The Sun is facing direct light at the northern hemisphere so it’s summer.

B. Because the Earth is tilted and the Sun is going around the Earth, then the Earth has seasons.

C. We have different seasons because the Earth orbits the Sun.

D. The Earth is tilted towards the Sun so we have seasons.

Helpful Sentence Starters

- I *agree* with part of idea (A/B/C/D) because…
- I *disagree* with that part of idea (A/B/C/D) that says…
- Idea (A/B/C/D) should *add* something about ____________ because…

Figure 20. Entry-task featuring four student ideas from the prior lesson.

After students worked independently on the entry-task sheet, Ellie selected two students to share their work under the document camera and lead discussion around their responses. Here, the whole-class discussion was split into two episodes because students focused first on idea B from the list (episode 1) and then on idea A (episode 2). Figure 21 shows a student projecting her response about idea A. Both episodes were medium and high rigor, respectively. So, in combination with other conditions, being responsive to specific student ideas could support higher rigor whole-class talk.

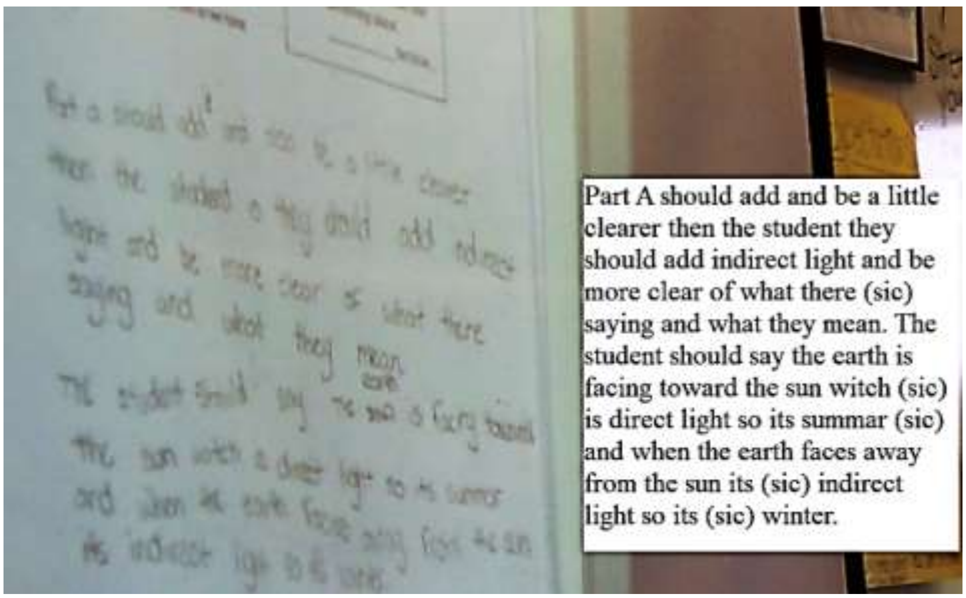


Figure 21. A student's written response to the entry-task about idea A shared to the class.

Invoking non-specific student resources. There were 10 instances of whole-class discussion episodes preceded by a teacher invoking non-specific student idea(s) (○). Of those, 2 preceded a high rigor episode, 5 preceded a medium rigor episode, and 3 preceded a low rigor episode. These 11 instances seemed to only have occurred *in-the-moment,* that is, in response to something students had just said or did rather than spanning across lessons. For example, Ellie used generic statements about student ideas as a transition between independent work time and whole-class discussion to remind students that she wanted them to interact with ideas during whole-class discussions but did not cite or reference *specific* ideas (e.g. "Okay, so Lakeesha, Delice, and Alma had some really interesting ideas. I want you to remember. If you think something different. Or if you agree. Or if you disagree. I want you to ask genuine questions, add-on, and critique and debate." EW042115).

Reinforcing a culture of working with/on ideas in this classroom. Finally, there were 17 places where the teacher explicitly referenced or reinforced a culture of working on/with ideas (○) that preceded or came early in a whole-class discussion episode. Of those, three were high-rigor episodes, nine were medium-rigor episodes, and five were low-rigor episodes. These trends suggest that communicating about building a culture of working on and with ideas helps support higher rigor. However, given that each episode also had a particular focus (science, student, or merged) and set of conditions (TMCs), it is not clear to claim that these kinds of statements, on their own, support high rigor talk.

Conclusions about responsiveness and rigor. Responsiveness happened at multiple time scales, in-the-moment and across lessons. Unlike other TMCs, responsiveness cannot be analyzed at the level of individual moves. Rather, responsiveness is ascertained by examining a collective of moves, tasks, topics, and tools that, when taken together, provide evidence that a teacher is attempting to be responsive to his or her students' ideas. Therefore, I provided lengthier examples, not just collections of short quotes, to show how teachers made attempts to be responsive to students' contributions in substantive ways.

All three teachers attempted to be responsive to their students' contributions throughout the year both in-the-moment and in lesson planning decisions and all teachers had examples of high rigor episodes. Assuming *episode focus* and *treatment of ideas* serve as proxies for responsiveness, then these data suggest that being responsive to students' ideas supported higher levels of discursive rigor.

Discussion

Assertion 1: Combinations of conditions support students' rigorous conversations. The presence of four or more teacher-mediated conditions, when used in combination, supported higher rigor episodes of whole-class talk.

The majority of discussion episodes were medium-to-high rigor—ranging from 54% of episodes in Amanda's classes to 79% of episodes in Henry's classes. This frequency was not surprising given that teachers in this study were committed to providing sensemaking opportunities and were coached to do so. However, it was surprising in that this was the first year these teachers were involved in the STEM Academy and the first time they reported focusing this intensely on improving their science instruction and on facilitating public sensemaking. This finding concurs with in my prior study (Colley & Windschitl, 2016) where I served as the guest science teacher teaching the same unit to four elementary classes at two different schools. Similarly, I focused on supporting students' public sensemaking and being responsive to students' science ideas. Out of all whole-class discussion episodes, the percentage of higher rigor episodes ranged from 58% to 82% across classes. This suggests that elementary classroom teachers, even ones who are new to supporting students' sensemaking, can do this work with students at a frequency that parallels an experienced, master teacher.

These frequencies of higher rigor episodes are higher than what other studies report from typical elementary classrooms. Less than one third of discussions in these studies engaged students in higher order thinking (Abrahams & Reiss, 2012; Banilower et al., 2013; Corcoran & Gerry, 2011). This could be due, in part, to how focused teachers in this study were on supporting students' sensemaking talk. They also had curriculum materials, coordinated and cohesive set of professional development experiences, and an instructional coach to support them in working towards this goal. With these supports, this study demonstrates that elementary teachers new to this work can successfully engage their students in public sensemaking.

In looking more closely at what supported students in engaging in medium or high rigor episodes compared to low rigor episodes, there were two main patterns: 1) single conditions, such as asking an open-ended question, are not sufficient to support rigorous talk, and 2) combinations of four or more conditions most frequently associated with higher rigor episodes.

Single-condition. We know that students have ideas worthy of inquiry and are capable of rich, sophisticated sense-making talk, yet, accessing these ideas and engaging students in classroom science discussions is not easy (Radinsky et al., 2010; Warren et al., 2001). The presence of a single teacher-mediated condition was insufficient to support rigorous talk as there were no instances of high rigor episode with only one condition present. Additional conditions, such as using follow-up presses or providing pre-discussion tasks, likely help support students in understanding what they will be doing and provide scaffolding for how to participate whole group. A single condition cannot convey to all students what they need to do in order to productively contribute. This finding aligned with a previous study, showing that tools, routines, or juxtapositions with activity, when used in isolation, were insufficient for supporting rigorous sensemaking talk (Colley & Windschitl, 2016).

Combinations of conditions. The data from this study indicate that combinations of conditions are necessary to support medium or high rigor talk and that 4 or more seems most supportive of rigor. Few studies have examined how combinations of conditions support students' rigorous talk. Kind and colleagues (2011) tested individual aspects of argumentation tasks which, on their own, did not prompt any improvements in engaging students in argumentation. They hypothesized that combining these aspects would encourage students to engage in argumentation but this was not tested. My findings from this study and my prior study support the claim that multiple conditions support students engaging in rigorous talk. In the following sections, I describe why each condition likely supports student sensemaking, understanding that no condition, on its own, supports students in engaging in rigorous talk.

Open-ended prompts. We know that teachers' questioning practices support or constrain student participation (Cazden, 2001; Webb, 2009). Open-ended questions purposefully invite students to share more information beyond a single word or short phrase response and attempt to explore students' conceptual understanding (Black & Wiliam, 1998; Minstrell & van Zee, 2003; Nystrand et al., 2003). With the open-ended prompts, students make decisions about what examples or ideas to focus on in their responses, given that multiple possible responses are equally valid and acceptable. Open-ended questions are necessary, but not sufficient on their own, for supporting rigorous talk. Along with open-ended prompts, additional teacher moves such as follow-ups, for example, provide feedback to students about the kind of discursive activities expected and allowed in science class (Webb, 2009). Open-ended prompts paired with teacher's follow-ups about students' prior contributions, help to co-construct a classroom space where students negotiate meaning and understanding in science (Varelas, Pappas, Kane, Hankes, & Na, 2007).

Follow-up moves. Follow-up moves such as clarifying, pressing, or probing allow students to further communicate about and elaborate on their contributions, and, during extended exchanges, serve to make students ideas comprehensible and available to the entire group (O'Connor & Michaels, 1993; Resnick & Michaels, 2010). Providing follow-ups initially falls to the teacher to model when and how to ask these kinds of questions, yet students can and do take-up this role (Jadallah et al., 2011; Thompson, Hagenah, Kang, Stroupe, & Braaten, 2016). In

Ellie's and Amanda's classrooms, the teacher provided follow-ups to individual students during whole-class discussions which often resulted in students providing additional reasoning, clarifying, or elaborating on their first utterance. In Henry's class, the teacher provided follow-ups during teacher-facilitated discussions but did not typically intervene in student-facilitated whole-class talk. Since I coded for when *teachers* provided follow-ups as part of '*teacher*-mediated conditions', not when students performed this move, my analysis draws conservative conclusions about the utility of follow-up moves to support rigorous talk. It does not include instances of when *students* provided the follow-up moves whole-group, given that this was a trend in one teacher's classroom.

In my episode analysis, one limitation is that I marked *when/if* teacher employed follow-up moves, but not *how* these follow-ups were used. As I coded, I noticed that how teachers used follow-ups shaped subsequent talk. For example, Ellie's follow-ups occasionally functioned as a controlling move to pivot students from exploring ideas to providing correct answers, or vice versa. Ellie used subtle phrases to continue a focus on student thinking, (e.g. after revoicing a student's prior contribution, Ellie said: "My question to you is…," "I'm asking you guys," "Let's hear what you think," "Explain to me why…"). In the same episode, at times followed-up in a way that pivoted towards providing correct answers (e.g. "So, she talked about___.What do we call…?," "What did we learn about…?", "Who can tell me about…?") or she repeated a question until she got a satisfactory answer which she then evaluated (e.g. "Oooh, did you guys hear that?," "[Student], just said something really brilliant," "She said something awesome."). These shifts, between positioning students as explanation-builders or answer-givers, were often subtle. It was likely not obvious to all students which "game they were playing" as shifts were in coded language and happened rapidly within the context of the larger episode, sometimes with only one or two exchanges before pivoting. This created inequitable patterns in who had access to and who was able to actively contribute to the whole-class discussions. How teachers press shapes how students participate, shifting students who were providing sophisticated mechanistic explanations towards providing one-word or short phrase responses aimed at science terms or facts (Russ, Coffey, Hammer, & Hutchison, 2009). It is important, therefore, for teachers to understand how to use follow-up moves *and* to reflect on how their follow-ups relate to how students participate in subsequent exchanges, as it may unintentionally shift the rigor of the episode.

Proximity or reference to activity. In this study, teachers provided materials from activities and/or representations of activities (e.g. public summary charts) for students to use in recalling their experiences and supporting their reasoning. Records of activity that teachers invoked included items inscribed during or after prior activities including data charts, data maps, labeled diagrams, and Summary Tables. The utility of this condition with respect to rigor seemed uncertain (present across all rigor levels in about 75% of episodes). However, it should not be dismissed as an irrelevant condition as other studies found this condition valuable to support student reasoning. In my prior study, for example, the proximity to activity or having a referent to an activity did seem to make a difference for some classrooms—it was not required to achieve higher rigor in discursive episodes at one school (with higher SES and lower rates of free-and-reduced lunch) yet was necessary at the other school (lower SES, and higher free-and-reduced lunch percentage) (Colley & Windschitl, 2016). Other studies indicate that proximity to activity or creating/having a referent to that activity may be a supportive condition for higher levels of reasoning. It is possible that public class-created records help to structure student interactions and stimulate thinking as they embody a co-construction of knowledge, serving as common referent or target of questions and revised ideas (Danish & Enyedy, 2007; Lehrer & Schauble, 2005; Windschitl, 2001). Varelas and colleagues (2007) observed that when elementary students manipulated objects during tasks aimed at making sense of new science concepts, some students used these materials to illustrate the new concepts to develop their current reasoning and others abandoned their current thinking. Although their study did not look specifically at the rigor of student talk, from the examples and descriptions provided in the article, it is reasonable to assume that the availability of materials, the introduction of new science concept, alongside the open-ended nature of the tasks the authors described supported students to reason at deeper levels (as opposed to reproducing facts or vocabulary provided). In this study, students were specifically given sensemaking tasks in using these material objects and referents to activity; however, sensemaking does not happen without such directions.

Invite others. From my prior study, inviting others seemed a fruitful condition, yet there were too few instances to draw conclusions. In this study, however, inviting others to comment on a prior students' contribution co-occurred in approximately one-third of all episodes and co-occurred more often in higher rigor episodes (15% of low-rigor and 45% of high rigor episodes). This condition is likely to support higher rigor exchanges because inviting others to comment, add-on to, question, or clarify another students' contribution provides opportunities to negotiate meaning, create a shared understanding, and coordinate and co-construct theories with evidence (Richard Duschl & Osborne, 2002). One area of future analysis could be to look at the nature of the invitations in context, not just *that* they were present, to understand more about how and when students took up these invitations.

Pre-discussion task. From my prior study, we hypothesized that pre-discussion tasks would be a supportive condition for rigorous talk yet there were insufficient instances across the four classrooms to draw strong conclusions. In this study, pre-discussion tasks were part of 52% of all episodes and increased in frequency as rigor increased. Pre-discussion writing tasks potentially serve as external memory support allowing students to preserve, revise, and consult information (Wells, 2008) as required in the subsequent discussion. Pre-discussion speaking tasks allow students to converse in their everyday language with their peers about science concepts as they make sense of and address the teacher's prompt (Wells, 2008).

Language scaffolding. In this data set language scaffolding often complemented a pre-discussion task and/or meta-talk conditions. Providing language supports can be helpful for students as science learning is mediated by social interactions and facilitated though language (Moje, Collazo, Carrillo, & Marx, 2001). Students do not often have opportunities to understand the language of science. Yet addressing sophisticated linguistic demands such as hypothesizing, explaining, and arguing are necessary for making ongoing changes in students' conceptual understanding (Mercer, Dawes, Wegerif, & Sams, 2004). Well-designed sentence frames support students' science reasoning (Kang, Thompson, & Windschitl, 2014) by providing guidance as to the specific way to use language to achieve an academic function (Walqui, 2006). In my coding, I only noted if a language scaffold was provided, but did not distinguish the quality or purpose of the language scaffold, which may have obscured relationships between the language scaffold and the depth and quality of the explanations students provided.

Reference to general talk norms. All teachers had talk norms posted and expectations around how to listen to peers. Prior to or during episodes, teachers provided general reminders to reinforce these norms (such as, "Turn your bodies to face him (the speaker)," "Speak louder so we can hear you," or "Remember to ask questions if you don't understand.") Ellie and Henry used these reminders during low, medium, and high rigor episodes; however, they did appear in larger percentages of episodes as rigor levels increased. This trend partially held for Amanda, who frequently reminded students of these norms (45% of low rigor, and 54% of medium rigor episodes), yet these reminders were only in 30% of her high-rigor episodes. Instead, Amanda tried being more explicit about talk, not just more generic norms but getting specific about the purpose of talk moves. It would be worth further study to see which students continued to participate when teachers invoked these reminders and for what purpose (i.e. if multiple students shouted out at once, a talk norm reminder as used as a management move potentially shutting down ideas from certain students, as only a selected student or two were subsequently heard).

In traditional schooling, the kind of talk and valued ways of participating in this talk are not familiar to all students and can be in conflict with home or community norms (Michaels, O'Connor, et al., 2008). When teachers are explicit about expectations and provide examples of what this language sounds like, more students are able to participate (Delpit, 1988; Nasir, Rosebery, Warren, & Lee, 2014). Overall, my data suggest that these general talk norm reminders, when used in combination with other conditions, increasingly co-occur with higher rigor talk. However, I caution that simply invoking talk norms may have unintended effects. I only tracked *if* these reminders were present. I did not track patterns about which students responded next, who was called on, or which students continued to contribute. Therefore, I am not sure if these talk norm reminders inadvertently functioned to shut down talk for some students while encouraging talk from others. Overall, this inequity may be masked in the average positive trend between reminding students of talk norms and higher levels of rigor. Therefore, I advise that teachers to pay attention to subsequent student participation and behavior when they invoke talk norms. Better yet, instead of relying on generic talk norms, teachers can engage in meta-talk.

Engaging in meta-talk. There were instances where teachers engaged students in meta-talk, that is, talking explicitly about the goals and purpose for talk and how to achieve such goals through language. Sometimes this was paired with providing language supports to go along with the meta-talk in the form of specific talk moves written on the board. For example, in one instance, Amanda experimented with meta-talk, diverging from her more typical generic talk norm reminders (during which she felt her students tuned her out). Before a whole-class discussion around student-generated models, she spent around four minutes talking to students directly about how to ask genuine questions to the presenting students about a part of their model. Together, they generated a list of question stems which they subsequently used. The resulting episode broke from the more prevalent presentation activity, and precipitated students talking to each other about their ideas, which also turned out to be a high rigor episode. In another example, Henry consistently used meta-talk as part of his student-led discussion routine. After the student-led discussion ended, Henry stepped in to facilitate a debrief for a few minutes where Henry and/or his students named examples of who used language for specific purposes during the discussion (e.g. Students referred to a set of posters on the wall that featured different purposes so they pointed or stated if/when students: asked genuine questions, generalized, justified why, showed metacognitive reflection, etc.). Often, but not always, Henry pressed students to name specific examples (e.g. Student: "I justified because I drew… I justified my work because I drew, uh, I drew pictures and explained it and made connections to other experiments," HP021816, 97-98). Henry used this debrief task and the same language purposes in his math lesson, so students were accustomed to a near daily experience of naming what they did with language, and highlighting examples of what that sounded like. For this study, I did not analyze student participation, but from my coaching observations and conversations, Henry and I agreed that this routine helped students know how to participate and helped more students contribute. He also noticed and highlighted when he heard students using the conversation starters on the wall (see Appendix C for more about Henry's entry task routine).

Generally, teachers do not offer explicit guidance on how to use language for sharing and constructing knowledge (Mercer, Wegerif, & Dawes, 1999). Herrenkohl and Guerra (1998) found that when peers in the audience were given specific roles about how to respond to the presenting students along with language scaffolding, students were more likely to engage in a discussion compared to classrooms without these roles where teachers took up the prompting role towards the presenting students. My study, along with others, shows that the combination of meta-talk along with language scaffolding supports student participation in particular kinds of talk. Therefore, if we want all students to be apprenticed into formalized forms of scientific discourse, such as critiquing explanatory models or engaging in evidence-based argumentation, then teachers must pay explicit attention to how language is used, explain to students and support students in using language as a tool to achieve these disciplinary and discursive goals.

Curtailing moves. In analyzing episodes, I noticed that particular moves in certain contexts functioned as curtailing moves, by which I mean teacher's talk moves that served to inadvertently stunt the potential for rigorous talk in a given episode. Often these episodes had been set-up with and/or initiated combinations of with four or more teacher-mediated conditions in-place. This confluence of supportive conditions has been shown to increase the likelihood for a higher rigor whole-class talk episode. Yet, despite these supportive conditions, episodes containing a curtailing move were low rigor. Interestingly, it did not seem that the specific move itself induced the curtailing effect, rather, it was more dependent on classroom context within which it was used. For example, Amanda and Henry both made turn-allocation moves before and during whole-class discussion episodes. In Amanda's class, these moves seemed to curtail the subsequent rigor, yet in Henry's class did not seem to have any effect on the unfolding rigor (see "Combinations of Conditions" subsection in the Findings for examples and comparisons of curtailing moves). For her students, Amanda's moves invoked and reinforced a presentation routine, rather than a discussion. Even when Amanda prompted students to ask question or agree or disagree about the idea that was just presented, students did not. Instead, they waited silently until Amanda called the next group to present their idea, which meant that these whole-class episodes were low rigor. On the other hand, when Henry intervened in student-led discussions with similar moves ("Alright, so let's have James. And let's have Mirriam;" "Alright, two more"), they did not seem to stunt the unfolding rigor of the episode. Here, the importance of social practices and contextual histories, rather than specific talk moves, explains how, across settings, teacher's overt moves, though similar, may function in markedly different ways (Michaels, O'Connor, et al., 2008; Resnick & Michaels, 2010). Therefore, it is important for teachers to understand how to deploy talk moves for specific purposes, but also to assess if their moves function in the ways they intend.

In summary, there is not one specific combination of conditions that guaranteed high rigor across classrooms, rather, multiple conditions, used in combinations, seemed to support students in engaging in higher rigor whole-class discussion episodes. When focusing on the teacher's talk moves, particularly the open-ended prompts, follow-ups, and invitations to others, it is important to note that often these moves cannot be judged on the single utterance alone but must be taken in context (Connor & Michaels, 2007; Wells, 2007). Therefore, teachers should not only pay attention to what they say, their "talk moves," but also how these moves function in the overall discussion (i.e. a teacher question may be phrased as an open-ended prompt, but if students provide one-word guesses or short phrases, it is not functioning that way). Then, consider what complementary conditions could reinforce the intended purpose and include them to better support students in public reasoning.

Assertion 2: Teachers' responsiveness supports students' rigorous conversations: Using student ideas in whole-class discussions co-occurred with higher rigor episodes.

Higher rigor discursive episodes often had a merged-focus (student resources plus science ideas). Also, for these episodes or for other lesson tasks, teachers invoked specific student-generated ideas and positioned them as focal objects, worthy of inquiry. Assuming that a merged-focus during whole-class discussion taken together with other ways teachers' used student ideas in lesson tasks is a theoretically sound proxy for responsiveness, then this study demonstrates that responsiveness supports higher rigor student talk.

Responsiveness to students ideas and experiences is likely to support rigorous talk because, by using student ideas or experiences as a central object to unpack, discuss, build-on, or work with, students feel a sense of ownership in the collective discussion which, in turn, may fuel motivation to achieve understanding (see Brown & Campione, 1996; Engle & Conant, 2002; Warren & Rosebery, 1993). Students bring in their everyday practices and discourses into the science classroom, often as evidence, and, if given scaffolded opportunities, will use them as resources with peers to think, debate, argue, and explore ideas together (Varelas et al., 2007). Yet, despite the generative power of interrogating everyday experiences (Rosebery et al., 2010; Warren et al., 2001), teachers rarely respond to student experiences in ways that support student sensemaking (Thompson et al., 2016).

Though professional development and coaching support, teachers in this study learned how to elicit, attend to, and leverage selected student ideas for collective sensemaking. Students' stories and experiences were welcomed in all classrooms. Sometimes they were elevated as sensemaking resources for the whole-group, and other times they were not. Student experiences, at times, served as a key sensemaking resource, recalled for use later in the lesson or unit by the teacher or students when needed. For example, in a lesson in her fall unit, Ellie recognized the utility of a student's personal experience (her mother getting the car stuck in the snow) and referred to it throughout the lesson where other students reasoned about and worked to explain why it happened using the science concept (friction). (A few students even featured that student's story in their exit task as evidence that friction is needed to get objects moving.)

When teachers invoked a specific student idea, elevating it as a focal object for discussion, subsequent episodes were likely to be higher in rigor compared to when they invoked a non-specific student idea or made general statement about how we can work with/on our ideas. These specific ideas often were situated within or positioned alongside specific student's experience (e.g. why the car was stuck in the snow, why Alex slipped in the hallway yesterday) rather than generic experiences (e.g. any instances slippery surfaces).

Relying on students' everyday sensemaking, though potentially rigorous, is not enough to warrant a claim that teachers are being responsive to students' science ideas. Part of being responsive is maintaining accountability to disciplinary goals. The ways students explain the natural world may be personally useful and relevant, yet not considered "scientific" (NRC, 2000). We can support students' sensemaking by providing known scientific concepts alongside first-hand experiences (Palincsar & Magnusson, 2001) in ways that are accountable to knowledge, standards of reasoning, and the learning community (Michaels, Connor, et al., 2008).

High rigor is not likely to occur without responsiveness to students ideas, participation, and/or lived experiences (Thompson et al., 2016). Generally, higher rigor episodes were most often had a merged- or student-focused. However, there a very few instances of high rigor episodes with a science focus. That said, these episodes were not devoid of responsiveness to student ideas, rather, students' resources were backgrounded in favor of supporting students in making sense of accepted scientific knowledge.

All teachers worked on learning to be responsive to students' ideas. How teachers respond to students' stories supported if/how other students using these ideas or experiences to reason further. To position students' ideas as generative resources for their peers, teachers used simple responses either directed to the student, ("What made you think of that experience?") or directed to the class ("How can her/his story about ____help us all better understand what we observed here?"). Through the professional learning work, each teacher experienced tensions as they learned about, tried out, and took up about being responsive to their students' science ideas.

Conclusion

This study provided evidence that when teachers are responsive to students' science ideas and provide forms of scaffolding students are likely to engage in the rigorous kinds of intellectual work that making progress on ideas demands. I note that my analysis only looked at whole-class conversations; however, rigorous episodes of talk likely happened in small group and partner tasks which means that a whole-group analysis may not have illuminated all the conditions that support rigorous talk. Additionally, I did not analyze patterns in student participation. Future analyses tracing individual student participation in these whole-class episodes may reveal patterns in participation that are affected by the particular condition that are in-play. The study demonstrates that teachers with various levels of experience can facilitate rigorous and responsive discussions. Yet, preparing teachers to do such complex work requires support in using students' ideas are legitimate sensemaking resources, intentional use of supportive conditions, and scaffolding how students use language.

SECTION 2

How responsive coaching mediates elementary teachers' enactments of responsive teaching practices

Simply adopting and implementing NGSS may not result in intended instructional changes as teachers interpret and take-up practices they believe embody or address the policy (Spillane, 2009). Collective professional learning opportunities allow teachers to work together and share representations of their teaching practice to make sense of how being responsive to students' science ideas in productive ways can address these demands and support student learning. If elementary teachers are expected to enact these science reforms in substantive ways, then teachers need multiple intentional, sustained, and coherent professional learning opportunities. Conventional forms of professional development such as one-session workshops or training-and-coaching models often result in practitioners acquiring numerous strategies and activities (Goldenberg & Gallimore, 1991; Little, 1993) but fail to support substantive changes in teacher practice (Ball & Cohen, 1999). These activities and structures do not follow learner-centered principles (Hawley & Valli, 1999), as they tend to be: shallow and fragmented (Ball & Cohen, 1999); involve experts transmitting and exposing some new knowledge to teachers (Hawley & Valli, 1999); are noncumulative (Cohen & Hill, 2000; Little, 1993); and reinforce the idea that teaching is a private, individual activity (Hawley & Valli, 1999). This short-term, transmission model does not follow learner-centered principles, yet it is still a staple of the professional life of teachers, due in part to their lower cost, shorter time commitments, and ease of "covering information" in comparison to other forms of professional learning. Though this transmission format has utility at times, to substantively change practice, professional learning must be sustained work with teachers to collectively problematize and inquire into the work of teaching and learning over multiple years.

Over the past decade, there has been visible shifts in education towards more job-embedded professional development models that adhere to learner-centered principles and the generally agreed upon characteristics of high-quality professional development. Instructional coaching provides one such professional learning activity and can be enacted in ways that meet the agreed upon criteria for high quality, effective professional development such as: grounded in teachers' daily work with students, driven by goals for student learning, is collaborative with other professionals, and sustained over an extended time (Darling-hammond, et al., 2009; Desimone, 2009; Fishman, Davis, & Chan, 2014; Garet, et al., 2001; Gibbons & Cobb, 2017; Hawley & Valli, 1999; Little, 2006; Penuel, et al., 2007; Putnam & Borko, 2000). Instructional coaching, generally, has been shown to be an effective strategy for teacher development (Cornett & Knight, 2009; Joyce & Showers, 1995; Teemant, Wink, & Tyra, 2011) and, has shown positive outcomes for elementary math instruction (i.e. Campbell & Malkus, 2011) and literacy instruction (i.e. Bean, Draper, Hall, Vandermolen, & Zigmond, 2010; Matsumura, Garnier, & Spybrook, 2013). Given the documented promise of coaching in literacy and math, coaching is promoted as an effective part of a coherent professional learning plan for supporting elementary science teachers (Duschl, Schweingruber, & Shouse, 2007).

Teachers need a vision for what this kind of instruction looks like as well as access to tools and other resources that support them in trying out these new practices. Teachers need professional learning activities that help them envision, try-out, enact, reflect, and refine their science teaching practices. Coaching provides one such professional learning opportunity, rooted in teachers' classrooms with their own students. Coaches often shift between approaches or methods in response to the needs of a given situation (Deussen, Coski, Robinson, & Autio, 2007). Instances *that* coaches make these shifts have been documented in the coaching literature; however, we do not yet have a clear definition for what responsiveness means for teacher learning and if or how it impacts teacher learning trajectories. Without these on-going, relevant professional learning opportunities, teachers may relabel their existing practice with NGSS language and not enact the substantive shifts required to legitimately implement these new standards (Cohen, 1990). In these cases, elementary science will largely remain focused on activity without opportunities for sense-making or participation in authentic disciplinary work. Yet, little is known about the nature of coaching, particularly in one-on-one coaching models. In this study, I explore two questions:

1. Is it possible for responsive coaching to support elementary teachers in taking up responsive instruction?
2. If so, what dimensions of responsive coaching appear to support teachers' pedagogical experimentation aimed at being responsive to their students' science ideas?

Coaching approaches. Do we know what works?

Instructional coaching has been popularized in recent years in response to the adoption of Common Core State Standards and due to the availability of federal funds to support the requisite changes to reading and math instruction (Russo, 2004). These funds allowed for several larger-scale efficacy studies of instructional coaching while studying the roll-out of Common Core. These studies found, overall, that coaching was a beneficial professional support (Biancarosa, Bryk, & Dexter, 2010; Desimone, Porter, Garet, Yoon, & Birman, 2002; Hopkins, Ozimek, & Sweet, 2016; S. E. Scott, Cortina, & Carlisle, 2012).

Larger-scale studies have looked broadly at the *effectiveness* of coaching by tracking teacher and student outcomes and comparing them with coaching activity diaries and time-logs (Cantrell & Hughes, 2008; Carlisle & Berebitsky, 2010; Matsumura, Garnier, & Spybrook, 2012; Sailors & Price, 2010). In these cases, coaching focused on supporting teachers' implementing a specific instructional sequence, such as for reading or writing instruction (Bean et al., 2010). Some utilized prescriptive coaching interventions using standardized templates, whereas, other coaching models were strategic and collaborative, encouraging joint-problem solving (Kennedy, 2016). For the majority of these larger-scale studies, it is unclear from the limited descriptions provided *how* the coaching was enacted—only *that* having a coach trained in these strategies resulted in teachers, on-the-whole, trying-out and taking up part or all of the strategies.

If we accept that coaching is an effective professional learning activity, it is important to better understand how it works and under what conditions. There is a small but growing body of literature examining the *nature* of coaching interactions and conditions that supported teacher learning. Given that coaching has been a popular approach to professional learning (Russo, 2004), it is important to understand more about how coaching supports teachers in learning to take-up reform-oriented teaching practices in order to better specify productive coaching practices (Ball, 1996; Gibbons & Cobb, 2016). Certain characteristics of coaching interactions have a supportive influence on the coaching relationship and on teacher practice, such as: building trust in the teacher-coach relationship (Anderson, Feldman, & Minstrell, 2014), building and sustaining a shared vision and understanding of teaching practices (Gibbons, Kazemi, & Lewis, 2017), and using a combination of coaching approaches to address teachers' individual needs and interests (Sailors & Price, 2015).

However, not all teachers who are supported by instructional coaches appropriated new forms of instruction (Supovitz & Turner, 2000; Teemant et al., 2011). This may be, in part, because teachers, coaches, schools, and districts interpret the roles and goals of coaching in very different ways (see Deussen, Coski, Robinson, & Autio, 2007; Poglinco et al., 2003). Or there is a lack of alignment between initiatives at the district and school levels leaving teachers to make sense of which to prioritize. Also, on the whole, coaching studies have not examined coaching at the grain-size necessary to make claims about when/how coaching helps teachers appropriate new forms of instruction.

Why *responsive* coaching? Proposing a coaching orientation

In Section 1, I summarized benefits of responsive teaching on student learning. Now, I argue that taking a responsive approach toward teacher learning in instructional coaching interactions can support teacher learning and ultimately result in shifts in practice. Taking a responsive stance supports teachers-as-learners because it demands attending to teacher's self-directed work, while being accountable to some shared professional learning objectives, and requires time and structures to support teacher-coach joint sensemaking.

A responsive stance in professional learning would mean making room for teacher's self-directed work. We know that professional learning tasks, when done in ways that are self-directed by teachers and personally relevant to their teaching, aligns with how we know adults learn (Bransford, Brown, & Cocking, 2000; Knowles, Holton, & Swanson, 1998). Teachers perceived that coaches customize coaching support based on teacher's particular needs and help them understand the *why* behind their teaching (Gibbons & Cobb, 2016; Vanderburg & Stephens, 2010).

A responsive stance would require the coach to use talk moves and questioning practices that provide opportunities for sensemaking, either individually or collectively. Findings indicate that productive teacher talk about their instruction contribute to teacher learning (Horn & Kane, 2015). And that some coaching activities that feature debriefing with a more knowledgeable other show promise for supporting teacher learning (Garet, Porter, Desimone, Birman, & Yoon, 2001; L. Gibbons & Cobb, 2016; Putnam & Borko, 2000).

Additionally, a responsive stance would require a professional vision and understanding of the aims of the professional learning so that the facilitator can be responsive with respect to and within the boundaries of these goals. Much like how responsive teaching requires the teacher to have a big-picture understanding of the science unit goals and content knowledge in order to support the pedagogical nimbleness to make on-the-fly changes as well as making lesson adjustments. A professional learning facilitator would also require a big-picture vision of professional learning goals for a group of teachers, and what possible multiple pathways would support all teachers in working towards these shared goals. Helping teachers to share-in and build this vision can also support improvements in instruction. Teachers with more sophisticated instructional visions are more likely to demonstrate greater growth when trying out practices coherent with their vision than teachers who do not have such a vision for instruction (Munter & Correnti, 2017). This seems a dramatic shift from current models of professional learning opportunities for teachers.

Responsive coaches use their principled vision of high-quality teaching and learning: (1) to inform decision-making about which ideas, remarks, concerns they notice, prioritize, and respond to during interactions with teachers, (2) to draw boundaries around what is professionally inquiry-worthy (or not) during coaching cycles, (3) to manage risk for teachers in trying-out or taking-up new teaching practices, (4) to support changes in teachers' thinking and actions by allowing for individual learning trajectories that vary by teacher yet work towards the shared instructional vision, and (5) to assess and flexibly adapt coaching work over time in response to teachers' ideas, questions, and needs.

Taking a responsive stance in instructional coaching means that:

1. The teacher-coach relationship is predicated on supporting students' progress in learning and participation over time;
2. The coach takes a resource-oriented view of the teacher's current practice, identifying and recognizing the productive routines, tools, existing practices, and content knowledge the teacher is already using and works with these resources;
3. The coach assesses the teacher's practice, identifying problematic aspects of practice. These are aspects can be ones that the teacher self-identifies as well as ones the coach notices.
4. The coach must prioritize addressing these aspects of practice in ways the teacher finds relevant and feasible while simultaneously attending to the goals of the collective professional work. In responsive coaching, there is a negotiation of the problem space within teacher-coach interactions. The coach must ensure the work is simultaneously focused on supporting student learning while recognizing and managing tensions between the teachers' and coach's expectations and goals;
5. Responsive coaching works best when it focuses on a set of teaching practices, rather than strategies or implementing a curriculum, as the common object of work. A focus on practices mediates working on supporting student participation and

learning. And practices allow for productive variations within a given context, while still being recognizable by others who are familiar with the practices.

If a responsive approach supports students in making progress on their understanding over time, then it follows that a responsive approach in professional learning contexts would support changes in teachers' reasoning and/or instruction over time. This could manifest in changes to how teachers talk about students and student science learning, visions of high-quality instruction, and teachers' reasoning as they make instructional decisions. When a responsive professional learning stance is used in combination with other conditions, such as a set of high-leverage teaching practices this could result in substantive shifts in teacher learning and classroom practice over time.

Figure 22 illustrates my framework for responsive coaching, showing interactions during an episode of joint-negotiation. These negotiations can constrain or enable work between participants in order to achieve some goal. These goals are informed by both collective and individual professional learning goals and the principled vision for instruction. In responsive coaching interactions, these discursive episodes originate from either the coach or teacher.

At the top of Figure 22, there are two starting places indicated by the downward pointing triangles. On the left side, this interaction is started by the coach. The coach identifies and assesses a problem or aspect of practice based on a lesson observation or examination of lesson artifacts. Then the coach decides how to deliver the bid in order to inform the teacher of the perceived issue while respecting the teacher's professional expertise. Next, the teacher and coach negotiate through one or more exchanges to clarify, interrogate the issue, and decide on what actions will be taken. Then these actions play out in a future enactment (bottom of figure 22) which the coach and teacher can use to inform the next cycle. The right side of figure 22 starts with a teacher's bid to address an aspect of practice followed by the coach assessing how or if to address the bid and weighing its potential for productive sensemaking about the vision and/or professional learning goals.

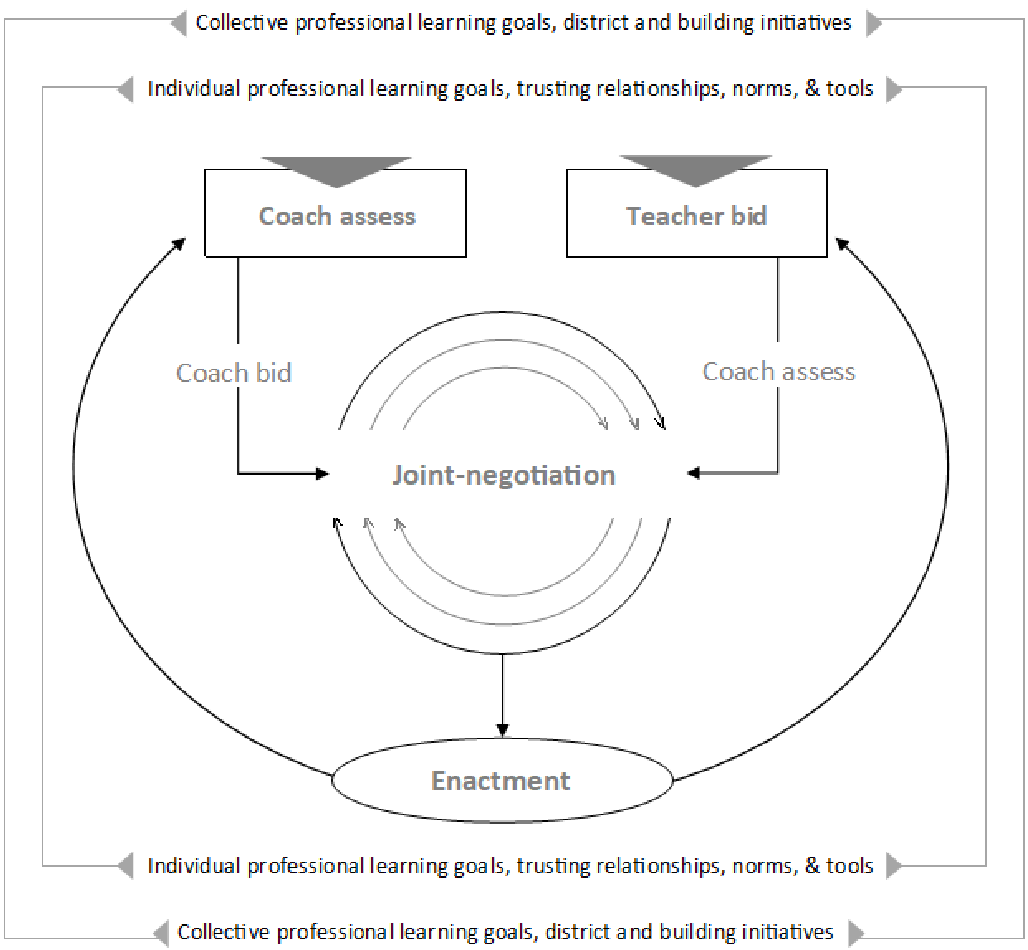


Figure 22. Responsiveness Framework for Coaching

Analyzing these interactions allows for looking for evidence of learning as shown through active sensemaking. At times the coach plays a role as an expert; at other times, as a co-inquirer. This figure purposefully leaves the timescale undefined as it varies. During a lesson observation, it may take a few moments to bid and negotiate and enact an on-the-fly change based on observations of student performance. Or, during a coaching cycle, this unfolds over the observation-debrief-planning-enactment cycle. Though many coaching interactions can follow this pattern of interaction, it is responsive when the coach makes principled decisions about what to focus on and how to interpret and recast teacher bids to work productively towards the instructional vision. This vision serves as a filter and as a reflective tool for both the teacher and coach (Munter & Correnti, 2017). Over time, a series of these interactions supports professional learning. However, in the context of coaching, most studies have not examined how these interactions in terms of learning opportunities provided to teachers (Gibbons & Cobb, 2016).

In summary, the teacher learning focus of my research seeks to fill a literature gap by (1) focusing on how elementary generalists (non-specialists) take-up and enact responsive teaching practices, (2) elaborating on what we know about how coaching and how it relates to when/how teachers try and take up new practices, and (3) extending the application of responsive teaching beyond student learning by defining what responsiveness looks like in support of teacher learning.

Methodology

In this qualitative, multi-case study (Merriam, 2009), I describe the professional learning pathways of three upper elementary science teachers around three focal practices: a) developing and using models, b) developing and using summary tables, and c) creating and revising lists of students' ideas. The data I analyzed for this study came from coaching work with *individual* teachers; yet understanding how my study is situated in a larger and *collective* professional learning context of STEM Academy is important because participation in these activities impacted, in specific instances, what teachers decided to experiment with and take-up into their own science classrooms. I will share the context of STEM Academy and my role as participant observer before describing my participant sampling process, data collection, and analysis.

Study Context: Three-Year Job-Embedded Professional Development

The three-year STEM Academy (Fall 2013–Spring 2016) was designed to improve science instructional practice and to support upper elementary teachers in implementing the Next Generation Science Standards (NGSS). Facilitators anchored professional learning around an NGSS-aligned set of high-leverage science teaching practices (see Ambitious Science Teaching Practices, www.AmbitiousScienceTeaching.org).

To achieve the District's goals, STEM Academy utilized a variety of coherent professional learning experiences with small cohort of teachers supported over three years. Year 1 was a "slow start" with three full-day workshops on NGSS featuring the redesigned curriculum guides. In upper elementary, each grade had three science units per year, one per quarter and also had a curriculum workshop each quarter to launch each unit. These workshops introduced teachers to the NGSS through the redesigned unit guide. Year 1 also offered instructional coaching for those interested. Years 2 and 3 were more intensive. These were launched with a week-long summer institute where students attended each morning and experienced a mini-unit on sound energy which teachers observed, and at times, co-taught. After students went home, teachers stayed for the afternoon to debrief their morning observations of student ideas and co-plan upcoming lessons. Also, for Year 2, we added Studio Days. These provided unique opportunities for teachers to visit each other's classrooms three times during the year to observe their typical classroom routines, to collect and analyze data on student understanding, and to see a focal science teaching practice demonstrated. Finally, for Years 2 and 3, teachers had more push from the District to take advantage of instructional coaching cycles offered. Table 10 summarizes the professional development activities during the 3-year STEM Academy.

Table 10.

STEM Academy overview of professional learning activities

Prof. Learning Activity	*Year 1 2013-2014 "Slow start"*	*Year 2 2014-2015*	*Year 3 2015-2016*
Curriculum revisions and workshops	3 full days, one per unit, 6 hours each	3 after-school workshops, one per unit, 3 hours each	3 after-school workshops, one per unit, 3 hours each
Science instructional coaching cycles	Provided, if requested	Highly encouraged, most regularly engaged	Highly encouraged, most regularly engaged
Week-long summer institute	n/a	5-days in August, Prior to Year 2	5-days in August, Prior to Year 3
Full-day Studios	n/a	3 full days per year, by grade level, one per unit	3 full days per year, by grade level, one per unit

My Role

To support this professional learning work, the District partnered with researchers at the local University who study science teacher learning. As a University partner, I designed and facilitated the professional development activities, taking up roles as a curriculum writer, instructional coach, and primary professional learning facilitator. I informed teachers and district staff about my role as a researcher, consented participants to data collection, and they understood my affiliation with the University; however, during the project, I prioritized my role as a participant in the STEM Academy over my role as a researcher, taking a role of participant-observer (Merriam, 2009; Adler & Adler, 1998). I did this by taking the lead in (1) writing NGSS-aligned unit guides that repurposed existing materials, (2) designing and facilitating week-long summer institutes, full-day studios, and after-school workshops, and (3) working as a science instructional coach one-on-one with STEM Academy teachers in their classrooms.

My prior work history gave me valuable insights and expertise to use in designing and facilitating the STEM Academy work. Prior to the STEM Academy, I had two years' experience as a district-level elementary science instructional coach in another district as well as an additional two years working with pre-service science teachers around the sets of high-leverage science teaching practices and principles which undergirded the STEM Academy professional learning experiences.

Over these three years I had opportunities to build relationships with teachers, students, and the district coach. Facilitating the "slow start" events during Year 1 and leading the summer institutes, which Amanda, Henry, and Ellie attended, helped me begin to build trust with teachers as I took risks publicly by lead-teaching lessons rather than only providing advice or suggesting what teacher should do. I described my role to teachers as being a partner and sharing responsibility for teaching—that the teachers and I were "in this together"—rather than positioning myself as an expert prescribing actions.

Participant Selection

To identify the cohort of STEM Academy science teachers, the District targeted 5th and 6th grade science teachers at five of their 18 elementary schools, resulting in a group of 10 teachers. District leaders selected these five schools because of their historically low student performance on grade 5 state science tests. Principals of two other elementary schools negotiated their teachers' participation, adding three more teachers to our group, making a cohort of 13. Then, the District required that participating teachers departmentalize—these teachers would be required to teach 2-3 subjects (including science) rather than all subjects. This allowed participants to teach the same science lesson multiple times to different classes. This opportunity to practice, reflect, refine, and try-again is not typical for self-contained elementary teachers when they teach all subjects and do a lesson just one time.

One key stipulation of this project was that teachers' participation in the STEM Academy was linked to the 5th and 6th grade science teaching *positions* at these schools and not to the *teachers*. This meant that our small cohort was affected when any teachers changed grade levels, schools, or districts. Between Years 1 and 2, the STEM Academy group changed dramatically. After Year 1, eleven out of thirteen participating teachers had changed grade levels, schools, and/or districts which meant they were no longer participants in the STEM Academy. Therefore, starting with the summer institute in Year 2, we had teachers who took these science teaching positions join us for STEM Academy. Between Years 2 and 3 we had minimal changes (only 1 teacher left) but we also had significantly diminished participation of four of our teachers because of competing initiatives at their schools which diminished the time for and focus on science. For Years 2 and 3, despite competing school initiatives, all STEM Academy teachers attended most of the collective professional learning activities (see Table 3 above for the activity schedule), and, additionally, half of the teachers were able to regularly engage in one-on-one cycles of science instructional coaching in their classrooms with either the district science coach or myself in the role of coach.

From the Year 2 group, I selected three teachers to participate in my study using criterion-based sampling (Merriam, 2009). These teachers met the following criteria: (1) agreed to fully participating in STEM Academy events, (2) it was their first-year learning about the principles and practices featured in the STEM Academy, and (3) they committed to multiple cycles of one-on-one science instructional coaching cycles throughout at least one school year. These criteria allowed me to address the purposes of my research, namely describing teacher learning trajectories, and noting how responsiveness in my coaching approach impacted what teachers chose to try-out and take-up in their practice. Table 11 below summarizes descriptions of my three focal teachers.

Table 11.

Participant descriptions

Teacher	*K-6 Elementary School*	*Grade*	*Years of Teaching prior to STEM Acad.*	*Subjects taught*	*Frequency of science lessons*	*Science lesson duration*
Henry	Misty Creek	5th	0 years	Science, Math	1-2x per week	45-75 mins
Ellie	Barclay	5th	5 years	Science, Writing	3-4x per week	45-75 mins
Amanda	Madison	6th	7 years	Science, Writing, Social Studies	2x per week	60-75 mins

Two taught fifth grade (Henry and Ellie), and one taught sixth-grade (Amanda). Each had 2-3 classes of 24-28 students, and taught science between one and four times a week, and their science lessons ranged from 45 and 75 minutes each lesson. Both Amanda and Henry joined in Year 2 and continued through Year 3. For Henry, Year 2 was his first full year of teaching. For Amanda, Year 2 was her 8th year teaching. I mention that Henry and Amanda continued because data from Year 3 provided some additional sources, yet were not my main focus for this analysis (with the exception of Henry, who, due to his school constraints, was not able to engage in coaching cycles in the spring unit so I followed him through winter of Year 3). Ellie participated only during Year 2 because she moved out of the district before Year 3. She had 5 years of prior teaching experience. Amanda and taught science and writing.

Although these three teachers participated in all (or a nearly all) of the professional development activities offered in STEM Academy, there was variation in when these teachers took advantage of the science instructional coaching cycles. Figure 23 below shows when each of these three focal teachers participated in collective professional development sessions such as workshops and studios, and also when they engaged in individual coaching cycles. The shapes (circles, triangles) indicate when particular professional development activities were offered and shading indicates teachers' attendance/participation. The asterisks and Xs denote frequency of coaching by quarter. In my role as one of the science instructional coaches, I served as their science coach for these coaching cycles and visits. In summary, this figure shows teachers' participation in the STEM Academy professional development sessions (left side of their column) alongside their coaching support (right side of their column) to illustrate the continuity of support—that even when teachers had a gap in coaching for a variety of reasons, they continued to have support from colleagues to maintain a focus on improving science instruction.

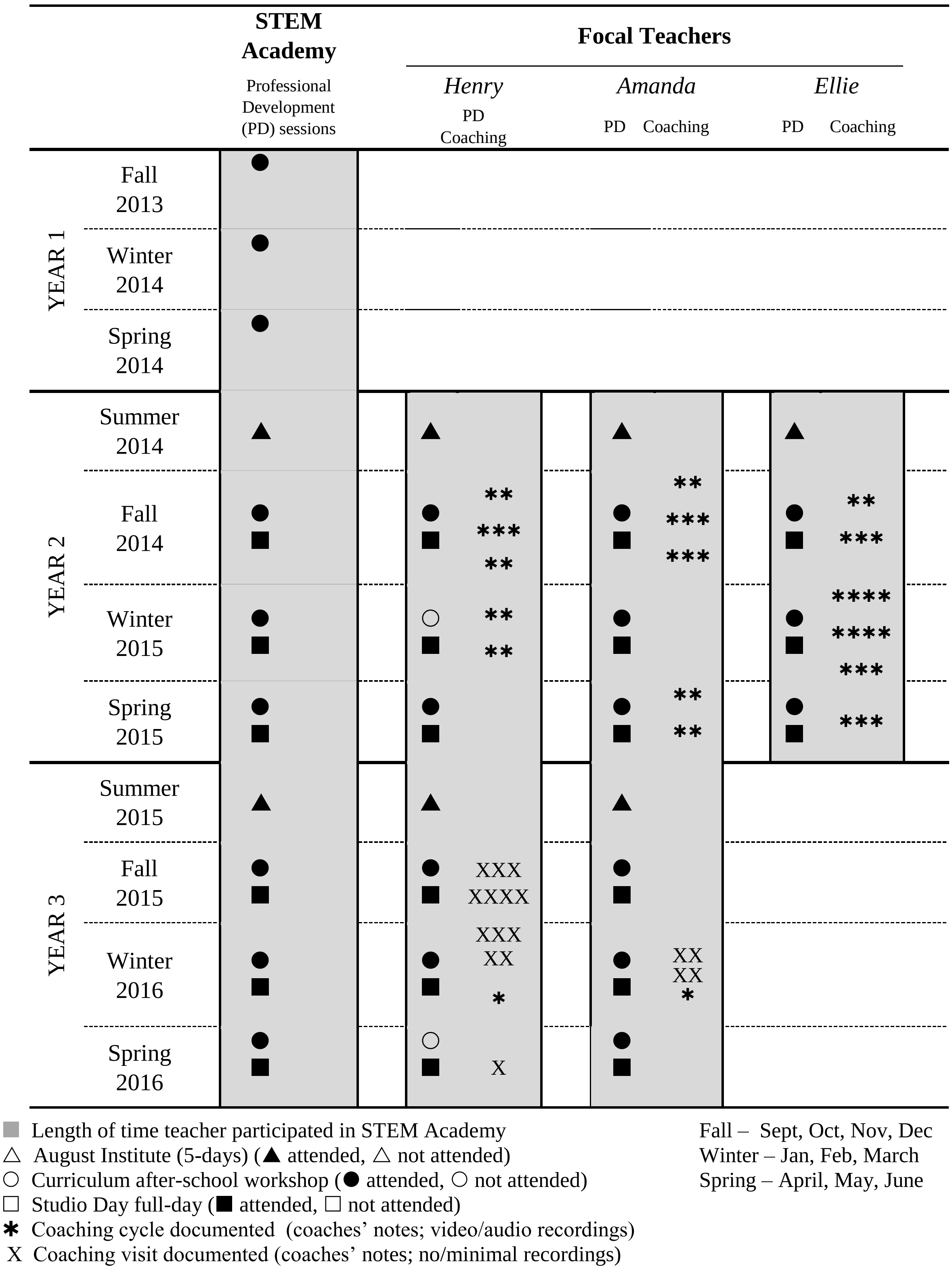


Figure 23. Teachers' participation in STEM Academy activities, 2013-2016

Data collection

Documenting coaching cycles. A coaching cycle was defined as a sequence of three phases featuring the typical coaching activities of planning, observation, and reflection (Gibbons & Cobb, 2016; Matsumura et al., 2012; Scott et al., 2012): (1) planning—discussion between the teacher and coach prior to engaging with students to decide on lesson purpose, structure, and tasks; (2) observing the lesson—which included some combination of the coach making silent observations with note-taking about the teacher's enactment or student performance, co-teaching, and/or the coach demonstrating a segment of the lesson; and (3) reflective debrief between the teacher and coach—reflecting on the lesson, making decisions about plans for future lessons, often included student work/talk analysis as a professional task. The asterisks (*) in Figure 3 (above) denotes the frequency of coaching cycles and shows when I collected coaching cycle data. Some additional shorter coaching visits took place (indicated with Xs) that were not full coaching cycles. These visits consisted of either: a planning meeting, a partial lesson observation with some brief feedback, or light coaching interactions. Light coaching (Knight, 2009) typically consisted of talking on the phone to clarify a task, emailing to share or critique resources to use in an upcoming lesson, or short, spontaneous hallway chats about lessons and student learning in-passing. I documented these visits in my coaching notes, but did not collect video/audio recordings. Due to scheduling challenges and other initiatives competing for teachers' time, these shorter visits and light coaching were, during some quarters, the only option to support teachers with coaching (see Henry, Fall 2015).

Video recorded lesson observations. Derry and colleagues (2010) recommend using the research interests to inform how video is collected. So, given my interest in teacher actions around trying-out new practices, the video camera was positioned to capture as much of the classroom as possible and directed towards the area of the classroom where the teacher spent most of his/her time during whole-class interactions to capture any work projected from the document camera or written/posted on the board that might be used featured. One advantage to having this video record in addition to other sources (photographs and coaching notes) is that I was able to revisit the video (Derry et al., 2010) to note how the teacher and students engaged in particular practices that I would not be able to capture using only audio recordings and photographs. Additionally, I was also able to replay segments of the video with focal teachers during our debriefs to use as a coaching tool to discuss parts of the lesson.

Audio recorded coaching conversations. I audio recorded the coach-teacher interactions during planning and debriefing conversations and I kept notes in my coaching journal. I noted what each teacher was trying-out, working on, and planning to do next and concerns or questions teachers raised during the debrief and planning activities. During observations, I jotted notes about lesson flow, sequence of activities, ideas or phrases I heard from students or saw in their work. I referred to these notes in the debrief and planning conversations with each teacher.

Artifacts. During coaching cycles, I took photos of lesson artifacts; these were most often charts, lists, or tables that the teacher constructed with or for student use. Particularly, I was interested in artifacts that captured or addressed student ideas or questions. This provided a photo record of which kinds of artifacts teachers were utilizing, if/how they shifted over time or if certain artifacts persisted in-use and others fell away. I also collected a sampling of actual physical artifacts to review later once the teacher and students were finished using them. These artifacts, along with photographs and my coaching notebook, enriches the data collected through video

(Derry et al., 2010) and allow for triangulation across data sources to corroborate claims or identify inconsistencies to be explored (Miles et al., 2014).

Scheduling. There was a wide variation of number of coaching cycles, the duration of each phase in the cycle, and how the coaching cycles were distributed/clustered during the school year because of differences in school and class schedules. The majority of coaching cycles were completed within a 24-36 hour timeframe. Often, planning occurred the afternoon prior or the morning prior to the observation. Then I observed one or more class periods happened sometime that day. During these observations, I often did not simply observe, but interacted as needed to co-teach, demonstrate lessons, collect data on student ideas and participation. This was followed by debriefing conversations, which occurred after school that day or the following morning. Some planning emails and phone calls were exchanged about the lessons over the weekend, then the lesson observation and debrief happened during a science lesson the following week.

In addition to the duration of a cycle, the frequency of coaching cycles varied due to scheduling factors. For example, on the higher-frequency end, with 19 coaching cycles, Ellie was eager to take advantage of this coaching opportunity and her school schedule allowed her to teach science three to four times a week which resulted in more available opportunities to schedule coaching cycles. On the lower-frequency end, Henry, though interested and accepting of science coaching, had a school schedule that limited him to teaching science once, sometimes twice, per week for 45-75 minutes per lesson (usually closer to 45 minutes). And he also taught math, a high-stakes subject, and consequently felt pressure to make time in his schedule for math coaching support as well, so he had fewer coaching cycles, 12 full cycles plus light coaching.

What Figure 23 above does not represent is number of contact hours per coaching cycle. For example, due to Amanda's block schedule, she taught science all day to three classes twice a week. So, on these days, her coaching cycles were often full-day visits: We planned the lesson a day or two prior, and then I could stay and observe in two of her class periods and then we debriefed during her afternoon planning period or after school for 45 minutes to an hour. So, in Amanda's case, each coaching cycle asterisks in Figure 23 often represents 5-6 contact hours with the coach; whereas, Henry's coaching cycle asterisks were, on average, closer to 2 hours each.

Missing data. In some instances, there is missing data from a full coaching cycle. Ideally, a coaching cycle was scheduled to allow time and data collection from all three phases; however, due to the realities of scheduling on the part of the teacher and/or the coach, some coaching cycles were missing all or part of a phase or phases. For example, the coach and teacher engaged in planning and debriefing, but a scheduling conflict prevented the coach from observing some, part, or all of the lesson. In a few of instances in the coach's absence during a lesson enactment, the teacher video recorded segments of the lesson to share with the coach during the debrief to discuss how a particular change to the lesson worked for students.

For these research questions, focused on teacher learning trajectories, I used the teacher-coach interaction as a unit of analysis because it allowed me to capture how and when coaching influences instructional practice. I analyzed the coaching interactions between each teacher and coach and compared it to the teacher's instructional actions evidenced through lesson observations. Due to my primary role in the STEM Academy, I elected to analyze data after the completion of the STEM Academy to preserve my participant status. First, I describe my data analysis of whole-class sensemaking discussions, then I go into my analysis of the coaching interactions.

Data Analysis

Due to my primary role as a facilitator/coach the STEM Academy, I elected to analyze data after the completion of the STEM Academy to preserve my participant status.

Transcribing lesson observations. I started my data analysis by transcribing the video recordings of lesson observations, being sure to capture, in-full, any whole-group discussions between students, or between the teacher and students. In the transcripts, I included descriptive notes about any visual resources referenced or used in these whole group exchanges. I did not transcribe but descriptively summarized other activity structures such as partner talk or time for individual or small group tasks. Also, in the transcripts, I noted and described (or if audio was available, transcribed) interactions between the coach and teacher during the lesson, using my coaching notes to provide a short description of what we discussed in these coaching moments.

Next, I located photos from lesson observations or took screen captures of key moments in the video when the teacher used or introduced a tool or referenced a public record, where having a visual record of that moment, as opposed to only a written description from a transcript would be useful. At the top of each lesson transcript, I added a lesson outline generated from my coaching notes, included photos, and screen shots video records. After revisiting the audio recordings of our coaching conversation, I returned to these lesson transcript documents to note places in the transcript that aligned with tasks that were present in our co-planning conversations.

Finally, I marked places in these transcripts that were related to teachers' treatment of science ideas as well as the three focal responsive teaching practices (developing and using models, developing and using summary tables, and creating/revising lists of students' ideas). These moments were visually represented in the barcode representations for each lesson. (See section 1 for an extensive description of how lesson barcodes were created.) By looking at the barcodes over time for each lesson observation, I was able to identify patterns in when/if teachers made attempts at the three focal practices teaching. These were places I noted to revisit when analyzing data from our coaching conversations to see if they invoked this practice based on something we had discussed or previously debriefed.

Audio recordings of coaching conversations. I reviewed the audio recordings of our coaching conversations (planning, debriefing), pausing them and replaying segments to help me write more comprehensive summaries of our work together, including transcript segments of key moments. This complemented the coaching notes I had taken when I was participation in these interactions with teachers. From these audio recordings, I transcribed segments of conversation related to planning or debriefing aspects of the focal responsive teaching practices (developing and using models, developing and using summary tables, and creating/revising public lists). Also, I noted quotes about how both the teachers and I talked about students' ideas during these coaching conversations, transcribing when necessary. This helped me track how teachers talked about student ideas with me and compared it with how teachers framed treatment of ideas with students during lesson enactments. This was consequential to understanding if/how teachers experimented with new practices and if/how they were attending and being responsive to students' science ideas.

I went back-and-forth between lesson transcripts and coaching conversation notes within each coaching cycle. This helped to identify what we discussed in our coaching conversations and if/how it appeared in the classroom. Furthermore, looking across these data, I was able to trace what each teacher tried at different points in time to see patterns in if and how they made progress on the three focal responsive teaching practices.

Analyzing responsive coaching. This next part of my data analysis required looking more closely at when and how teachers took-up and tried-out the focal responsive teaching practices indicated in the top of the barcode representations. I analyzed the barcodes of lesson observations to provide evidence of when/if teachers tried-out these practices and used photos, screenshots, and lesson transcripts to examine how teachers introduced and facilitated related lesson tasks. I matched these instances with coaching conversations between the teacher and coach that happened before, during, or after each lesson observation to see how/when what was planned actually was attempted in the lesson or which unanticipated moments in the lesson were later discussed in a lesson debrief. Then, in these moments, I selectively transcribed from the planning or debrief conversations in order to analyze the interactions between the teacher and coach to identify who made the bid, how the issue was jointly negotiated, if it was resolved, and how that related to on-going instruction. Then, in these extensive notes on coaching cycles, I identified if or where the five dimensions of responsive coaching were present (dimensions defined in my conceptual framework). Furthermore, because I was the coach, I was able to speak to why I made particular decisions and how I navigated the tensions of balancing and prioritizing the individual needs within the collective professional learning work.

Findings

Participants made concerted attempts throughout the year to be responsive to their students' science ideas. These attempts were, at times, complemented and supported by using specific teaching practices, such as developing and using models, which made students' science ideas available to the teacher and to their peers. They experimented with these practices in recognizable, yet varied ways. Tracking teachers' experimentation with each practice over time revealed unique patterns of incremental improvement, plateaus, and/or regressions. These phases, when recognized and problematized by the coach, provided opportunities for teacher learning which ultimately supported teachers' continual experimentation with new practices.

Below I provide evidence that 1) all teachers made attempts to be responsive to their students' science ideas, 2) teachers had varied pathways in trying and taking up new practices, and 3) these variations were likely due, at least in part, to the responsive nature of my coaching.

Teachers were responsive to students' science ideas: Patterns and trends over time

I examined teachers' responsiveness across the data-collection timeline by 1) examining the focus for each whole-group discussion episode, and 2) looking at when and how teachers positioned student ideas as sensemaking resources.

Episode focus: Merging student and science ideas. In my analysis of whole-class discussion episodes, I characterized each episode by its overall focus: science-focused (SCI), student-focused (STU), or merged-focused (MER). If an episode was student-focused, then the teacher allowed discussions mainly about students' ideas. And, although eliciting and understanding students' ideas are important parts of being responsive to student thinking, student-focused episodes lacked accountability to the science discipline. At times, student-focused episodes had superficial mentions of science concepts, but not used substantively in the episode by students. Whereas, in a merged-focus episode, the teacher and students student ideas as equal to science ideas and/or used science ideas to be conceptual tools used in service of developing students' ideas, ostensibly merging science and student ideas together. Assuming merged-episodes serve as a proxy for responsiveness, then, tracking the merged-episodes over time is one way to show if/when each teacher demonstrated attempts at responsiveness.

Figure 24 below reveals patterns in episode focus for each teacher over the data collection timeline. Each narrow rectangle, shaded by focus, symbolizes one whole-class discussion *episode* (not lesson), regardless of length (visually simplified here to call attention to patterns in focus, not duration, of episodes).

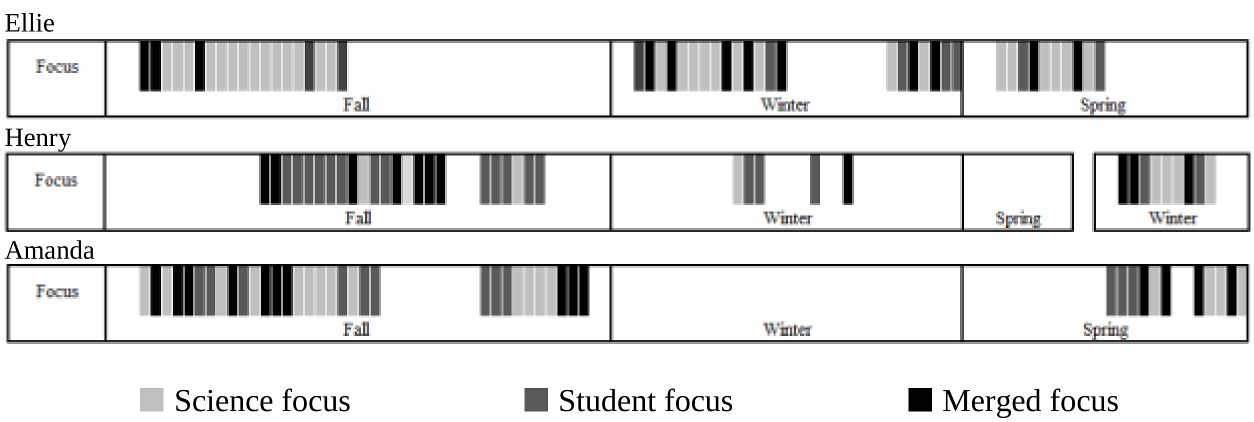


Figure 24. Timeline, by teacher, showing the focus for each whole-class episode

Notably, each teacher had examples of each focus (student, science, or merged). Yet, patterns across timelines differed by teacher. Ellie had a majority of science-focused episodes early in the year. Then, later in the year, she had more alternations in focus, but, importantly, showed an increase in student- and more merged-focus episodes. This indicates that she was elevating student ideas within whole-group discussions more than she did in the fall episodes. For Henry, his student- and merged-focus episodes dominated the start of his year. Over the timeline, Henry showed an increase in science-focused episodes, yet still had merged-episodes present across his timeline. Amanda's episodes showed a balance between student-, science-, and merged-focus episodes appearing somewhat evenly throughout her timeline. In looking across each timeline, changes in focus likely indicate that teachers were trying-out variations on their existing discursive practices for different purposes, resulting in shifts in focus. Overall, teachers either increased or continued to push students to merge science ideas with their own ideas.

Treating student ideas as legitimate resources, worthy of inquiry. All three teachers positioned students' ideas as resources for collective sensemaking and continued to grapple with tensions and challenges of adapting instruction to work with students' ideas.

During lessons, this happened in spontaneous ways, often, when students volunteered unanticipated ideas. After which, teachers determined which parts of the ideas were worth elevating for whole-class discussion, and, if so, delivered a follow-up, often posing the idea, or part of the idea, back to the class for consideration. All three teachers had at least a few instances of using students' unanticipated ideas in subsequent discussions.

During planning, teachers and I worked together to strategically plan ways to use student ideas in lesson tasks. All three teachers tried-out tasks grounded in working with and on students' science ideas. That said, from our coaching cycles, I observed differences in how teachers talked about student ideas (e.g. *interesting, logical explanations* compared to *fixable misconceptions*), how they framed the purpose of tasks that featured student ideas (e.g. *agree/disagree/debate* compared to *fix/correct*), and in what each teacher counted as evidence of student learning (e.g. r*evising ideas, meta-cognitive reflections on how thinking as changed* compared to *using correct vocabulary and providing definitions of concepts*). These orientations seemed to influence how teachers perceived students' ideas and how/if they decided to use them in lesson tasks with consequences for how robustly teachers took up responsive teaching.

Descriptions of teachers' orientations to science teaching and learning

Over multiple coaching cycles, I inferred each teachers' orientation towards science teaching and learning based on how they talked about student learning and from observing their lessons. The descriptions I provide here are not intended to convey a monolithic characterization of each teacher. However, assessing teachers' general orientations towards science learning informed, in part, how I interacted with each teacher in our coaching cycles. This information allowed me to be responsive to what each teacher held as centrally important to science teaching and learning while simultaneously attending to their on-going sensemaking of responsive teaching and attention to students' science ideas.

Traditional, content-orientation. Of the three teachers, Ellie held the most traditional view of science teaching and learning. Throughout the year, her comments and actions revealed that she: wanted students to have the right answers and use correct science vocabulary; did not want to inadvertently propagate incorrect ideas; and, viewed her role as one of fixing student misconceptions and preparing students to perform well on district and state assessments. Having a more traditional orientation did not mean Ellie was unwilling to experiment with new practices or push on her own view of what 'doing science' means. Ellie's traditional, content orientation prompted different kinds of professional sensemaking opportunities and negotiations in our coaching work than I had with Amanda or Henry.

Traditional, student-orientation. Henry positioned students' voices as central to learning, even when students did not yet have the canonically-accepted understanding ("Even if they were wrong, I was gonna put it up there because it's their voice and we can always go back to it and we can always go back to it…"). Exemplifying this stance, from the start of the year, Henry established a student-led routine in his math lessons to publicly share, discuss, and compare ideas, strategies, and reasoning. So, when I observed this in the fall, we worked together to add this student-led discussion routine work to his science lessons. Prioritizing students' voices did not mean Henry was not interested in pursuing a focus on science content understanding. In fact, he expressed concerns about ensuring students had accurate content-knowledge, which, at times, seemed traditional. Yet, science content was an area of uncertainty for him—He felt he had gaps in his content knowledge, low confidence in that knowledge, and did not know how to introduce science content ideas to students.

Responsive orientation. From the start of the year, Amanda demonstrated responsiveness to students' science ideas, balancing the development and revision of their personal theories alongside progressing towards disciplinary goals. In assessing student work, she noticed if/when students used science concepts in their reasoning and noted if they were "getting there" or had "interesting" (alternative) ideas. That said, she did not seem at all concerned when students expressed scientifically inaccurate conceptions. Instead, she remarked that this was part of their learning journey. For Amanda, students' meta-cognitive reflections about why their ideas changed was evidence of students' science learning. When students provided alternative theories, she provided additional opportunities to push or press on these alternative ideas to eventually prompt revisions in student understanding over time.

In summary, all three teachers were committed to providing opportunities to support students' learning, yet each had their own views on what counted as evidence of students' science learning. Assessing teachers' orientations informed what changes I suggested that I thought they would find feasible and relevant to support continued pedagogical experimentation.

Responsive coaching supported variations in teachers' experimentation

To support teachers' responsiveness to their students' science ideas, I targeted three specific practices during our professional learning activities which had the potential to help teachers elicit and respond to student thinking over time. These were: 1) developing and using models, 2) developing and using summary tables, and 3) creating and revising lists of student ideas. Teachers experimented and attempted each of these practices using directions provided in the curriculum guide plus examples they observed during the summer institute, after-school workshops, and studio days. The third practice, creating-and-revising lists of student ideas, was not a central or significant focus of any coaching cycles. Therefore, I focused my analysis of responsive coaching around the variable pathways of teachers' experimentation with the other two practices, developing and using models and developing and using summary tables.

To examine my responsiveness to teachers' learning, I looked for the five dimensions of responsive coaching during coaching cycles and if/when they co-occurred with productive experimentation. The five responsive coaching dimensions (RCDs) are summarized as follows: 1) *student learning and participation*: The teacher-coach relationship is predicated on supporting students' progress in learning and participation over time; 2) *resource-orientation*: The coach takes a resource-oriented view of teachers' current practice; 3) *assessment:* The coach takes stock of and assesses teachers' practice; 4) *negotiations:* The coach negotiates with the teacher to work on what is *relevant* and *feasible* for the teacher to try while being accountable to larger professional learning goals; and 5) *focus on practices:* Responsive coaching works best when focused on instructional practices rather than strategies, activities, or implementing curricula.

Next, I provide sections for each practice, including: a description of the practice, a table summarizing the experimental attempts unique to each teacher, descriptive data about each teacher's learning pathway for that practice, and patterns in dimensions of responsive coaching.

Development and use of summary tables. A summary table serves as a public record of activity, co-created with the teacher, and later referenced by students when they need evidence for their explanations. Developing a summary table row potentially offers opportunities for students to make sense of new science concepts, explain patterns in data, and propose connections to explaining pieces of real-world phenomena. This public tool has four hallmark areas: (1) description of the activity with the question, description, and/or sketch of the set-up, (2) observations and data from the activity, (3) what science concepts students learned about and how students used them to explain patterns in the data, and (4) connections from this activity to explain a part of the overarching unit phenomenon.

During the week-long summer institute, teachers observed both the development and use of summary tables with students. Twice, teachers observed how I summarized student sensemaking about an activity with input from students. I enacted this practice using whole-class discussion punctuated with time for thinking and partner talk before returning whole group. The teacher's role, as I demonstrated it, was to facilitate a whole-class conversation by asking questions, monitoring air-time of multiple contributing students, and then making summarizing moves to record a summary of responses on large chart (see Figure 25). At the end of the summer institute week, I asked students to review and use the summary table to locate evidence they needed to justify claims in their explanations of the unit phenomenon.

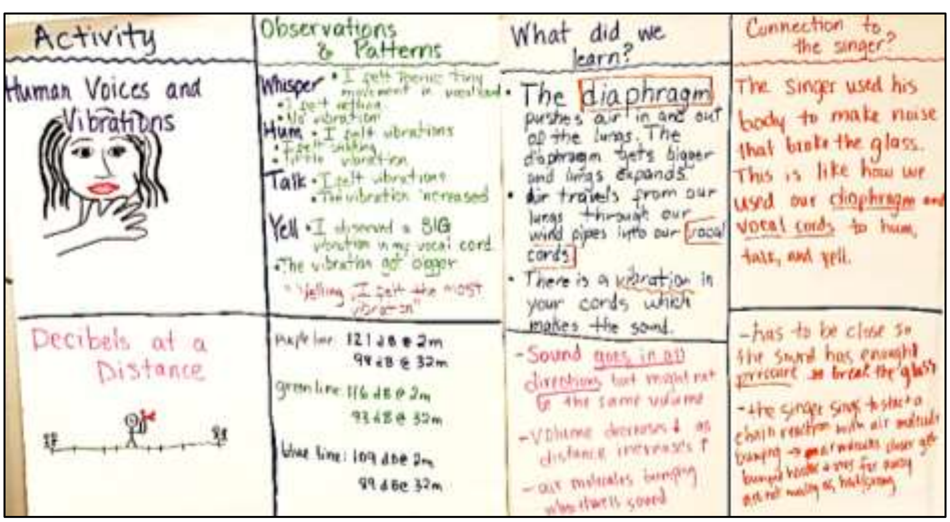


Figure 25. Picture of summary table generated in the summer institute.

During the school year, the curriculum guides provided vague directions after each activity ("Work with students to fill in the row on the summary table") and I provided coaching support. Table 12 summarizes teachers' unique attempts with respect to this practice.

Table 12.

Variations in teacher practice: Developing and using summary tables

	Ellie	Amanda	Henry
Fall	**Unique-to-teacher, coach suggested**: Multiple attempts at summarizing student ideas on chart paper on the wall, abandoned.	**Teacher enacted:** Full summary charts created per activity; tensions around pacing and student engagement. Co-planned modifications to address pacing and engagement issues.	**Coach demonstrated:** Coach demonstrated how to create a version of a summary chart to include observations and key learning during a whole-group discussion.
Winter	**Unique-to-teacher, coach negotiated**: Negotiated a KLEWS chart to serve same function. Tried out on sheet of paper under the document camera instead of large chart paper on the wall. **[Studio**: Observed a 5th grade teacher enacting this practice using small groups, checklists, and public summarizing discussion. Did not try small group summary tables.]	**Colleague observation:** Amanda observed a 5th grade teacher who enacting this practice using small groups, checklists, and public summarizing discussion. *(No data from coaching cycles winter unit; Amanda reported creating a version of the summary chart for her social studies lessons this quarter.)*	**Studio**: Observed a 5th grade teacher enacting this practice using small groups, checklists, and public summarizing discussion. **Teacher enacted**: Students created summary charts with checklists in small groups. Then used student input to create summary charts a few times in this unit; Coach-raised tensions around pacing and student engagement.
Spring	**Unique-to-teacher**: Ellie continued using a KLEWS chart;. Applied a modified version of it health unit as well (closer to KWL than KLEWS).	**Teacher enacted:** More responsibility on students to manage/facilitate; Coach raised tensions around selecting sequencing in whole-class talk.	*(No data from spring quarter; Henry had less time for science this quarter due to test preparation intervention schedules at his school.)*

Ellie's uptake of developing and using summary tables: "It's not my thing." Here is the year-long story of Ellie's initial attempts at, abandonment of, and, partial uptake of the practice of developing and using summary tables. This story documents just how incremental progress can be. In a year of support, Ellie nominally appropriated part of this practice into her repertoire. Given that this practice was not the only focus in our coaching, there were times I chose to abandoned work on this practice and other times I pushed and kept our focus on summary charts.

Fall: Abandoned attempts at summary charts. In my first few lesson observations, I noticed Ellie spent most of her lesson time facilitating whole-class discussions *(RCD3. Assessment)*, without any scaffolds to help students track key ideas, relying on students' listening and speaking skills *(RCD1. Student learning and participation)*. I suggested she create a chart to use during discussions to track and summarize students' ideas. She was willing to try this and made some preliminary efforts by setting-up charts, Yet, during lessons, she did not use them—either she ignored the chart entirely or jotted a few notes, then abandoned it. Figure 26 shows one of the abandoned charts from the fall unit (left). Figure 26 (right) shows a completed chart from a students' notebook. I include this work sample as evidence that students discussed and wrote about their ideas, yet Ellie did not summarize these ideas on a public record.

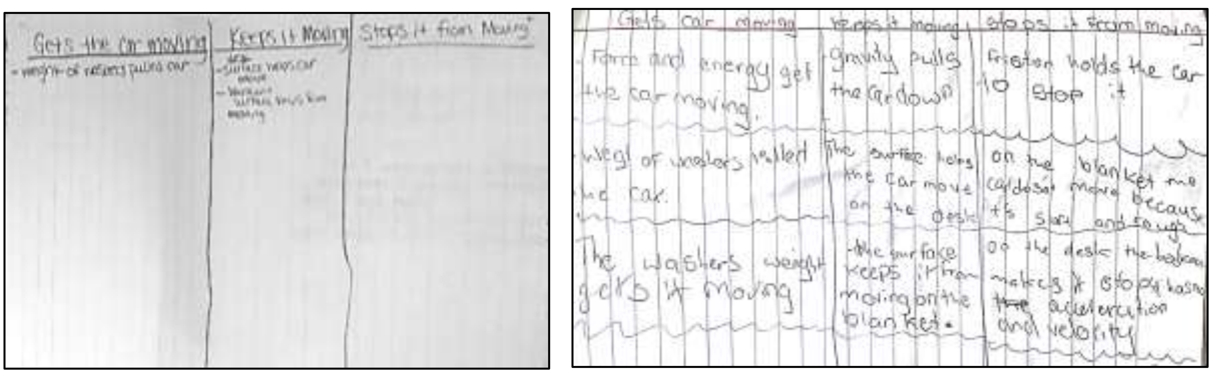


Figure 26. Ellie's abandoned summary chart and individual student summary chart.

In the debrief, we looked over student notebooks to assess student understanding and depth of ideas in their charts. We noticed that the typically high-achieving students had the most writing, and her underserved students, like English Learners and students with IEPs, had less writing or no writing recorded *(RCD1. Student learning and participation).* The existing activity sequence appeared to serve the traditionally high-achieving students, reinforcing an equity issue around who had access to records of important science ideas or information *(RCD3. Assessment)*. Having a public record, such as a summary table, would make key information, learning, evidence, and questions easily referenceable by all students and it could be a publicly revisable record as students accumulate more evidence.

In observing these repeated abandonments, I wanted to figure out what was preventing Ellie from making progress. However, in the fall, summary tables were not the only focus of our coaching cycles. Therefore, I did not actively push on this practice beyond the first few attempts. We were also working to create richer tasks to anchor student discussions to support sensemaking in these whole-class discussions, rather than reliance on terms and repeating facts.

Winter: Willing to try again. In the next unit, we returned to this practice. Figure 27 features an excerpt from our planning conversation. When Ellie recapped her lesson plan for the next day, she asked me for suggestions about how to close the lesson (337-338). I saw this as an opportunity to try a summary chart as a closing task (339, and 342-343). Ellie agreed (347), I provided information (349-352), and Ellie set-up the chart (see Figure 28). This excerpt involves superficial, easily-resolved negotiations. First, whether or not to have a summary chart (343-347), and then, what part would be completed by the end of class (367-375). There was no discussion around how to engage students in summarizing learning as a *practice*.

Line	*Planning excerpt with Ellie on Summary Charts (EW012715)*	*Responsive Coaching Dimension*
337	Ellie: Okay. So, then... How should I close it and what should be learning target	
338	be?	
339	**Carolyn: So, I'd say... your closing could be... some... record...**	
340	Ellie: Or we could share it. They could share their observations and we could	
341	have a discussion?	
342	**Carolyn: Sure. And I was also wondering... if... you wanted to... start a**	*RCD4. Negotiation*
343	**summary chart?**	
344	Ellie: Okay.... okay...	
345	**Carolyn: Just a thought.**	
346	Ellie: Okay. We could do a summary chart. […] Okay, how would you format	
347	your summary chart for this lesson?	
348	**Carolyn: It can look any way. But summary charts always have three pieces.**	
349	**Observations. Learning. And the connection or so what? Like why**	
350	**do we care about learning this? How does it help us explain the**	
351	**phenomenon?**	
352	Ellie: Okay.	
-----	[…]	

Carolyn: I was just curious cuz that could be a way of closing. Somehow, recording your observations so far. Some summary statements about temperature and growth? And then the next day you could add some learning statements. But if you're like, not sure about that we don't have to…	*RCD4. Negotiation - feasibility*
Ellie: So, observations, new learning, and so what? Well, we can do observations.	*RCD4. Negotiation - feasibility*
Carolyn: Yeah, if you'd rather just close with a discussion today and we can tackle summary charts... tomorrow.	
Ellie: Well, the observations, like the summary chart could be part of the obser-- the discussion, right? Like, as we're discussing?	
Carolyn: Sure, right.	
Ellie: Just fill it in…Yeah.	

Figure 27. Excerpt of planning conversation with Ellie around summary tables.

Lesson observation. I came the next day to observe the lesson. She posted the chart from our planning session on the board. Near the end of the lesson, she had students share their observations from the activity verbally and discuss what they saw and trends in their data, yet she did not jot them down under 'observations.' This chart remained blank as another example of an abandoned practice. From our planning conversation, I did not clearly frame summary tables as a solution to a problem of student learning and participation (RCD1) nor did I include any assistance in helping Ellie see using summary tables as a practice (RCD5) rather than a task to complete ("Just fill it in," 376). I did not include enough support or make feasible suggestions that would help Ellie enact this practice.

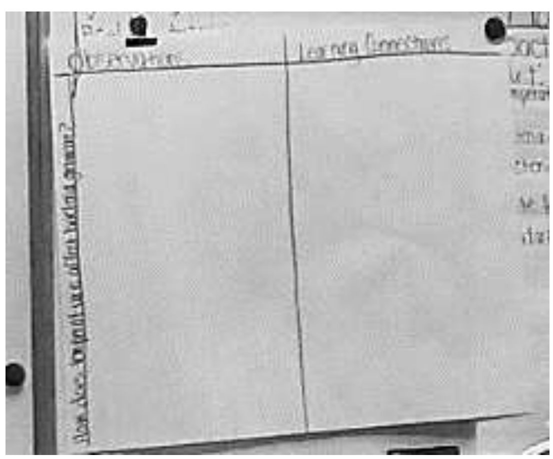


Figure 28. Picture of Ellie's abandoned summary chart

Debrief and planning. I opened the debrief by sharing my observation about the lack of scaffolding for whole-class discussions *(RCD3. Assessment of teachers' practice)*, resulting in problematic student participation patterns (*RCD1.Student learning and participation*). This was not a new concern, as we had discussed this in prior coaching cycles.

In this first excerpt (Figure 29), I proposed that a summary table could help students keep track of the conversation about the activity by pausing to take stock in what was said so far and summarize key points on the chart. Coming from this student-focused need (*RCD1.Student learning and participation*), I made a bid to try summary tables again, even though I knew she had abandoned them in the fall unit and in the prior lesson. Ellie provided reasons for abandoning the charts ("not her thing," and pausing to write was "not an organic part of the lesson.") Yet, this excerpt ended with Ellie problematizing ("I need to find a way to make it organic," 71) and committing to try again ("So, tomorrow, we could do the summary chart," 75).

Line	*Excerpt from lesson debrief, EW012815*	*Responsive Coaching Dimension*
50	**Carolyn:…I'm just wondering like when-- when these conversations happen**	*RCD1. Student learning and participation; RCD4. Negotiation – relevance; RCD3. Assessment of teaching practice*
51	**only in talk--**	
52	Ellie: There's not a visual, yeah.	
53	**Carolyn: Or-- yeah. So, it doesn't have to look that way. But just... like some,**	
54	**like a sentence about what we learned today. Even that kind of a**	
55	**record.**	
56	Ellie: Okay.	
57	**Carolyn: If that seems like--**	
58	Ellie: Not my thing.	
59	**Carolyn: Right.**	
60	Ellie: Okay.	
61	**Carolyn: But...**	
62	Ellie: It's so not my thing. And I think I can make an effort to do--	
63	**Carolyn: And for the record, the summary table, I hear you. When I first**	*RCD4. Negotiation, feasibility*
64	**started doing this, it took me like I tried a couple ways and the first**	
65	**unit I did, I was like ehhh we're not doing... we're just gonna write**	
66	**what we learned, whatever. And I did it a couple different ways and**	
67	**I finally found a groove with doing it. And so it's totally normal to**	
68	**think, 'It's not my thing, but I'll keep an open mind.'**	

69	Ellie: Well, I wanna do it and I've obviously put it up with the intention to do it.	
70	But then once the lesson gets rolling... like... it's not an organic part of	*RCD4. Negotiation, relevance*
71	the lesson so I need to find a way to make it organic.	
72	**Carolyn: Some people, do it like a two-part lesson. So, like part one is the**	*RCD4. Negotiation, feasibility*
73	**graph, the observations, all of that, and day two is the summary**	
74	**chart.**	
75	Ellie: So, tomorrow, we could do the summary chart.	

*Figure 29***.** First debriefing excerpt with Ellie about summary tables, late January**.**

In the next excerpt (Figure 30), I proposed summarizing learning as part of Ellie's existing exit routine which would also address her stated desire to have individual accountability *(RCD2. Resource-oriented view of teachers' current practice)*. By working with Ellie's existing practices and attending to her concerns, I hoped to suggest solutions that she would find feasible and relevant (*RCD4. Negotiation*). Although having students summarize individual learning in their notebooks is not the goal of this practice, I saw this as a potential first step to build on. It also seemed a feasible entry point for Ellie, who was concerned with individual accountability and could easily incorporate a task like this into her existing exit task routine.

Line	*Excerpt from coaching session, EW012815*	*Responsive Coaching Dimension*
104	**Carolyn: … Um. But there's really not-- Like the only rule is that it's, it winds**	*RCD4.*
105	**up being a written artifact that kids can refer to.**	*Negotiation-*
106	Ellie: Right.	*feasible; RCD5.*
107	**Carolyn: And that it generally has observations, learning, and connections.**	*Focus on*
108	**But it could be, just like, 'What did we learn today? How do we**	*practices –*
109	**know?' Like... I was even playing, since you're**—*(Holds up stack of*	*flexibility*
110	*exit tickets)*	
111	Ellie: Cuz I've been having them do exit tasks. You know, so that's one way?	
112	**Carolyn: I know. That is one way. Right?**	
113	Ellie: Um, and I'm better at exit tasks than I am about that. Cuz then I feel like	
114	each individual child is being held accountable and I can go look through	
115	and then I can pull-- And if it's something that I can do, like, a small	
116	group re-group the next day... um...	
117	**Carolyn: Mm-hmm. Yeah. So, I was wondering--**	
118	Ellie: I'm good at that.	
	[…]	*RCD2. Resource-*
175	**Carolyn: And it can even be in their notebook. That could be your exit ticket**	*oriented view of*
176	**is that they fill in the row in their summary table** *(pointing at*	*teachers' current*
177	*notebook)***, what I observed, what I learned, and the connect-- How I**	*practice. RCD4.*
178	**think it helps us understand the food-poisoning.**	*Negotiation-*
179	Ellie: Okay.	*feasible*
180	**Carolyn: Then that's individual accountability.**	
181	Ellie: Yeah.	

*Figure 30***.** Second debriefing excerpt with Ellie about summary tables, late January.

In this final excerpt pertaining to summary tables (Figure 31), Ellie made a bid for a KWL chart (**k**now, **w**onder, **l**earned), indicating some knowledge of this chart. I inferred she was comfortable using a KWL so I took up the substance of her bid (*RCD2. Resource-oriented view of teacher's practice*) and countered with the science-version called a KLEWS chart (Hershberger & Zembal-Saul, 2015; Hershberger, Zembal-Saul, & Starr, 2007). Here, we negotiated to find an approach that Ellie would find feasible to try (*RCD4. Negotiations)* which showed how our focus on practices provided the flexibility needed to find an on-ramp for Ellie to try out a new practice (*RCD5.Focus on teaching practices – flexibility*).

Line	*Excerpt from coaching session, EW012815*	*Responsive Coaching Dimension*
225	Ellie: *(In recapping the lesson plan, considering a public record, she pauses)*--So	
226	could we do just like a K-W-L... then? With the overarcing [sic] question	
227	above it, 'How does temperature affect bacteria growth? What do we	
228	know? What do we wanna know? What have we learned?'	
229	**Carolyn: Mm-hmm. Yeah, you can do that. There's something called a**	*RCD2.*
230	**KLEWS chart.**	*Resource-*
231	Ellie: Okay, what's that?	*oriented view of*
232	**Carolyn: It's like a KWL on steroids, for science. Um. It's what you know,**	*teachers'*
233	**what you learned, an evidence statement, what you're wondering, and**	*practice*
234	**like a science concept. So, like you have a column for big science words**	
235	**that are concepts. So, like 'reproduction' might be the word from the**	
236	**video that you wanna make sure that it's somewhere in the room. And**	
237	**what's nice is that that column turns into a word wall for kids when**	
238	**they're writing about science.**	
239	Ellie: *(Writing notes)* What do we know...	
240	**Carolyn: What do we know. What have we learned.**	
241	Ellie: Would those-- because we're doing it at a point, won't those columns kind of	
242	blend together for the kids? Like, they kind of blend together for me.	
243	**Carolyn: Sure, so you could ble-- you could just blend 'em.**	
244	Ellie: Okay, so, what do we know--	
245	**Carolyn: And not do the column ahead of time, so do it after the activity. So**	
246	**instead of 'know' just have it be like 'Learned' slash 'Know'? Or I**	
247	**don't know, right?**	
248	Ellie: Mm-hmm.	
249	**Carolyn: Then 'evidence' which is where you would reference a particular**	
250	**activity that justifies, like, how you know that. Like, 'I know cells come**	*RCD4.*
251	**in different shapes and sizes.' How do I know that? 'Cuz in the reading**	*Negotiation;*
252	**it said that and under the microscope I saw…' […] So, your evidence...**	*RCD5. Focus on*
253	Ellie: Evidence.	*teaching*
254	**Carolyn: Wonderings. And then, um... science terms or concepts. That's the**	*practices –*
255	**'S.' Ah, this seems like it's more up-your-alley. So, it counts as a public**	*flexibility*
256	**record, so there you go.** (*Both laugh)* **We can find something for you!**	
257	Ellie: I like this. We will find--- We will make it work. Alright.	

Figure 31. Last debriefing excerpt with Ellie about summary tables, late January.

Through this conversation, we negotiated how to adapt the practice to support student participation while working with a format more familiar to Ellie. Later in the conversation, I shared suggestions to address her need to make it feel more ‘organic’.

Future incorporation of the summary tables into lessons. After the next activity, Ellie tried the KLEWS chart. Instead of a wall chart, she used a sheet of notebook paper projected using the document camera (one of my suggestions to make it feel more ‘organic’). She changed the column headings. Instead of ‘science concepts’ being included in the last column (S of KLEWS), Ellie titled the very first column ‘Terms’ which reflected her traditional orientation to vocabulary. At my suggestion, she drew lines to connect what knew with their evidence sources. On her own, she revisited the KLEWS chart after each unit activity and had students help her add new ideas, evidence, terms, and wonderings.

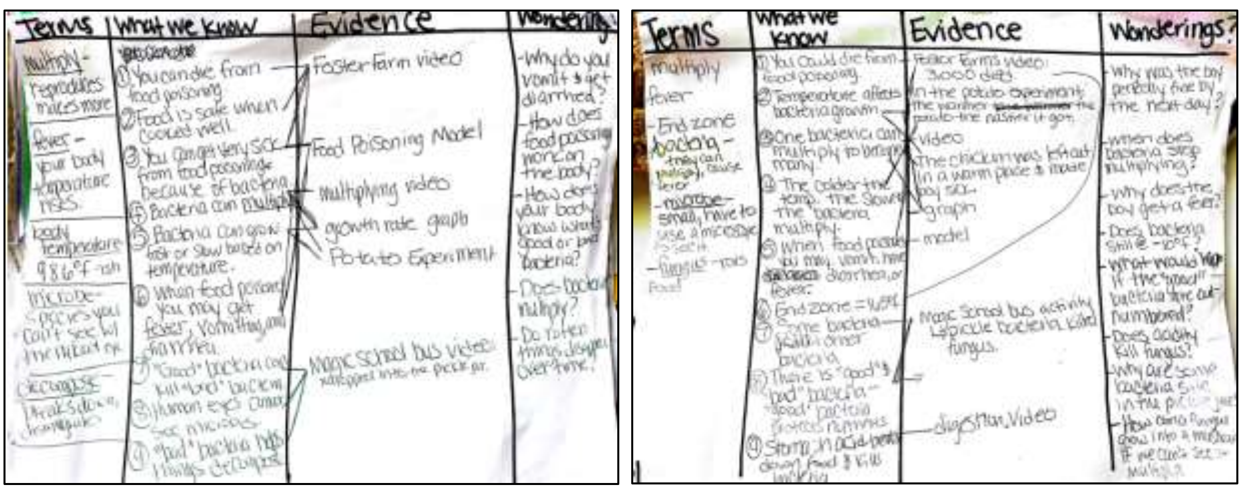


Figure 32. Pictures of KLEWS charts from two of Ellie’s classes.

Figure 32 shows photos of KLEWS charts from two of her classes at the end of the winter unit. These charts were similar since students engaged in the same activities and were focused on the same concepts. However, there were small differences. First, there is a difference in the ideas Ellie recorded in the ‘what we know’ column. On the right, item 7 (“some bacteria kill other bacteria”) and item 9 (“stomach acid breaks down food and kills bacteria”) were not recorded on the other class' chart (left). Second, in the 'terms' column, there were some identical terms (multiply, fever, microbe) and some differences in terms (left: included more about fever and body temperature; right: included student-generated term of 'end zone'). Finally, the most variation between classes was the lists of 'wonderings.'. These small differences indicated Ellie was allowing some degree of student-focused input. I took this as evidence that she was making attempts to be attentive to variations in students' ideas.

She continued using the KLEWS in both winter and spring units. We did not continue to focus on this practice in our coaching cycles; however, during spring I observed how she continued adding to the chart with student input without explicit coaching support.

By the end of the year, Ellie's summary table practice addressed the original problem by providing a way to track key points in their discussions and served as a reference when students were pressed to locate evidence. Yet it was not used in ways that disrupted the problematic patterns in student participation. Ellie's use of the KLEWS chart in the spring unit transitioned into more of a note-taking scaffold (i.e. students copied down her chart) rather than as a place for students to synthesize and record their sensemaking. That said, differences between each class' KLEWS showed Ellie was attentive to some variations in students' ideas and was willing, to some degree, to record them. Her instantiation of the practice did not achieve the potential of developing and using summary tables to support students' public sensemaking; yet she did stick with using a summarizing chart, that earlier in the year she repeatedly abandoned.

Summary. My intent with this in-depth description of the evolution of Ellie's summary table practice is to document the nature of my coaching support and to show the challenges of experimenting with new practices, and how non-linear and incremental progress can be. This story highlights that the five dimensions of responsive coaching. Ellie had some successful attempts at working on this teaching practice with coaching support (*RCD5. Focus on teaching practices*) which had not previously happened (*RCD3. Assessment of teacher's practice*) in a way that worked for her (*RCD4. Negotiation – feasible and relevant*), to provide a visual record for students to help track learning (*RCD1. Student learning and participation*), that worked with her existing practice and addressed her needs (*RCD2. Resource-oriented view of teachers' practice*). It also shows a pathway supported by an experienced instructional coach, attending to teachers' needs, concerns, and existing practices over multiple coaching cycles did not show smooth, incremental progress, but had starts-and-stops, incremental improvements, then a plateau.

Amanda's uptake of developing and using summary tables. Amanda developed summary charts with students from the first science activity she did that year. Her early enactments mirrored what I demonstrated in the summer institute. Over time, Amanda and I worked to make the summary table practice work better for her and her students.

Prior to engaging with students, Amanda wondered the best way to address the logistical challenge of wall space for three classes worth of summary tables. After we discussed some options, she decided to record a summary charts on notebook paper for each class. Then, Amanda would summarize observations, learning, and connections on the main body of a large chart. She said she would glue the small charts from each class at the bottom so, as she said, students knew she got the information from them (see figure 33, left).

After her first day attempt at engaging students in summarizing their learning *(RCD5. Focus on teaching practices)*, Amanda identified a problem with pacing and student engagement *(RCD1. Student learning and participation)*. She wanted a sensemaking discussion, but instead it turned into a sharing out of multiple, disconnected ideas, student-by-student, with little crosstalk and a lot of “dead space” as students waited silently for Amanda to record each contribution on the notebook paper (Amanda: “I feel it kind of takes the air out of the class, you know, or like the wind out of the sail. I don't know the kids just kind of sit there and I don't know how to keep them engaged when we're doing that,” AV093014, 7-10).

At our next planning meeting focused on summary tables (see figure 33), Amanda resurfaced the pacing and engagement concern *(RCD1. Student learning and participation)*. I suggested adding a time for small-group talk prior to the whole-group conversation which I knew she would find feasible and relevant because she told me before she liked small group tasks because more students have to be engaged *(RCD2. Resource-orientation; RCD4. Negotiation - feasibility).* Then, each table group would generate one a sticky note summarizing their group’s response and bring it up to the class summary chart, eliminating the pacing issue of waiting for Amanda to record ideas *(RCD4. Negotiation – relevance)* and leaving more time to discuss and compare ideas on the sticky notes. To prepare students for small group talk, I suggested making use of her existing entry task *(RCD2. Resource-orientation)* to prepare students to discuss their learning and connections with their group. Here is an exchange from our coaching conversation.

Line	*Excerpt from coaching conversation with Amanda (AV 100714, debrief)*	*Responsive Coaching Dimension*
247	Amanda: I feel like sometimes I feel like those times drag out.	*RCD1. Student learning and participation*
---	[…]	
253	Carolyn: So, instead of us writing what they're telling us, should we do something with	
254	sticky notes? Where each group has to write one sticky note about what they	
255	talked about to share out and as they bring it up and stick it on the list they	
256	read it and go sit down. Then that would get seven ideas up there.	
257	Amanda: Oh my God, that would be so nice!	
---	[…]	*RCD4. Negotiation – feasibility*
276	Carolyn: Anyway... we could try it this afternoon? But we don't have to.	
277	Amanda: We can try it. Yeah, I have sticky notes.	
---	[…]	
284	Carolyn: They could do it as their writing entry task?	*RCD2. Resource-orientation to teacher’s existing practice*
285	Amanda: Like the connection they can make from--	
286	Carolyn: --Yeah, it's like, what did you learn about vibration and volume last Thursday?	
287	And then we can put a little picture of the guy with a voice. And 'How does	
288	this help us understand what the singer does?' Cuz then there are two points.	

Amanda: Okay, yeah.

Carolyn: What do you think?

Amanda: Mm-hmm

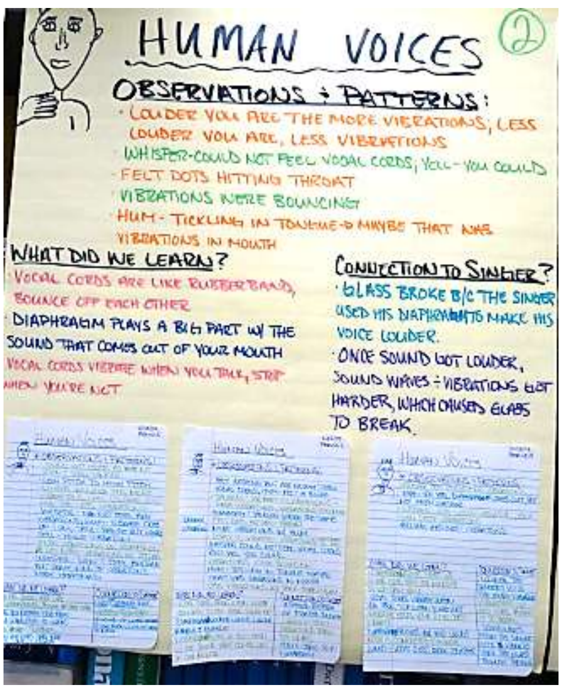
--- […]

Carolyn: So, Tuesday, entry writing with question. Then, that can lead into the conversation about finishing... to finish singer connection … on chart *(jotting down lesson plan)*. Okay. And then that writing can give us a little insight into... their understanding...and now they'll have the chart, the important words list, and their own notes from the data chart that they can use.

RCD1. Student learning and participation
RCD5. Focus on practices

Figure 33. Planning excerpt with Amanda about summary tables

In the next lesson, Amanda tried what we had planned. These changes eliminated Amanda's pacing concern and increased the number of students engaged. Amanda preserved the sticky notes from each group at the bottom of the chart (see figure 34, right). She continued to summarize across classes so students could read the chart from across the room.



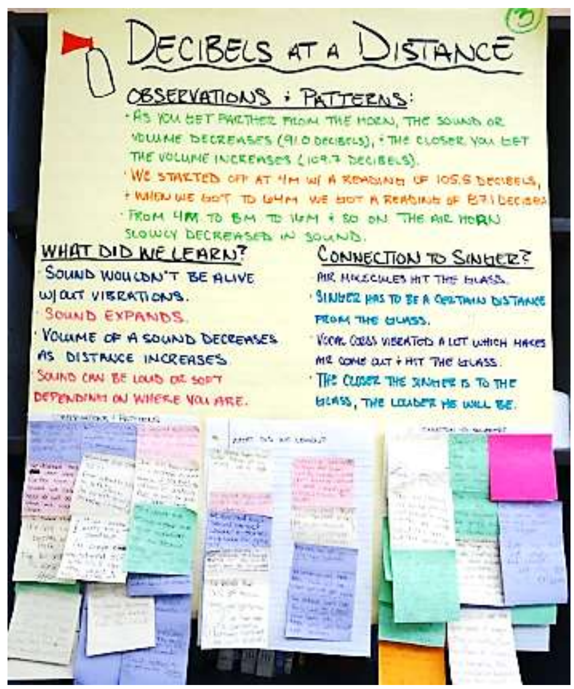


Figure 34. Two summary chart examples from Amanda's fall unit.

Noticing and better supporting student participation was a central theme for Amanda in our coaching conversations. Throughout the fall unit, Amanda and I worked to improve how she supported students' sensemaking of activity, which is a key purpose in creating these summary charts. She publicly posted summary charts for each major activity (see Figure 35). These captured students' "thinking in progress" are not typical of elementary science teachers.

Figure 35. Unit-long display of summary tables, Amanda's fall unit.

Another way I was responsive to Amanda's developing practice was encouraging a small-group focus as part of her developing summary tables practice. I knew that Amanda preferred small group tasks instead of whole-class because more students were simultaneously, actively engaged *(RCD1. Student learning and participation; RCD2. Resource-orientation).* So, I focused on how we could better support student participation in these small group interactions *(RCD3. Assessment of practice).* I arranged for Amanda to observe a fifth-grade teacher (also in STEM Academy) in her building who had worked on this practice for two years using small group tasks.

After observing her colleague, Amanda experimented with small-group generated summary charts during her spring unit. She was satisfied that engaging students in this small group task, more students were processing the activity by talking, adding phrases and drawings to their group's summary chart *(RCD1. Student learning and participation)*. We did notice improvements in the quality of students' small group conversations, yet we continued to struggle when we took the discussion to the whole-class to compare and discuss each group's charts. This often remained a small group presentation, with little or no exchange between groups.

Amanda's case is interesting because, originally, her practice nearly immediately (early in the year) mirrored the "expert" practice (my demonstration in the summer). In a more traditional coaching model, where teachers mimic an expert or master teacher, we may have assumed Amanda mastered that practice and moved on in coaching around other practices. However, in taking are responsive stance, Amanda and I problematized and persisted with this practice in her classroom all year. Finally, we landed on a version of the practice that better fit with her norms, routines, and orientation while still fulfilling the purposes for the practice.

Henry's uptake of developing and using summary tables. Like Amanda, Henry eventually took up small-group based summary chart tasks instead of facilitating conversations using partner talk and whole group discussion.

In the fall unit, I did not prioritize working on summary tables because other issues he raised seemed more pressing to him *(RCD2. Resource-orientation; RCD3. Assessment of teachers' practice)*. Furthermore, I knew I summary tables would be a focal practice at our winter studio day where Henry would see a solid example of that practice from another teacher *(RCD3 Assessment; RCD5. Focus on teaching practices)*. So, I decided to delay a focus on this practice until later in the year.

In our winter studio, Henry observed another fifth-grade teacher in the STEM Academy facilitate a lesson featuring the practice of developing summary tables. This lesson was the very same lesson he would teach the following week. Therefore, in our planning conversation, he was pleased that he could directly apply what he observed without needing to translate across content, topic, or grade level. He used the checklist and prompts with his students to support their small group work (Figure 36). After groups created their charts, Henry used his established student-led discussion routine to discuss observations, learning, and connections.

In observing these enactments, I raised one concern *(RCD3. Assessment)* about the pacing of having too much time spent on lower intellectual demand tasks (the observations/data column) and running out of time for the higher demand tasks of summarizing learning and making connections *(RCD1. Student learning and participation).* Henry countered that he felt some of his students, particularly English Learners, needed more time to make sure they understood each other and also “understood the basics” but he did adjust his pacing to make sure there was sufficient time to get to the ‘connections’ conversations but enough time for all students to agree on the observations and learning.

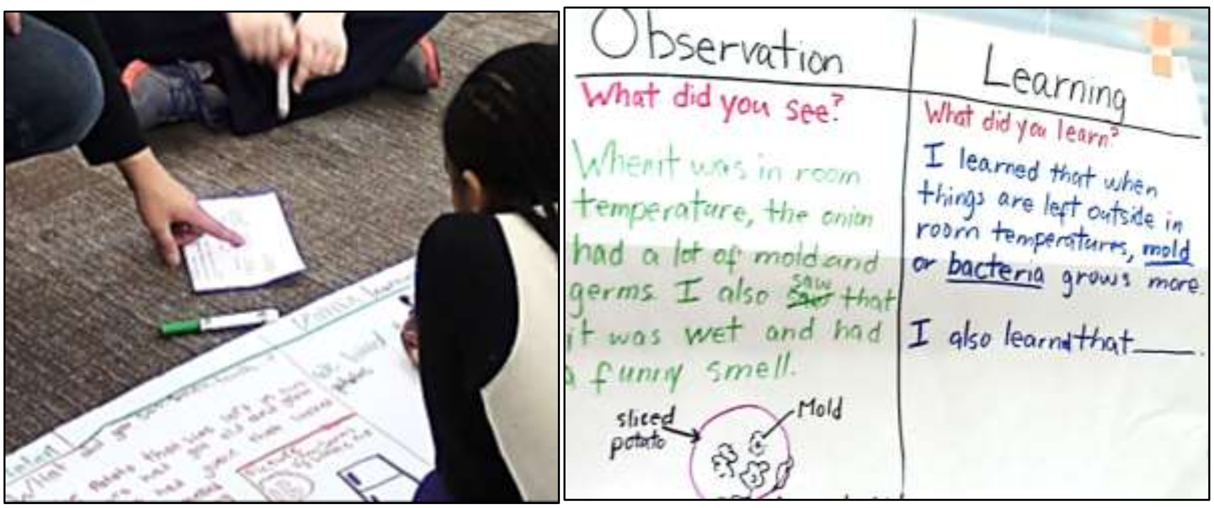


Figure 36. Henry’s small-group summary table attempt

He tried out this practice several times during his winter unit, making incremental improvements each time, indicated to me that he felt comfortable with this way of enacting the practice, and he would be able to continue refining this practice on his own in future years and units *(RCD3. Assessment)* so did not continue as a focus in our coaching cycles. That said, we did not have any coaching cycles during his spring unit due to scheduling conflicts.

Summary. Developing and using summary tables has the potential to surface students’ current thinking and allow students to publicly take stock in what they currently know and the evidence they have. Across teachers, early attempts at understanding and taking-up this practice included concerns around pacing and student engagement while managing the logistics of creating and filling-in the chart in real time with students. Ultimately, the way Henry and Amanda enacted this practice allowed for the records to come directly from students, in their own words, with very little teacher intervention. Because each group had variations in ideas or may have recorded alternative ideas, this allowed Amanda and Henry to become aware of and then be responsive to their students' unfolding understanding in future lessons. Ellie, however, often, but not always, subverted the sensemaking purpose of this practice to one of note-taking. In her classes, the summary table served its reference function but not its sensemaking function, which limited her ability to use this practice in ways that allowed her to be responsive to her students thinking. Furthermore, I demonstrated that my responsive stance in coaching supported teachers in trying-out, experimenting, and taking up this practice in their own ways and persisting with the practice for multiple lessons (or more).

Developing and using models. Modeling provides opportunities for students to surface and communicate their current thinking in multiple ways. Often, models are drawn on paper or whiteboards using symbols, possibly across panels to show changes over time. Sometimes, students use physical materials (e.g. globe and lamp) to make a physical model which they manipulate to communicate their causal explanations about how/why certain events happened and under what conditions.

In these coaching cycles, students' modeling opportunities came up in two places, either students were asked to model-to-explain: 1) the unit phenomenon, or 2) observations from lesson activities. With respect to developing models to explain the unit phenomenon, teachers had guidance from the curriculum guide, summer institute, and after-school workshops. At the start of each unit (fall, winter, spring), each teacher had students develop their initial models. Then, had students do some kind of model revision at one or two places during the unit, and then had a final model near the end-of-the-unit to explain the unit phenomenon. We examined these models together to see what students were including and representing which we used to plan future lessons and/or to assess progress. These shared instances of developing and using models were excluded from Table 13. Table 13 provides a summary of what each teacher tried for the practice of developing and using models that was unique to their classrooms over the data-collection period. I expand on some of the instances in table 13 to illustrate where, when, and how developing and using models came up in our coaching cycles.

Table 13.

Variations in teacher practice: Developing and using models.

	Ellie	Amanda	Henry
Fall	**Coach-bid, not enacted:** Carolyn bid to have students models investigation results, not taken up by Ellie in the lesson, and not forced by Carolyn; Discussed after the lesson. **Unique-to-teacher with coach suggestion**: Ellie created a teacher-led whole-class consensus model; Then followed Carolyn's suggestion to have students draw on the model and explain their idea to the class. **Unique-to-teacher:** Created list of model norms and conventions	**Unique-to- teacher, co-planned with coach:** Amanda and Carolyn examined student work and selected student-generated models to pose as focus the whole class to discuss/critique; **Unique-to-teacher**: Students spontaneously critiqued a model provided in a video during content instruction. **Unique-to-teacher, modeled in summer institute:** Revising chart of various student-generated representations of sound.	**Unique-to-teacher, coach negotiated:** Carolyn suggested Henry use his math entry task activity sequence in science and feature modeling tasks. **Studio**: Henry demonstrated his entry task routine featuring student-led discussions around their models in a studio day. **Curriculum suggested, coach negotiated**: Henry took up the idea of pairing checklists with models to target the key science ideas. **Scaffolding**: Henry made changes to the model scaffolds provided
Winter	**Unique-to-teacher:** Created list of model norms and conventions	*(No data from coaching cycles winter unit)*	**Unique-to-teacher:** Model-based entry task routine **Curriculum/studio**: Henry continued pairing checklists with models.
Spring	**Unique-to-teacher, coach negotiated:** Ellie tried Henry's entry task routine. Carolyn suggested using student ideas in entry task prompts instead of generic science questions. Student models more varied representations with deeper levels of explanations, compared to prior student units.	**Unique-to-teacher:** Amanda continued having students create, share, and ask questions about peers' models. Continued to work on turning presentations into discussions.	*(No data from spring unit)* Winter 2016: **Unique-to-teacher:** Model-based entry task routine, continued.

Henry's uptake of developing and using models. Given Henry's student-focused orientation, it was not surprising that, once we had a routine in place, he provided frequent opportunities for students to develop and discuss their own models.

One unique element of Henry's existing routine in his math teaching was his entry task. I happened to observe this part of a math lesson and was impressed with how students represented their math solutions and their skill at facilitating discussion (this was a student-led discussion). Recalling his earlier comment to me about liking routines and knowing this routine could help Henry engage students in developing models (part of a focal practice), I proposed we adapt the same routine to use in each science lesson, featuring a modeling task. From then on, his entry task routine nearly always emphasized modeling to explain a contextualized scenario. Students were accustomed to publicly sharing ideas, calling on peers, and answering questions about their ideas in math, and this transferred relatively smoothly into science as well (see Appendix C for more on this entry task routine). Henry frequently had students display and discuss their models of various related scenarios or to explain pattern in data in nearly every lesson.

Making space for students to focus, share, and compare their ideas was important to Henry; however, one area we worked on in the fall unit and through the winter unit was highlighting the specific science concepts that could be included in these modeling tasks alongside students' ideas. Henry seemed pleased to emphasize science content in the entry task, because they could review or apply a concept from the prior lesson ("You know, I feel like, first of all, that the entry task was pretty cool, awesome and gets them settled in. Thinking about what did I learn last week and how can I apply it now," HP102714, debrief).

As an example, in one of the fall lessons, we targeted the science concept (balanced and unbalanced forces) in an entry task. Henry suggested using a tug-of-war scenario because we heard students mentioned that before. We talked together a bit about how students could represent this concept in their model (size, direction of arrows). Just as we had planned, Henry prompted students to use these representations in their models. However, even though students used the same modeling convention (size, direction of arrows to show forces), students' models were not identical.

Students' models from entry tasks gave us data on student understanding and also provided us an opportunity to examine our content knowledge and discuss how to better scaffold students in using science concepts in modeling tasks to support their thinking. In this excerpt in figure 37, Henry and I analyzed how students were showing forces in their work (770-781), calibrated our content understanding (808-823), as well as planned one of the items the needed for the checklist scaffold (823-837). This exchange revealed Henry's concern with making sure students understand science concepts. (Figure 38 shows the checklist (left) and students using it (right) that was referenced in this excerpt.)

Line	*HP110614 Planning Excerpt*
770	**Carolyn: What are you thinking about? You're flipping through the** (student work)**,**
771	**so what are you thinking about? Looking for?**
772	Henry: Cuz we're talking about the forces, right? And some of our kids-- Cuz we talked
773	about how forces, when there's always two forces, right?
774	**Carolyn: Right**.
775	Henry: They always have a pair.
776	**Carolyn: They always come in pairs. Like socks, don't lose one!**
777	Henry: Yeah, exactly. So, you know, and I'm thinkin' about...see there's two here
778	*(looking at student work)*
779	**Carolyn: It was--**
780	Henry: I guess, so?... I was assuming they didn't know there was a pair.
781	**Carolyn: Well, there's two (arrows) but I wasn't sure if he was sure. Like this tug-**
782	**of-war situation I'm realizing is more complicated than it seems cuz at**
783	**first they're both pulling in opposite directions but then if that group let's**
784	**go, their arrow goes to almost nothing and the pair arrow is now in the**
785	**rope and in the team**
786	Henry: I'm glad you said that because--
787	**Carolyn: I didn't think about that until I started looking that these and went,**
788	**'Oops!' I was thinking it would be a simple, fun thing that kids would have**
789	**experience with cuz a lot of your kids said they'd done tug-of-war before.**
790	

Henry: Right. So that's exactly what I was thinking about. What I'm saying is this...We need to know-- we need to make sure that they know that they're always in pairs
---
Carolyn: Okay
Henry: Are they always in pairs? Always, always?
[…]
Carolyn: Cuz that arrow could be bigger or thicker.
Henry: Yeah
Carolyn: But there's still resistance so even walking, I'm pushing with my foot on the ground. Friction is pushing back but my muscles are pushing me forward.
Henry: Right
Carolyn: So, there's still a pair of forces.
Henry: Yeah.
Carolyn: In simple terms.
Henry: Okay
Carolyn: Yeah, always a pair.
Henry: Good.
Carolyn: Except, so then, what if you're falling? If you are free falling, gravity is pulling you down... big, fat arrow. Air resistance is a little skinny arrow that's pushing back a bit.
Henry: Right, exactly. […] Yeah. Right, okay, so I think that um we need to really get that into their head that there's always a pair.
Carolyn: So maybe if that doesn't come up on the (check)list. Make sure that forces come in pairs is on the list. And that can be a teacher add. Like, you know I know you guys have been thinking about this but I wanted to make sure that we're all on the same page. And that this might be tricky so if you have one force arrow and you're like what could the other force arrow, the opposite, always in the opposite direction
Henry: What force is that? Right.
Carolyn: Huh?
Henry: What force is the opposite direction? Is the question.
Carolyn: Right. And maybe they don't know the name of it. But like, there always is one.
Henry: Yeah. Good point. They need to know. I mean, they need to know that they always come in pairs.

Figure 37. Planning excerpt with Henry around using science ideas in student models.

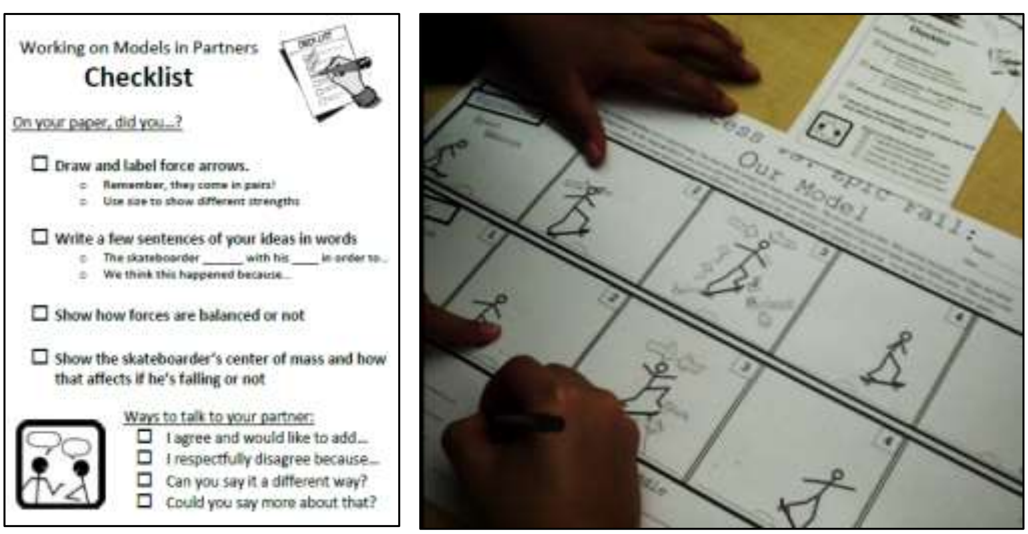


Figure 38. Henry's model checklist to scaffold students' modeling.

Through the fall and winter units, we worked on using his student-focused routines and layering in more of the science content focus. Being responsive is not only about being attentive to students' science ideas, it also is accountable to disciplinary ideas, so that was what we worked on together and Henry took up checklists as one way to remind students to use these key ideas in their models. Simple checklists started appearing in his entry tasks, with more robust checklists (like the one above) reserved for the unit-level modeling about the phenomena.

Ellie's uptake of developing and using models. Next, I describe Ellie's attempts at and experimentation with engaging students in modeling as a responsive teaching practice.

Given Ellie's traditional content-orientation, modeling was initially used to assess canonical science knowledge, facts, and vocabulary. Ellie expressed to me that she wanted students to explain more and show more in their models, yet her prompting and framing of the task pointed students towards labeling science vocabulary. For example, on the very first lesson in each unit, students create their own models to explain how and why a phenomenon occurs. This is purposed at eliciting students' ideas and questions and is a time for teachers to listen and notice. Typically, science vocabulary is not a focus of this unit launch lesson. In the summer institute and curriculum workshops, I modeled this lesson for teachers, including Ellie, and did not use, introduce, or ask about vocabulary. In looking at Ellie's students' initial models in the fall unit, I noticed that many included words like force and gravity as labels so I asked Ellie about it. She responded: "… I was feeding them vocab words. Like I was saying like, 'Let's talk about...' 'I want to see you guys using certain vocab words like let's some of you can throw in the word gravity, some of you can throw in the word force, like, I want to see... […] …to see if they would grab onto an idea and apply it" (EW100814 debrief, 136-141).

To help Ellie encourage students to use vocabulary to explain their ideas (rather than as labels). I made a bid to include a modeling task as part of the next lesson featuring zoom-ins to help students explain how friction affects motion (Carolyn: "…so we can get a better sense of how they're thinking about friction now, is doing something like a zoom-in. Like they zoom-in and do a comparison between the zoom-in of the wheel on the plastic and a wheel on the carpet, or the flannel on the carpet or the whatever felt. Right? And what it looks like? Do you think they'd be game for doing that?" EW100814 planning, 959-964). She agreed ("Mm-hmm." "Okay."), but did not mention it when she recapped her lesson plan to me at the end of our planning conversation.

During the lesson, I sketched a model scaffold on the front board showing a side-view of wheels on two different surfaces that we could use to explain the differences in motion due to friction. However, I chose not to intervene in the lesson to force a modeling task. The existing student discussions, partner talk, and comparisons between the demonstration and video with student stories seemed enough for Ellie to manage without me adding to it.

In the debrief, Ellie asked me about what I drew on the board ("Did you draw that?"). I explained what students could have done with a modeling task ("I did. Because I was, like, if we want to do a zoom-in we could like show what it looks like. They were probably like, 'What do you mean microscope eyes?' or whatever. It's like what's happening riiiiiight here, if we're gonna blow this up (zoom-in)," EW100914). Although we did not explicitly co-plan a modeling task in the next lesson, Ellie seemed to pick up on my idea of engaging students in modeling-to-explain and applied it, on her own, in the form of a whole-class consensus model in the next lesson.

In the next science lesson, for the first time, Ellie facilitated a whole-class consensus model to explain the role of friction when riding a scooter or bicycle up and down a hill. She kept a vocabulary focus ("Where do you see friction?") and seemed to look for specific answers ("What does that friction help us to do?" Get started, stay moving, stop moving). In observing the lesson, these discussions were teacher-controlled and short-answer focused *(RCD3. Assessment)*, which did not uncover how students were understanding the concept of friction *(RCD1. Student learning and participation)*. Over lunch, I suggested a small change that she give the marker to students to come up and add to the model and to explain what they drew or added *(RCD4. Negotiation – feasible and relevant)*. She tried this and it resulted in different symbolic representations, such as downward squiggly arrows for gravity and swirly tornadoes to show kinetic energy, as well as longer verbal explanations from students (see Figure 39).

Figure 39. Ellie's student adds to the whole-class consensus model and explains her idea.

Uniquely, Ellie was the only teacher to create lists of modeling conventions. In the fall, this list included symbols for science concepts such as gravity, energy, pressure, kinetic energy, potential energy. Ellie replayed how she framed creating these lists of model conventions with her students: "We talked about like how we wanna show bacteria multiplying...Then we wanted to show, like, bacteria dying. And then... what ended up coming up was so white blood cells are like the spiky guys but then one group came up with pac-men... for white blood cells. So, we have two... model norms for white blood cells so either the spiky guy or (inaudible)" (EW012215, 46-50). And, she explained, she wanted students to use these conventions to model-to-explain data from their experiments: “So, now we have a whole list of model norms, And then we did start uh a potato, the temperature potato experiment…[…]… It was one of the norms to talk about temp-- like how we're gonna show temperature,” EW012215, 42). Ellie told students that using the same symbols would help everyone understand each other’s models. With this focus on modeling conventions and labeling vocabulary, students’ models remained similar in appearance, featuring symbols and terms, across the fall and winter units. But how Ellie talked about modeling shifted from a heavy focus on labeling vocabulary to using conventions to make sure students could understand each other.

Near the end of the year, she experimented with using modeling in her entry tasks and student models showed more diversity of representation and depth of explanations. She told me she wanted to try “what [Henry] does” with his entry tasks whom she observed at a studio day (see Appendix C for description of Henry’s entry task routine). Her interest in enacting this routine meant that publicly comparing student-generated models was now on-the-table in our coaching work *(RCD4. Negotiation-relevance)* and that, to do this, students would need expansive, generative prompts that allowed for multiple representations to compare and discuss (i.e. prompts cannot funnel towards labeling vocabulary on the model because there is nothing to discuss) *(RCD5. Focus on teaching practices)*. Over several lessons in April during her astronomy unit, we worked on improving aspects of this routine to better support students in developing, explaining, critiquing, and comparing their models and to focus on developing students’ science ideas, rather than repeating canned definitions.

Initially, on her own, Ellie provided science-focused prompts (e.g. *Why do we have different seasons? Draw, label, explain*). So, I made a bid for using student idea(s) in the prompts so students would have an opportunity interact with each other’s ideas to make sense of a science concept, a responsive move. After some negotiation, Ellie began using student ideas from prior lessons to have students agree or disagree or combine ideas in the next lesson's entry task. Over a few enactments of this routine, however, Ellie's directions to draw or model fell away, though ample white space was still provided on the page. Some students continued to draw models to complement and more visually represent their written explanation and others did not. Ellie continued using Henry's sequence of activity: students worked independently on their responses, shared with a partner, then came to the front area and sat on the floor for a student-led discussion to compared, clarified, and elaborated on their responses.

After several iterations on this routine, with some attempts at featuring student ideas in the prompt, I made a rather bold suggestion of featuring an anonymized student's model that was canonically incorrect but represented logically consistent reasoning alongside one that was canonically correct. I saw this as an opportunity for students to use evidence from recent activities to revise and then combine the models but did not get a chance to explain my reasoning due to Ellie's immediate reaction. This suggestion of publicly displaying a 'wrong answer' directly challenged Ellie's traditional orientation to science teaching and learning. The excerpts below capture our negotiation about my suggestion.

This first excerpt (figure 40) is from our planning conversation. It opens with Ellie pushing back on my bid to display a 'wrong' model publicly (94-97), revealing her theory about how students learn through repeated exposures (105-112) and her concern that this public display would perpetuate wrong ideas (100-101). My role here was listening and assessing what seemed to matter most to Ellie so that I could find a way forward in this negotiation for working on and with students' ideas.

Line	*EW042315 Excerpt from planning*
94	Ellie: Because if I were just to present those two things *(the correct and incorrect*
95	*student models from prior days' exit task)* on a piece of paper, I'm gonna get kids-
96	Carolyn: That agree with this? *(canonically incorrect model)*
97	Ellie: Right, but then it's forever in there! You know what I'm saying?
98	Carolyn: But that might be what they're already thinking…
99	Ellie: Yeeah, but, I don't-- If-- If they're thinking that, I kind of want them to produce it
100	on their own, I don't wanna give it to them and support the wrong idea, you know
101	what I'm saying? Like I don't wanna reinforce an alternate pathway. Like...
102	Carolyn: Okay. But you-- But...
103	Ellie: You know what I'm saying? Like, if you hear-- It's like language development,
104	like you have to hear a word 60 times before you start to get that you don't know
105	it and start to develop understanding around it. I wanna -- So I'd rather them be
106	exposed to this over and over and sort of develop an understanding around the
107	correct thing, rather than presenting them with... Giving them alternate
108	understandings and exposing them to alternate understandings if they aren't...
109	Like if I have someone in the middle, I don't-- I'd rather they gravitate toward this
110	one *(correct model)* and not, not see this one *(incorrect model)* and suddenly be
111	like 'Oh!' and gravitate towards it. Like if they're going to cement their thinking, I
112	don't wanna cement it in the wrong direction.

Figure 40. First excerpt in negotiation with Ellie around entry task prompt featuring a wrong idea.

After a few exchanges, I suggested ways to introduce a task featuring an incorrect student model. One of the options I provided was to ask students to revise the model. The excerpt in figure 41 shows that Ellie seemed likely to present a student model that is incorrect if students were prompted to change it (130-131) while continuing to reveal her views that she does not want to perpetuate wrong ideas (135-136). Here, we made some progress in the negotiation with Ellie voicing her acceptance of one of my options ("I can get on-board with that", 131).

Line	*EW042315 Excerpt from planning*
130	Ellie Okay... so I present this as an alternate understanding? And say 'What would you
131	change?' I'm happy with that... like I can get on-board with that.
132	Carolyn: Okay. All about framing! Like how you... *(Ellie chuckles)* Right?
133	Ellie: Cuz I agree with that! I agree with that.
134	Carolyn: It could also be like--
135	Ellie: --But I also think if you were to tell kids the sky is green over and over they
136	would believe you eventually and they would start saying the sky is green.

Figure 41. Second excerpt in negotiation with Ellie around entry task prompt featuring a wrong idea.

Highlighting an incorrect model pushed against her traditional orientation and triggered her concern about reinforcing wrong ideas; however, because students would now be changing, or 'correcting,' the model, this aligned with her orientation as students would know, up front, that the idea presented was wrong, and their job was to could change it.

In this final excerpt (figure 42) from our planning conversation about the entry task, I shared some of my reasoning about why using students' ideas in the entry task is more beneficial than asking a 'straight' content-based question (144-147, 149-151, 153-154). Ellie seemed to agree with my reasoning but highlighted her own reason (155-157). Her traditional orientation was also echoed here as the language Ellie uses at the end of this excerpt ("…they're having to look at it, and re-read it, and really think about what's it's saying in order to respond to it…[…]…that's really useful," 155-157) which was strikingly similar to what I had heard her say before with respect to test-taking strategies and not getting tripped up by wording on the answer options.

Line	*EW042315 Excerpt from planning*
144	Carolyn: But I think that's one of the benefits of doing the entry task or an exit task or
145	both, right? Is that you can continuously see what ideas are there, um... which is
146	why I think comparing their ideas to an idea that somebody else has, is
147	sometimes, a stronger move, once they get used to that format, right?
148	Ellie: Mm-hmm.
149	Carolyn: Than having them answer a straight question cuz then they're not challenging
150	their own-- It's like-- To me, it's making them challenge their own thinking by
151	reading someone else's idea.
152	Ellie: Yeah
153	Carolyn: Right? I don't know. As opposed to answering a question? Because then, I'm
154	not comparing my understanding with somebody else's.
155	Ellie: Right. I like that they're having to look at it, and re-read it, and really think about
156	what it's saying in order to respond to it. I like that. And I think that's really
157	useful. Um... Okay.

Figure 42. Final excerpt in negotiation with Ellie around entry task prompt featuring a wrong idea.

Ultimately, Ellie did select a student idea for the prompt; however, she opted for a canonically correct idea. She did not prompt students to draw or create a visual model to accompany or communicate their response, rather she included prompts she often used in prompting talk (agree, disagree, add-on, or clarify). The prompt was:

> Here is one student's response from last Thursday about what is happening in the southern hemisphere with daylight throughout the year. 'I would say the southern hemisphere from January to March would have a lot of light. From April to August,

would have a little light. Then September to December would have a lot of light. So, it's actually the opposite of the graph of the light of the northern hemisphere.' So, the question is, do you agree or disagree? Do you want to add-on or clarify something?"

Some students chose to draw models with their written response and these varied widely (more so than with models from earlier in the year) — some sketched the orbit of the earth around the sun, others paired it with a graph they created, and a few only wrote their response in words (which raised a semantic exploration of "facing" as in "the sun was facing" or "the earth was facing away/toward the sun").

Overall, in this experimentation with entry tasks and modeling, Ellie made progress in being responsive to students' developing understanding by shifting the focus of tasks from primarily science concepts to understanding student ideas about science concepts. In terms of progressions on modeling as a practice, not all students opted to include drawn models, but for those who did, their models showed more diverse and varied representations with deeper levels of explanation than in models earlier in the year, going beyond the labels and vocabulary terms.

Amanda's uptake of developing and using models. One observation Amanda made during the summer institute was that students should create models not just to explain the unit phenomenon, but to explain patterns in data from lesson activities. So, Amanda looked for places within lessons (which the curriculum guide did not include or specify) to add opportunities for students to model to explain patterns in data. She thought it was interesting how students represented the same ideas in different ways and made time during lessons for students to compare and contrast their representations. Her focus was not on whether or not students aligned with the canonical science explanations, but rather on how seeing others' ideas and ways of representing them could help rethink some ideas. She did this in two main ways: 1) elevating student model(s) to publicly discuss as a class; and 2) critiquing student-created symbols.

Elevating student models for whole-class reasoning: Since Amanda had students engage in modeling in their science notebooks nearly every lesson, we had many representations to choose from to pose back to the class as a focal representation.

In an example from the fall unit, Amanda chose to feature Anthony's representation showing humming, whispering, talking, and yelling with increasing wave heights. She asked students to explain what they thought he was trying to show and if his representation reflected the differences between each sound. (We strategically selected his representation as an entry point for our content instruction in that lesson around the idea of amplitude.)

In another lesson in the fall unit, Amanda had students creating a model showing the relationship between the volume of sound and distance from the source. During a debrief, Amanda and I looked over student notebooks and noticed that Leilani was the only student who showed a graphical looking model—she numbered the horizonal axis from 5 to 40 in increments of five and then drew and increasing squiggle/zigzag increasing from left to right, with no labels or words (figure 43). Amanda projected her model, tracing it so that students could better see it.

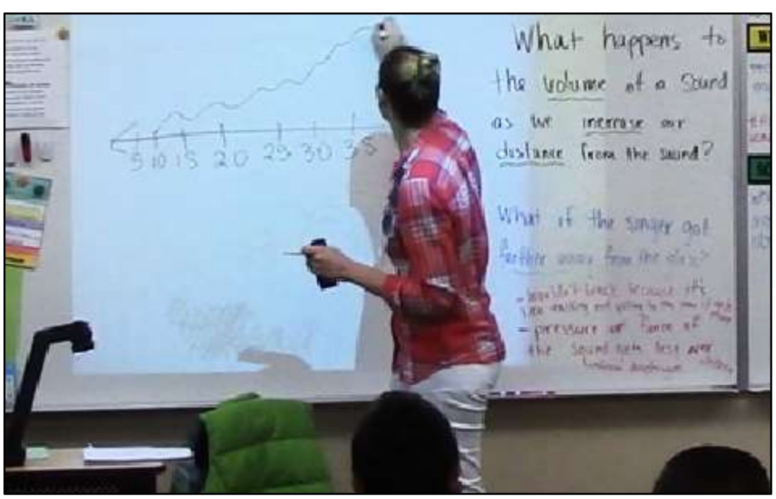


Figure 43. Amanda shares Leilani's model representing about volume and distance.

Using Leilani's graphical model in all three class periods, Amanda prompted students look at her model and discuss in partners what they thought Leilani was representing about the relationship between distance and volume. Amanda encouraged multiple interpretations of the model. Here is one table group reasoning about Leilani's model (figure 44). Not only do these girls posit plausible interpretations of Leilani's model, they connect to the unit phenomenon of how a singer shattered a glass with his voice.

Girl 1: Like a 5 is only like a little bit… and when you get close to 40 it's very high up.
Amanda: So, what are you thinking the numbers represent on the line?
Girl 1: The volume.
Amanda: The volume.
Girl 2: So, I think the number they kinda represent how high it's increasing and the line just shows like how it is increasing with the numbers.
Girl 1: Like 40 is loud but when you get to 100 it's louder like very loud. So, like it's like the TV or like the car radio like you know the volume makes it so the numbers show up and like you can hear how loud it gets.
Girl 3: OH! Um, I think the numbers and the squiggly line means like when the numbers go up the lines do to so when you talk louder, like when you talk louder then it vibrates louder or bigger.
Amanda: So, the line could not only represent volume but vibrations?
Girl 3: Yeah.
Amanda: So, if we were to draw the singer's face on there, where do you think it would go?
Girl 3: Uhhh...
Girl 1: His voice like ....
Amanda: What do you think? With everything you just said, like where do you think?
Girl 2: It increases.
Girl 1: Like maybe in the middle of 30 or 40?
Amanda: In the middle?
Girl 1: Yeah like it wasn't that loud but it was kinda loud.

Figure 44. Small group conversation excerpt about Leilani's model.

Having students talk and reason about another student's model provided a unique opportunity to talk through their own understanding of the relationship from distance and volume.

Creating opportunities for students to represent and share their thinking quickly became part of Amanda's teaching repertoire. She found places to add opportunities for students to model their thinking, and, at times, longer segments to publicly display and compare representations.

Critiquing student-generated symbols. In the fall, Amanda mimicked what I modeled in the summer institute with respecting to publicly listing ways students' represented sound on their models. Since sound energy was not something students could directly see, they invented several different ways of representing sound on their initial models. Then over the unit, students used them and referred to them. At times, representations were voted on to be eliminated (covered with a sticky note) if students did not think they were useful, were too hard to draw, were not flexible enough to capture properties of sound (e.g. change in volume) (figure 45).

Both Ellie and Amanda publicly posted symbolic representations for students to use on modeling tasks. However, these were designed and used in opposite ways. For Ellie, her model conventions chart had multiple science terms with one sometimes two symbols for each that all students would use. For Amanda, she had one concept (sound) and put up a multitude of different symbols students originally for that concept. Then, she made times for students to choose from the list the one they want to use and which to remove. These kinds of discussions gave Amanda access to students' ongoing reasoning about sound and how/why it causes the phenomenon, whereas, Ellie's discussions around model conventions, did not.

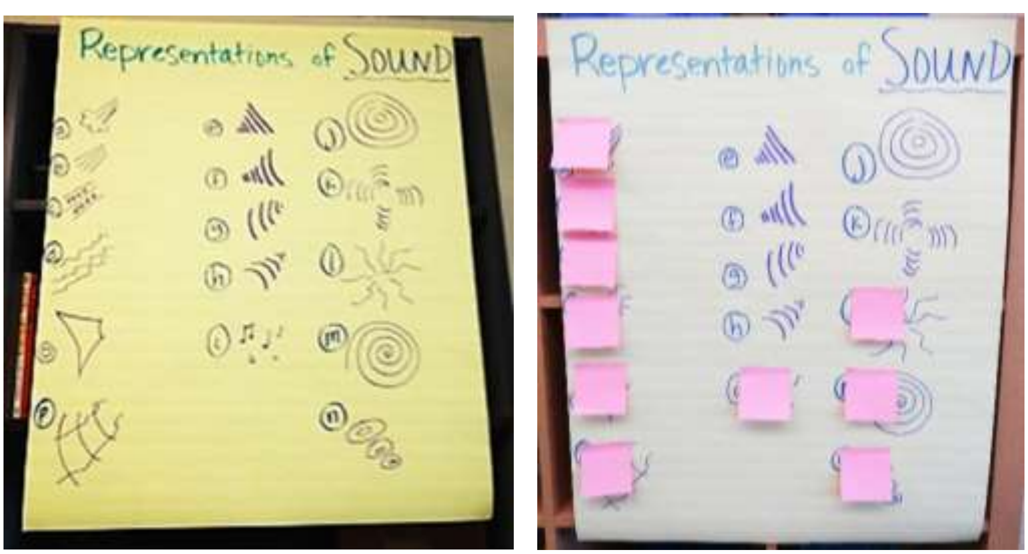


Figure 45. From Amanda's class: Students' representations of sound: Initial and revised charts.

In the spring, knowing Amanda had this experience of charting sound representations from the fall, I made a bid for her to create and use a similar chart of ways students were representing magnetic force or gravity. Magnetism and gravity are forces that cannot be directly observed so I thought it would be productive to make a similar chart of different ways students are representing these invisible forces on their models and then decide which ones are best for showing particular properties of magnetism.

Line	*AV050615 Planning Excerpt*
201	Carolyn: I was trying to think of something similar like, you know how in the
202	sound unit how we kept revising the [list of] representations of sound?
203	Amanda: Yeah.
204	Carolyn: Going back to that. So, what would be the thing in this unit we could
205	keep coming back to? Which is why I wanted to draw the--- I was kind of
206	also wanted to flip through their initial models. Like did anyone actually
207	draw magnetic force? In their model?
208	Amanda: Nnnnn-- They brought it up and I went through the initial ideas and like
209	here are some of the ideas you came up with and now you need to figure
210	out like how to draw like what does magnetic force look like? How do
211	you draw gravity? Um, I need to look at them again.
212	Carolyn: So maybe we can see if there's another representation list we can come
213	up with?

Figure 46. Excerpt from planning with Amanda around representing invisible force

Amanda did not make this chart likely because students did not show many ways to symbolically represent magnetism or gravity other than with arrows. However, she did press students to explain on their models how they used arrows to show these invisible forces (squiggly vs straight, quantity of arrows, length, thickness). When she had them publicly share their models, Amanda made sure to highlight the similarities and differences in how students used arrows to show the invisible forces of magnetism and gravity.

Summary

In taking a responsive approach to coaching these teachers, I made decisions about when and how to support each teacher based on what I knew about their general orientations about teaching and learning, their existing practices, and what seemed to them to be the most pressing or urgent needs for them and their students. In looking at coaching conversations and coaching cycles, I was able to identify places that the five dimensions of responsive coaching frequently emerged and co-occurred with moments of negotiations around how to support each teacher in taking up a particular practice given their orientations, priorities, student needs, and classroom and school contexts.

Discussion

Each teacher made progress and converged on more responsive work, in part, because of my coaching support. For example, I helped Ellie make progress by centering lesson tasks around students' ideas—bringing her science-focus to more of a merged-focus. This made students' ideas publicly available to interrogate, revise, and debate. At face value, this shift may appear as a small change, a "simple" revision to a prompt to use a student idea: "What causes the seasons?" revised to, "Jacob said that when it's summer in the northern hemisphere, the earth is facing the sun. What do you think about Jacob's idea? What do you think he's trying to explain?" Yet, by engaging students in discussions with each other about their ideas, this allowed Ellie to access students' current explanations in ways that her original prompts could not. I helped Henry make progress by adding more science content into his existing student-focused pedagogy—bringing his student-focus to more of a merged-focus. Having access to science content ideas allowed students to create or critique more complete explanations and allowed Henry to recognize productive moments to intervene in student-facilitated whole-class discussions. Early in the year, he did not intervene at all around science content learning in these discussions. However, later, he intervened strategically when certain contributions had science-learning implications (e.g. targeting Madeeha's question for the class' consideration). This increased his merged-focused episodes as well as science-focused episodes.

In my coaching work, I had to identify and consider their unique orientations to support their progress. Some may see teachers' orientations as an obstacle for changing practice, particularly when the teacher's orientation is not in alignment with a change initiative. In this study, however, teachers' orientations, though diverse, did not prevent progress even when they were not closely aligned with our vision for change. In these cases, I was able to support progress around these practices when I accounted for their orientations in my decision-making about what to propose next, and in how I framed the delivery of my suggestion for a next-step. Accounting for teacher orientations resulted in unique pathways for experimenting with the summarizing and modeling practices.

Furthermore, teachers may not attempt new practices if they are unclear about what the practice looks and sounds like. For this study, coaching was used in conjunction with other professional learning supports (summer institute, studio days), which allowed teachers to see successful enactments of these practices with students in classroom settings. This informed their vision of what was possible. Sometimes my coaching did not appear to be a sufficient support for teachers to make progress on a practice. In which case, studios, which I facilitated and designed to feature a practice, inspired teachers to directly take up the enactments of practice they observed from their colleagues (i.e. Ellie took up Henry's entry task routine around modeling; Amanda and Henry took up their colleague's summarizing practice using small group task-structures).

Next, I unpack how coaching conversations influenced teachers' unique experimentation pathways before I revisit and revise my conceptual framework around the five dimensions of responsive coaching.

Responsive coaching conversations mediated unique pathways for teachers learning about responsive teaching practices.

All teachers experimented with the practices of developing and using models and developing and using summary tables over an extended period of time (a year or more). Each had unique and varied pathways of experimentation for each practice. Here I argue that better understanding the nature of coaching conversations explains, in part, why pathways sometimes progressed along in small-but-steady increments of improvement, and, other times, a pathway plateaued or had starts-and-stops.

Coaching conversations are times for problem-solving (see Bean, Draper, Hall, Vandermolen, & Zigmond, 2010; Teemant et al., 2011). I claim that variations in teachers' pathways were likely mediated, in part, by the success of our problem-solving conversations during the coaching activities of co-planning and debriefing. Next, I revisit my conceptual framework around joint problem-solving and add Van de Sande and Greeno's model for achieving mutual understanding to explain how coaching conversations impacted subsequent experimentation.

Van de Sande and Greeno (2012) proposed a three-part model to explain how, when participants are engaged in a joint-task, resolve misunderstandings and achieve mutual understanding: (1) Detect a misunderstanding; (2) Consider and explore differences in understandings to construct mutual understanding; This surfaces participants' perspectives on the information that matters for accomplishing the joint task; and (3) Determine that a mutual understanding is established. Once the misunderstanding is resolved, participants are able to productively engage in the task at hand. This model is relevant here given how much of coaching work happens during conversations. Notably, Gibbons and colleagues (2017) used this model to look at how a coach facilitated groups of teachers negotiating meaning as a group. Here, I apply it to coaching conversations between one coach and one teacher.

In our coaching conversations, the teacher and I jointly-negotiated the problem space, proposed plausible solutions, and determined next steps. When we made it through this process, this often resulted in continued experimentation with a given practice in future enactments. However, if, in our coaching conversations, there was a breakdown somewhere in this process that was not resolved, then we were not able to progress to a decision-making point about what we would try next, resulting in a plateau (teachers maintained their enactment) or an abandonment of that practice temporarily.

We know that teachers have pre-existing orientations that filter how they make sense of new pedagogical ideas in ways that impact practice (Berg & Mensah, 2014; Tilgner, 1990), as do coaches, which influence how they encourage teachers to try practices in particular ways (Ippolito, 2010; Laxton, 2016). In teacher-coach conversations, if both professionals were aligned generally in their interpretations of what happened, what is most important to work on, and how to go about that work, then conversations often proceeded through the joint-negotiation loop and resulted in enactments.

However, if we had some misalignment in interpretations or priorities and/or when one of us detected a lack of mutual understanding, we engaged in a sequence of exchanges to ascertain what information was missing, why it was relevant, and worked to achieve some mutual understanding before we could move to problem-solving and negotiating what to try next. There were conversational episodes where we did not achieve a mutual understanding before one of us ended that episode by changing topics (e.g. asking a different question, directing attention to a different pattern in student participation, jumping to a different problem) or by invoking a routine that signaled changing coaching activities (e.g. in moving from debriefing to planning, Ellie grabbed a pen or pencil, placed a pad of sticky notes in front of her and said, “So on Monday, I’ll open with…”).

These misalignments and misunderstandings sometimes allowed for professional sensemaking, challenging conceptions (teacher’s or coach’s), and opportunities to be transparent with professional reasoning, which did not happen if there was a more immediate agreement. In this example, I directly but respectfully challenged Ellie’s traditional orientation when I proposed we use a student’s incorrect idea on a class entry task. She assessed my bid, provided information about her concerns. Then, we explored and shared each of our perspectives and reasoning around the advantages and disadvantages of such a move. Ultimately, she agreed that having students access each other’s ideas was beneficial, yet did not agree to put up alternative ideas, but continued using students’ ideas in entry tasks.

Overlapping dimensions of responsive coaching supported teachers’ pedagogical experimentation (A revised framework).

I proposed five responsive coaching dimensions as part of my original conceptual framework. From my analysis of these dimensions during coaching conversations over a year with three teachers, I propose some revisions and clarifications to this framework. Next, I explain how each dimension likely supported teachers’ pedagogical experimentation. My coaching often included multiple dimensions in succession— a feature that was missing from or not clearly articulated in my original framework. So, I represent these relationships in a revised framework to show how dimensions function together (figure 47).

First, responsive coaches establish and maintain a primary focus on supporting student’s progress in learning and participation over time (RCD1). This likely supported teacher’s willingness to experiment with aspects of new practices if these changes appeared to be immediately relevant to their students' learning and participation (Desimone, 2009; Hawley & Valli, 1999; Neufeld & Roper, 2003). Identifying problems related to supporting student learning and participation (RCD1) were connected to assessing teachers' current practice (RCD3), and often provided a reason to focus on teaching practices (RCD5). Using student data, alongside my assessment of teacher's current practice and me knowledge of and expertise with the focal teaching practices, helped me decide whether I should raise an issue in a coaching conversation or not.

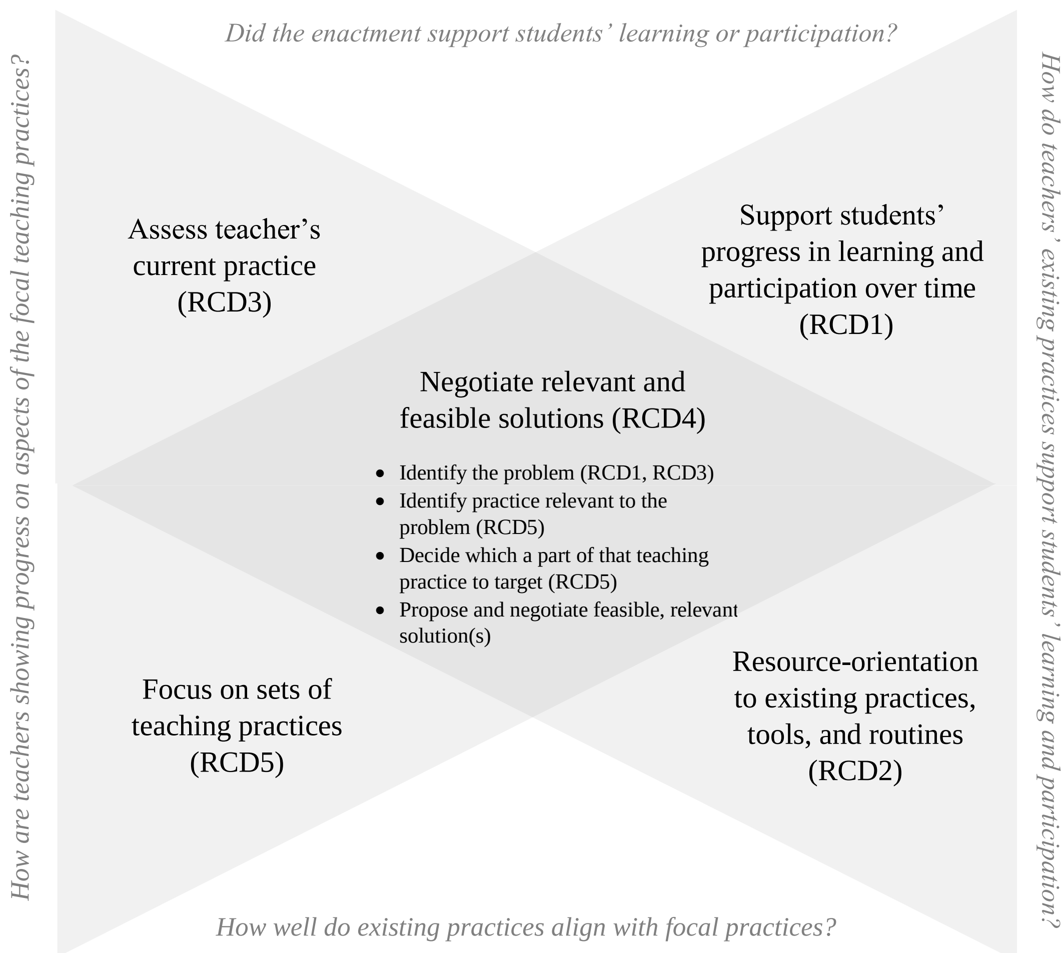


Figure 47. Revised conceptual framework: Dimensions of responsive coaching

Second, responsive coaches demonstrate a resource-oriented view of teachers' existing practice, identifying and recognizing the productive routines, tools, practices, and content knowledge the teacher is already using, and works with these resources (RCD2). In the context of the current study, this dimension supported teachers' experimentation in two ways. First, it opened opportunities to legitimize teachers' expertise and recognize the realities of their classroom and school contexts which supports risk-taking (Anderson, Feldman, & Minstrell, 2014; Knight, 2009; Mayer, Woulfin, & Warhol, 2014; Sztajn, Hackenberg, White, & Allexsaht-Snider, 2007). For example, when working with Ellie on her summarizing practice, she proposed using a KWL chart, which implied her familiarity with this tool. Instead of shutting down her bid, I used what I knew about KWL to determine how to use that tool productively within the summarizing practice. I recalled a similar tool, with key additions around evidence and science concepts (KLEWS), and countered with this version. From here, she began productively attempting and experimenting with the summarizing practice—she used the KLEWS tool across multiple lessons and two units, tinkering with how to structure it physically (i.e. changing column headings) and how to use it with multiple talk opportunities (i.e. when to have partner talk, writing time, and whole-class discussion). Until that point, I had not been successful with my attempts to help Ellie with the summarizing practice (e.g. the "abandoned chart" phase). It was not until I uncovered and worked from something familiar to her that we got traction and made forward progress in this practice. Furthermore, the coach identified teachers' existing practices, routines, and tools and, using knowledge and expertise with the focal teaching practices (RCD5), determined which parts of existing practice could be leveraged as on-ramps by making small changes to what was familiar. Making unfamiliar practices more familiar can help lower the teacher's perceived risk in trying-out a new practice, allowing for experimentation (Le

Fevre, 2014). In the data, this dimension overlapped with assessing teachers' current practices (RCD3), a focus on teaching practices (RCD5), and was useful knowledge when negotiating what to try next (RCD4).

Third, responsive coaches assess teachers' current practice, identifying strengths as well as areas to improve. These areas could be ones the teacher identifies and/or ones the coach notices. When coaches allow teachers to have some choice in what they work on, inquire into, and learn about, it is more likely that teachers will work to change their practice (Knight, 2004). In this study, when teachers identified and selected an area of their own practice to work on, they persisted with multiple cycles of experimentation and iteration. For example, when Ellie declared her interest with taking-up Henry's entry task routine, which overlapped with our modeling practice, we worked on this together for a few lessons, and then she continued on her own for the remainder of the year. Additionally, I assessed teachers' progress on our targeted teaching practices featured in the STEM Academy (RCD5). This helped to inform what I proposed in our negotiations around sand, using what I knew about existing practices (RCD2), and how we might go about working on an aspect of practice. For example, when I asked Ellie what she wanted to work on, she replied "awesome conversations." Using what I knew of her current discussion practice (i.e. high proportion of IRE exchanges, teacher-controlled, vocabulary-focused), I made suggestions to break these existing behaviors, like adding places for partner talk and co-planning open-ended discussion prompts so Ellie would be less likely to rely on her IRE habits. This dimension also related to supporting students' ongoing learning and participation (RCD1), namely looking at which students were supported by teachers' current practices and suggesting changes that support all students.

Fourth, responsive coaches prioritize addressing problems of practice in ways the teacher finds relevant and feasible, while simultaneously attending to a principled vision of high-quality teaching and learning. One way to make suggested changes more feasible is to take advantage of teachers' existing practices, routines, or tools (RCD2). This appeared to reduce risk, which in turn encouraged experimentation. Negotiating around relevance meant suggesting solutions the problem at-hand that are pertinent to that problem. Often, this overlapped with students' progress in learning and participation over time (RCD1), as focus was on improving students' learning opportunities. Both feasibility and relevance were considerations during the coach-teacher negotiations in co-planning what we might try next.

Fifth, responsive coaching focuses on a set of practices, rather than strategies or implementing a curriculum, as the focus of professional learning. A focus on a specific practice in professional development settings has been shown to support teachers' use of that practice in their classrooms (Desimone et al., 2002). This focus likely supported teachers' experimentation because practices can allow for flexible yet productive variations, compared with a focus on implementing a step-wise strategy. The main goal of experimenting with these practices was to provide better science learning opportunities for students; however, within coaching cycles, this focus on practices provided opportunities for teacher-coach sensemaking. Because practices can be decomposed in different ways into smaller, more manageable pieces, these practices offer multiple on-ramps for teachers to initially attempt the practice so this decomposition mitigates risk.

This framework does not include the kinds of activities coaches use with teachers. I analyzed the presence of these five dimensions during debriefing and co-planning activities, yet I surmise these dimensions would also be identifiable across coaching activities facilitated by a coach taking a responsive orientation to teacher learning.

Finally, to further specify language around responsive coaching, I clarify the conceptual distinction between *responding* to and *being responsive* to teachers' learning and their needs. Similar to coaches described in other studies, I deployed different approaches (e.g. taking a cognitive approach with Amanda in the opening exchanges of each debrief) and took up various roles (e.g. resource-provider role when I sent information to Ellie about the KLEWS chart), as needed, in our coaching interactions. This facility in shifting approaches and roles is something skilled coaches do in response to circumstances and changing needs and concerns of teachers (Cornett & Knight, 2009; Gallant & Gilham, 2014; Ippolito, 2010; Luebeck & Burroughs, 2016). However, *responding* to teachers' needs and concerns by adjusting approaches or roles is not sufficient to classify coaching as being *responsive* to teachers' learning. In choosing how to respond, responsive coaches use their principled vision of high-quality teaching and learning to inform their decision-making about which ideas, remarks, and concerns they notice, prioritize, and respond to during interactions with teachers. This means that a coach can be responsive while responding directly to a teacher's stated need, or a coach may be responsive while recasting or reframing the teachers' purported need in a way that addresses an aspect of the focal practice.

What responsive coaching means for addressing professional learning goals

Improving teachers' practice takes time, and this is no different for coaches taking a responsive stance. If anything, progress, at times, may be slower than with other coaching approaches (i.e. prescriptive, "Just do this."). Here, after the coach leaves, teachers who were told or showed what to do may revert to old practices. With responsive coaching, teachers and coaches jointly-negotiate problem spaces, taking time for professional sensemaking around focal practices and supporting student learning. In these negotiations, the onus is on the coach to negotiate this alignment to achieve mutual understanding in principled ways, which is why progress may be, at times, tentative. A responsive coach may also make strategic compromises to achieve other goals that are important but not wholly aligned with professional learning goals in that moment (i.e. teacher requests help planning for a science night). Such diversions may not help teachers make progress on professional learning goals, but do serve to continue to build relationships and attend to teachers' needs. Overall teachers made shifts in their practice in productive, yet measured ways. Given the intensity of this approach, I surmise there would be less reversion to old ways, with some aspects of the focal teaching practices persisting as part of their regular repertoire.

Also, responsive coaching could be seen an undisciplined approach to supporting teacher learning where coaches pursue whatever problems of practice teachers suggest. This view ignores the principled decision-making required in being *responsive* to, rather than *responding* to teachers' learning, and the role that a principled vision of high-quality teaching and learning plays in the coach's deciding which ideas, remarks, concerns to prioritize, and respond to during interactions with teachers, and where to set boundaries around what is professionally inquiry-worthy (or not) during coaching cycles.

Limitations

This study was set within larger system of coherent and sustained job-embedded professional development, the STEM Academy. Therefore, I cannot claim that responsive coaching, on its own, without the suite of other professional learning experiences would impact teacher learning in similar ways as was found here. Furthermore, I was the only coach involved in this analysis, which limits my claims about the list of five dimensions of responsive coaching.

Implications

There likely are coaches who, in practice, take a responsive orientation in their coaching, in ways defined in this paper—simultaneously balancing teachers' needs, existing practices, and expertise while attending to and working towards progress in collective professional learning goals. My findings have implications for instructional coaches who are charged with supporting teachers' improvements in practice who may find the language of the dimensions of responsive coaching useful in reflecting on, and naming parts of their own coaching as well as paying attention to where and how they make space for joint-negotiation in coaching conversations with teachers. More examples of the nature of coaching are needed, particularly in one-on-one settings, as these are characteristically different dynamics than with a group of teachers and one coach. Future studies could examine the conditions present during the negotiations in coaching conversations and when these negotiations serve as opportunities for coach learning, teacher learning, or joint learning.

Conclusion

I acknowledge the unique and robust professional learning model in this study limits my claims about how responsive coaching mediates changes in teachers' practice. I worked with three teachers, in a professional development model where coaching was just one component of many, sustained over time with an experienced instructional coach as a learning facilitator across these professional learning activities. Even with these optimum conditions, change was slow. Slow, but consequential. The progress these teachers made over a year may not be possible with coaching alone. It was evident from the data that instructional coaching complemented other forms of professional learning which, together, helped teachers both envision and experiment with responsive instructional practices. I have shown what is possible for non-specialist teachers, coached by an expert, to experiment practices that helped them be responsive to their students' science learning.

For districts considering adopting instructional coaching as a support for elementary teachers, I offer some considerations. Scheduling should allow for coaching to occur across consecutive lessons. This differs from coaching schedules where coaches pop-in for short visits and do one coaching cycle every one or two weeks. This infrequent schedule has a benefit that a coach can work with more teachers simultaneously and keeps elementary teachers accountable in teaching science on a weekly basis; however, it does not allow sufficient time for problem-solving around how to support students' learning over time. Also, I advise that coaches have time in their schedule to regularly visit other coaches and observe their coaching work with time to debrief and name the successes, tensions, and challenges of their work. Often experienced teachers become coaches with little, if any, training, particularly for science coaching. Regular times for coaches to meet and reflect on coaching and to observe others is critical for helping coaches improve.

This study adds to a small but growing literature around what we know about the nature of coaching. Additionally, it contributes examples of coaching in one-on-one interactions over time. I hope the five dimensions of responsive coaching are a useful to others who study coaching and offer these as a starting place for continued investigations into what responsiveness looks like in coaching setting.

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Appendix A

Additional examples of episodes coded by rigor and focus

Example 1: Low rigor, student focus

This episode was from Amanda’s class early in the sound unit (phenomenon: singer shattered a glass with his voice). Just prior to this episode students re-watched the clip of the phenomenon video to apply what they just learned in the activity about how we produce sounds (body system of parts, diaphragm, vocal cords, lungs) to explain how the singer made such a powerful sound with his voice. Several students raised their hands, Amanda called on Daurama.

This episode was coded as low rigor because the student shared stories without doing something with it, like making the relevant connection to the lesson or unit. This episode was coded as student-focused (STU) because the student shared her personal experiences and stories. In my role as the coach, I made some subtle moves to attempt to invite Daurama make connections to either the singer phenomenon or the lesson idea about how we produce sounds (line 9, 11-14) but these were not direct enough for Daurama to take them up.

Low rigor, student focused episode AV1007142-5 (3 mins)	**TMCs**
Amanda: Yes?	
Daurama: So, I was watching this TV show, right? So, okay this TV show Martin, right? And so, this girl and so...so so so, his girlfriend, so they had these glasses, right?	
Amanda: Like glasses, like spectacles? *(Moves finger in circles over her eyes.)*	
Daurama: No, like glasses. Cups. And then she said that his glasses were so cheap that he probably bought them from the gas station. And, so, and then he was like, ‘No, I didn't,’ and so she backed up and was like, 'No I didn't,’ and she started to scream and they shattered.	**Follow-up (B)**
Coach: But, she didn't make the same sound as the singer did, did she?	
Daurama: No, she made like an opera voice**.**	
Coach: Hahaha, okay. Oh wait, I think she *(pointing to another student)* **had a question.** *(To student)* **Do you want me to ask it?** *(Nods)* **So, I just heard a question about like doesn't it depend on what level she would be at with her singing? What the notes would be or what level of volume?**	**Follow-up (B)**
Daurama: The pitch.	
Coach: Was she loud?	
Daurama: Yeah	
Coach: And then she probably had a certain note, and it's also TV so she could have been overly dramatic and it could be a special effect but I'm pretty sure there's some science behind it too and I know opera singers can shatter glasses, too.	
Daurama: I was watching America's Got Talent and there was these two girls and they went up on stage, right? And they start singing with the microphone and hitting high notes and stuff and it sounded like when I was in 3rd grade we had music class and we were listening to this weird music and it was this opera music and Mr. Bird played it. And then--And then, he was making us dance and run around with these little scarves and we were dancing and we were playing music and-- The one I did with the green scarves, those girls sang some opera music, it was so hilarious. They sounded so weird. Dude, if you were there.	
Students erupt in chatter.	
Amanda: *(Raised her hand, finger on lips)* **Okay I love the connections you guys are making. Shh... Anything else?** *(Called on another student)*	

Example 2: Medium rigor, merged focus

This episode comes from Henry's class during the forces unit (phenomenon: skateboard failed jump). Prior to this episode, students worked silently to draw and write about the entry task prompt, then had time to partner talk about their ideas (pre-discussion tasks, E). Students had charts from prior activities posted on the front board to refer to and use (referent D/F). Henry asked students to explain why the skateboarder fell (open-ended prompt, A) paying special attention to using arrows to represent forces story.

This episode was rated as medium rigor because there the student includes some causal mechanisms or conditions under which the event would happen such as the skateboarder ("wasn't balanced," "right position," "feet weren't on the skateboard").

This episode is also an example of a merged focus (MER) because it contained student language (balanced, stiffer, in the right position) alongside science terms (kinetic energy, potential energy, gravity) and the student used both to explain the event.

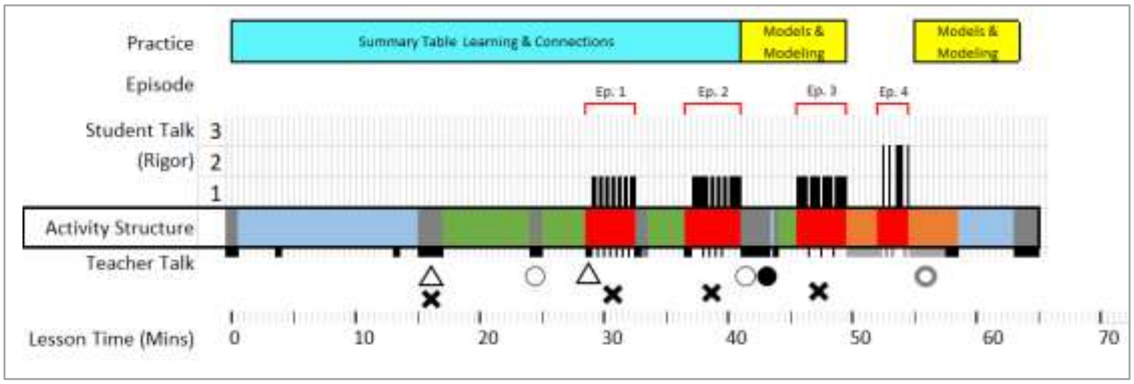
In this episode, Henry asked Naadifa to share her response to her entry task. She displayed it under the document camera so students could see where her arrows, labels, and sentences.

Medium rigor, merged focus episode (HP112014B-2) 2 mins	**TMCs**
Naadifa: *(Displayed her work under the document camera)* So, what I drew was the skateboarder and I drew (inaudible phrase) And the big arrow shows him going up and the small arrow shows like gravity going down. Because like when he is jumping his body is stiffer and he was in the right position, he was successful. And when, um he— It didn't work, his feet weren't on the skateboard, and it the skateboard wasn't balanced like with his body, he was not balanced and not in the right position.	[Entry task: Open-ended prompt (A), referent (D/F), pre-discussion task, E)]
Students applaud.	
Henry: So, Naadifa, you also talked about *(her labels)* **kinetic energy, gravity, potential energy. Can you talk a little bit more about those? And maybe those are something that your classmates remember doing but now that they see it, it might be something they can add to their model in the coming activity. So, can you talk a little bit more about those and why you put them on, okay?**	**Follow-up (B)**
Naadifa: Um, they're up there because they are sort of (inaudible phrase, buzzing). There's kinetic energy because the skateboarder-- uh, he was moving. There's potential energy because um -- There was potential energy because the skateboarder was moving. And that the gravity was pushing him down and so it (inaudible phrase).	
Students applaud again. Henry transitions to next task.	

Appendix B

Barcode representations for each lesson

Components of a barcode representation



Practice

= Summary Table (Observe, Learn, or Connect)
= Developing and Using Models
= Creating or Revising Lists of Student Ideas
(= Just-in-time Instruction)

Episode

= about a particular idea; stayed on topic/idea

Student Talk (Rigor)

Height of student talk bars represent level of rigor of whole-class talk episode

1 = descriptions, observations
2 = partial sense-making, pairing observation with inference
3 = connecting, justifying with evidence, building ideas together

Length of Student or Teacher Talk

| = Short contribution, one-word, or short phrase
= Long phrase, full statement
= Longer contribution, multiple sentences

*If **black**, contribution from student or teacher.*

If gray, contribution from instructional coach.

Activity Structure

= Whole class discussion
= Partner/Sm Grp talk
= Independent work
= Getting information
= Teacher directions
= Hands-on activity

Symbols about talk or ideas

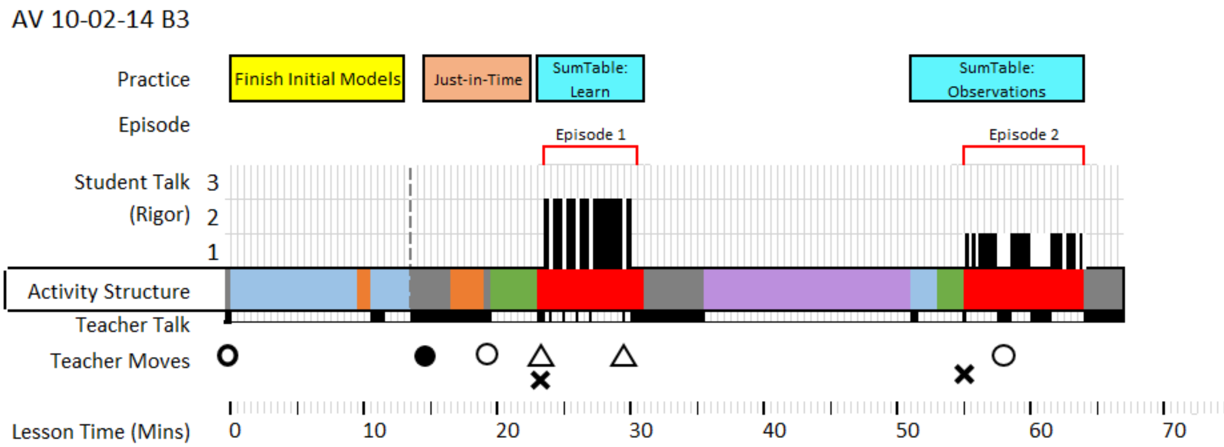
Note: Indicates teacher-only moves

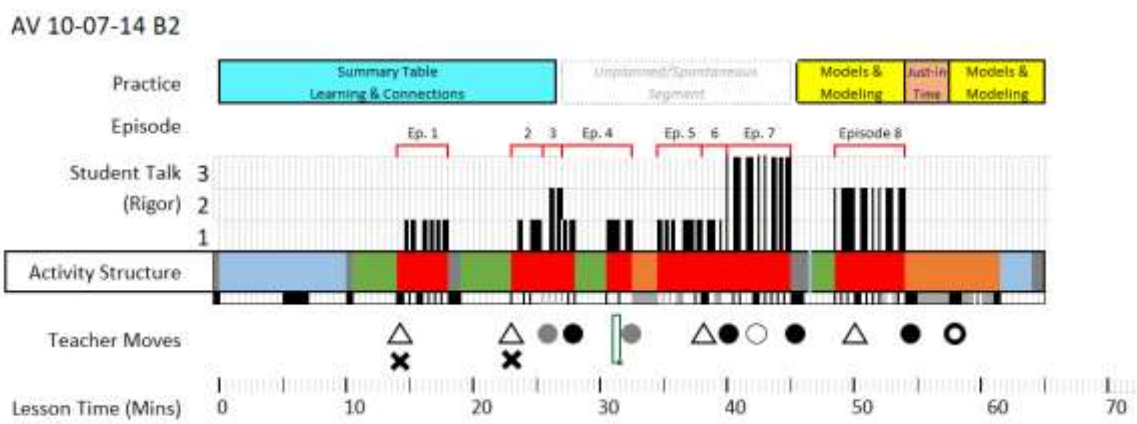
△ = culture of talk, generic norms
▲ = meta-talk
✖ = curtailing move
○ = general culture of ideas
o = non-specific student idea cited
● = specific student idea cited
↺ = student idea tossed to class
= recap move of what student said

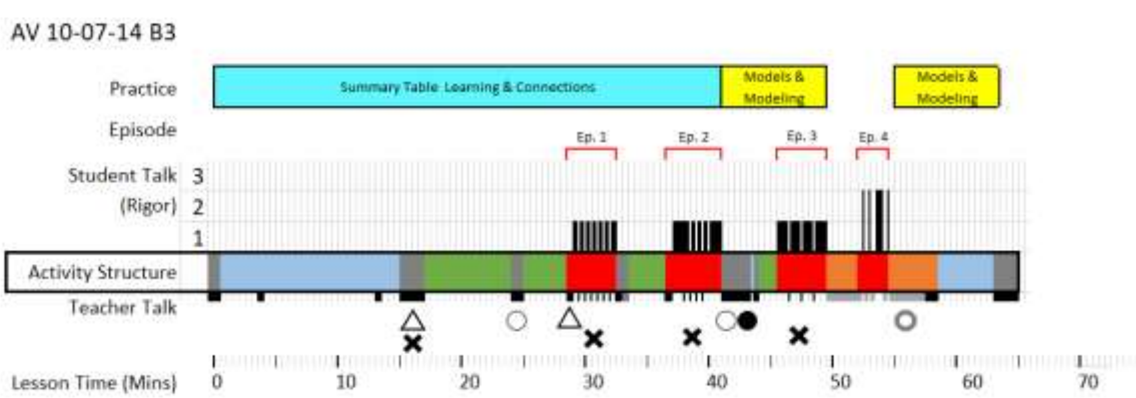
Timeline

Each vertical gray line is 30 seconds with tick marks every 5 minutes and labels every 10 minutes to gauge approximate lengths of activity structures and overall duration of the lesson.

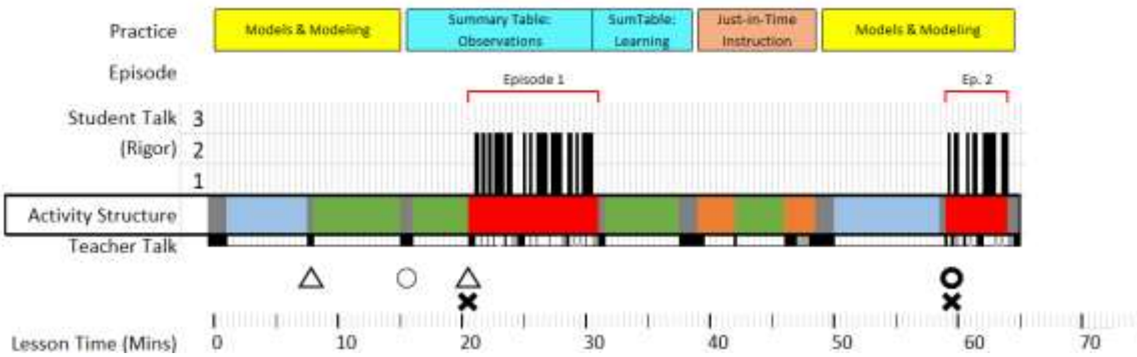
11 Lessons from Amanda's Classroom, Grade 6







AV 10-14-14 B2



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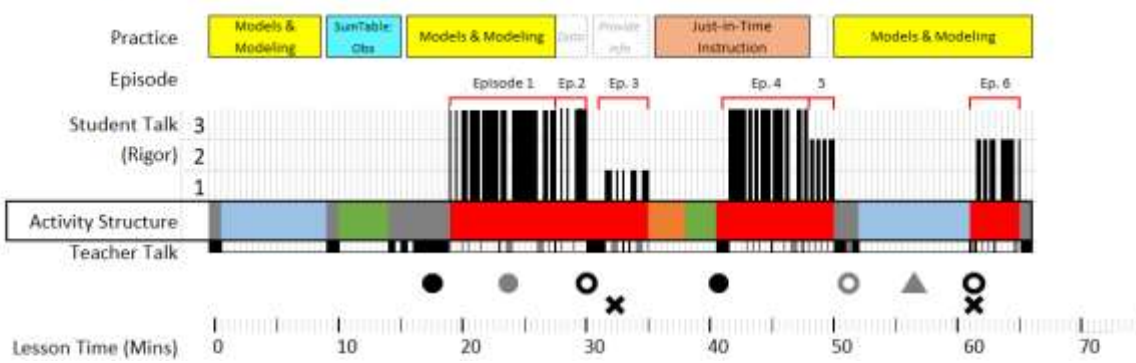
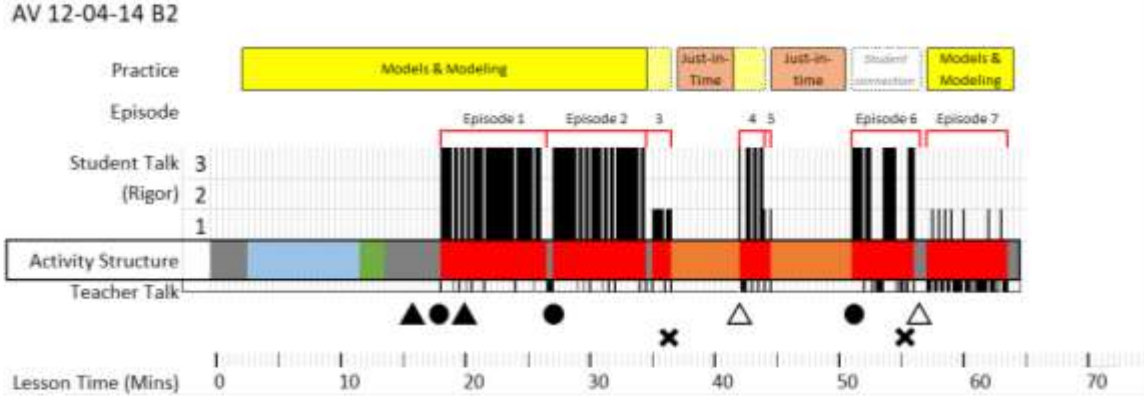
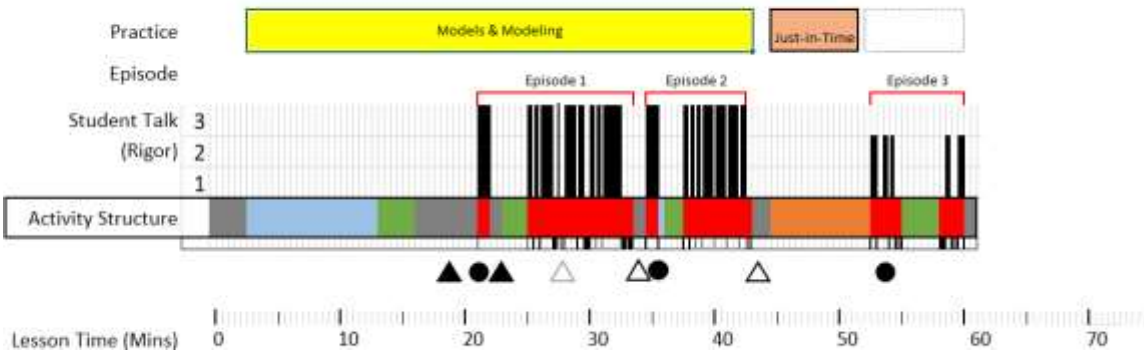


AV 12-04-14 B2



AV 12-04-14 B3



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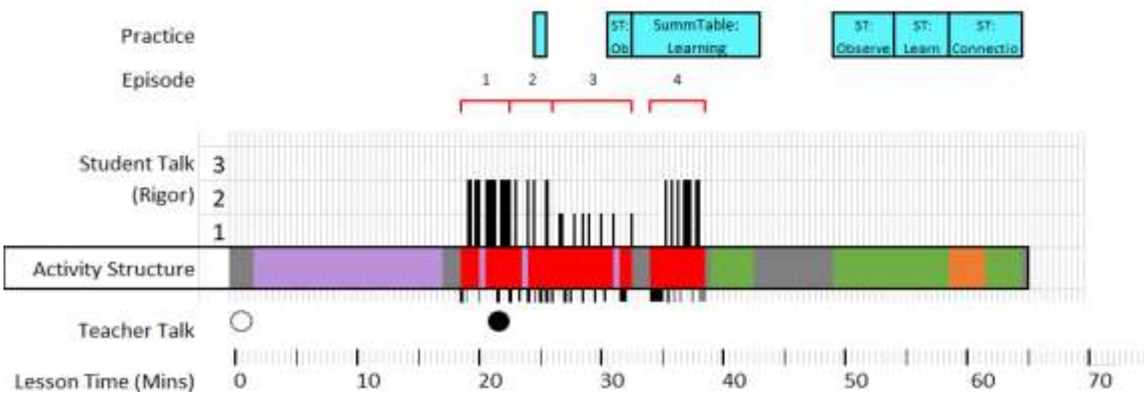

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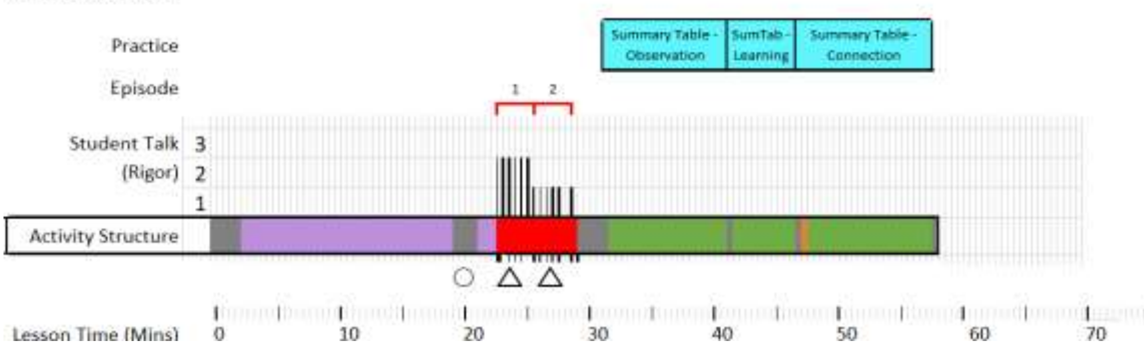
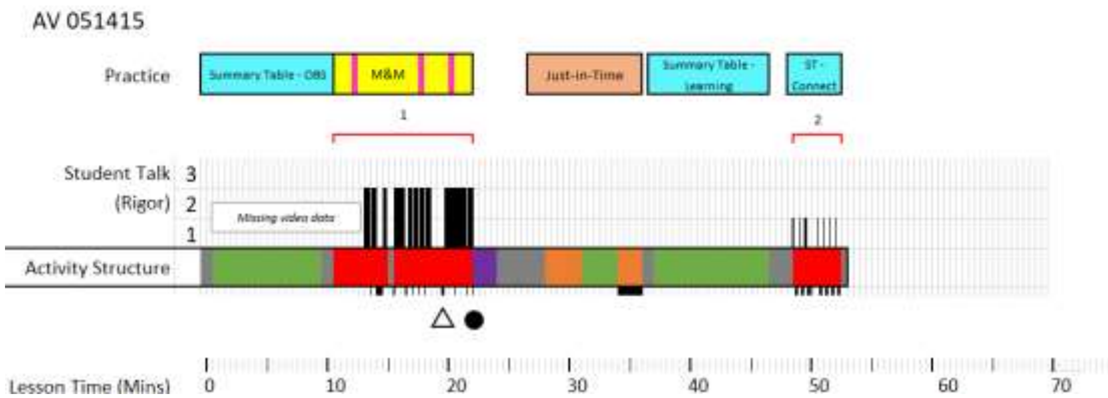
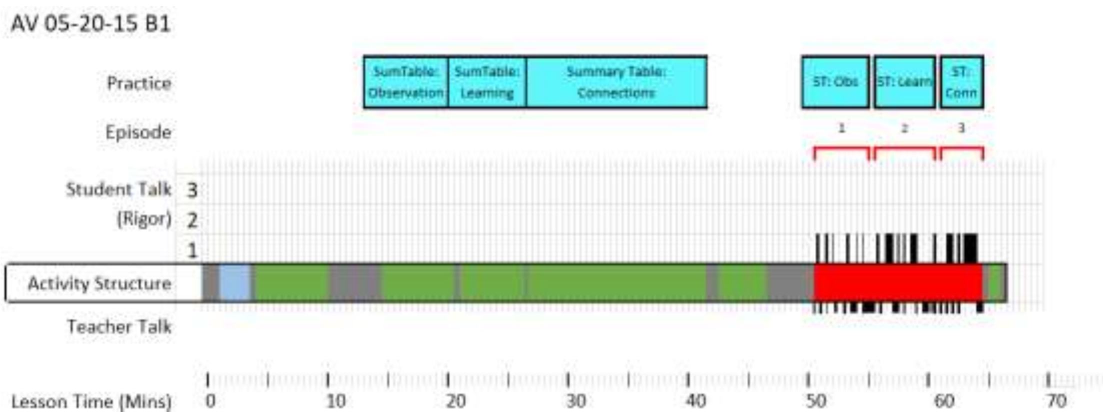
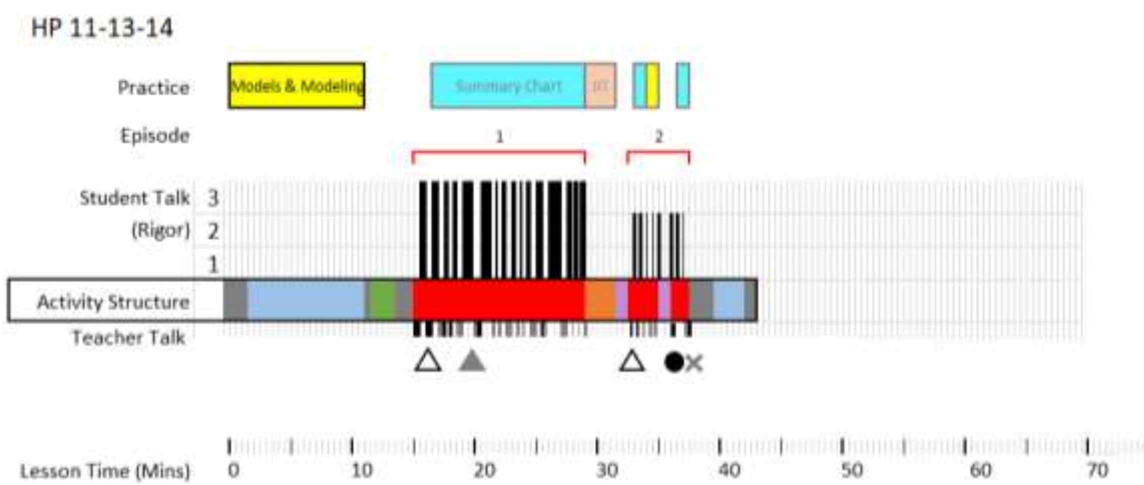






10 Lessons from Henry's Classroom, Grade 5



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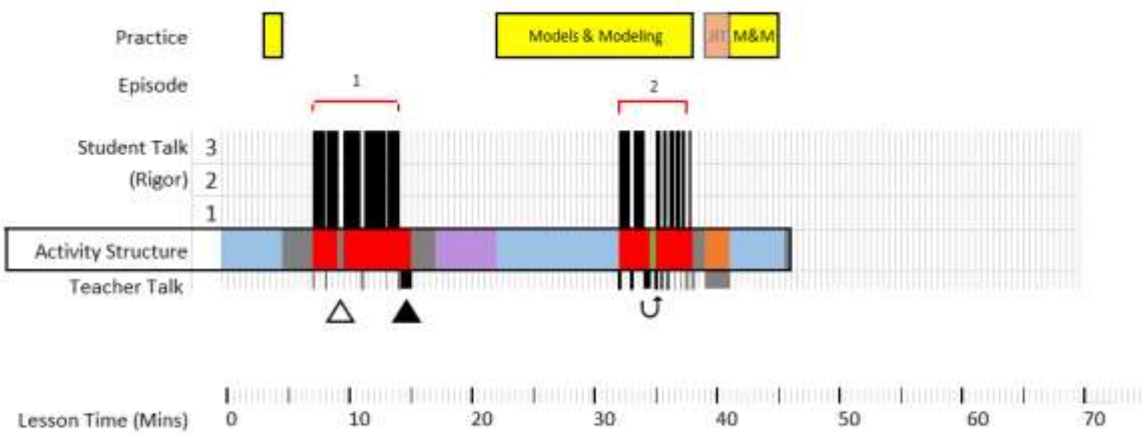

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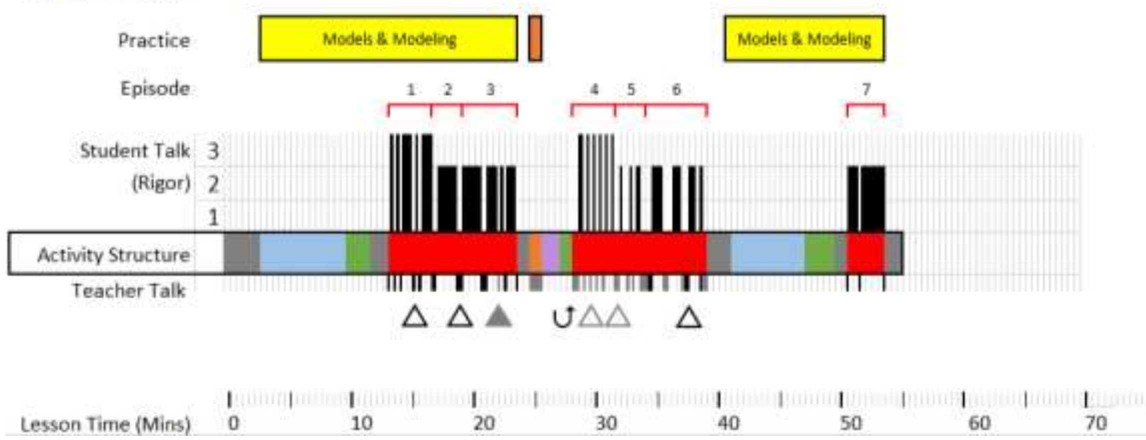

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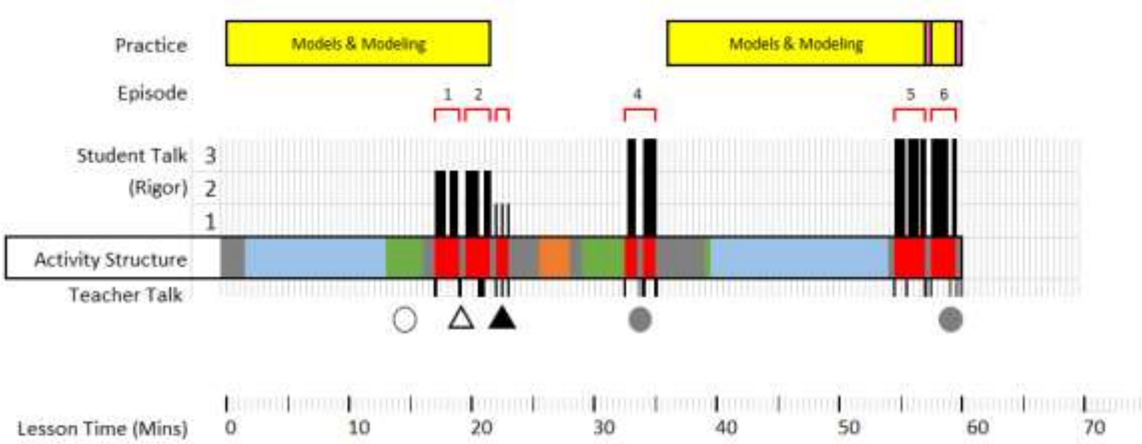

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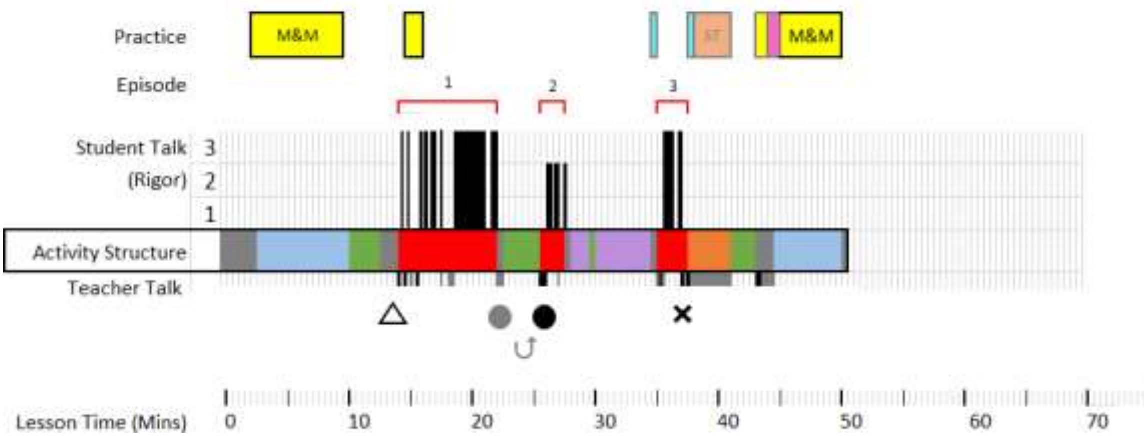

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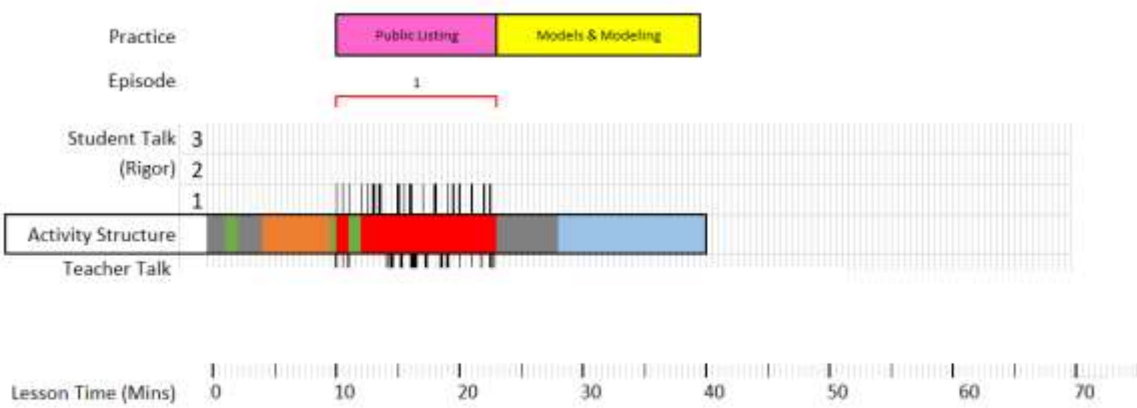

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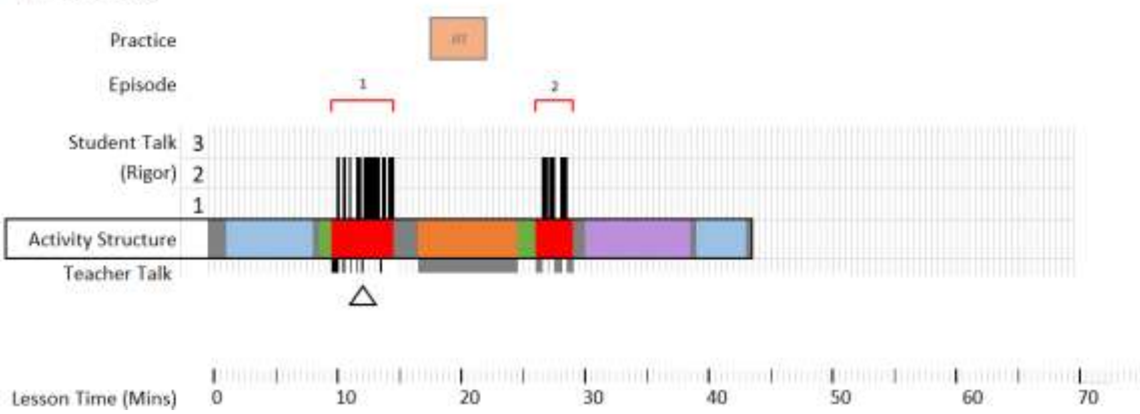

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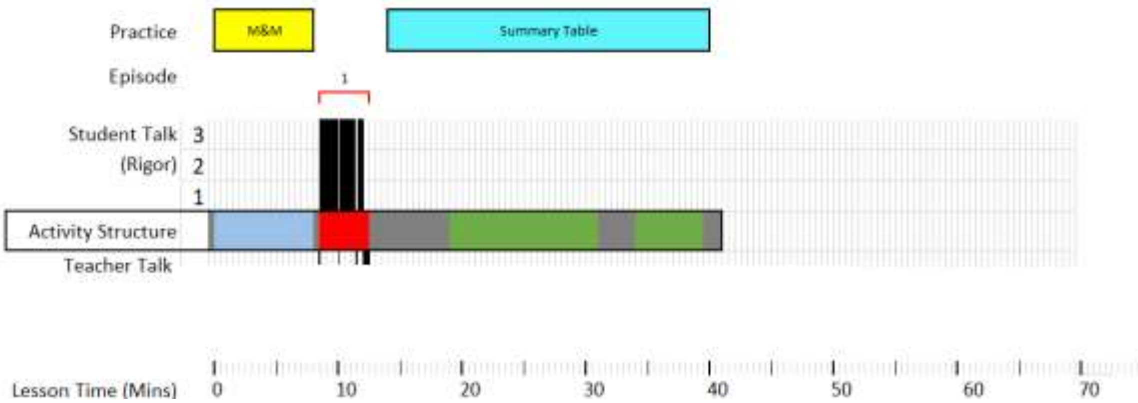

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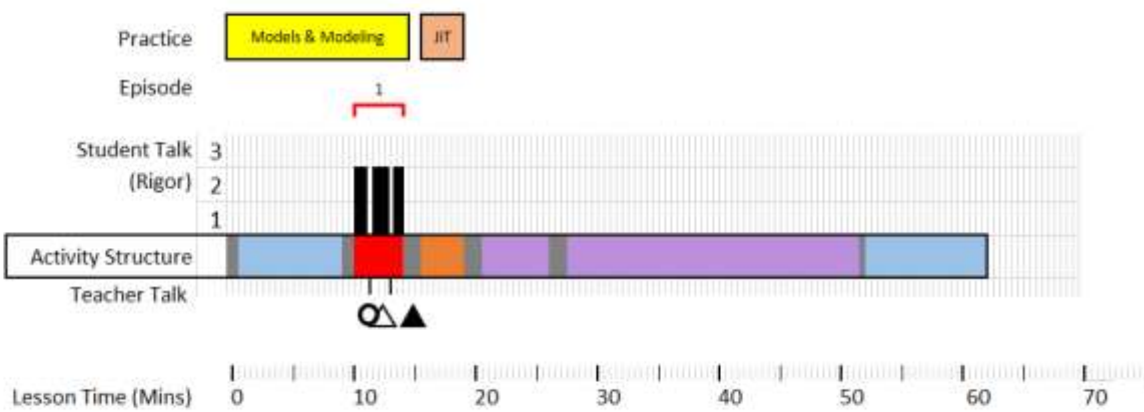

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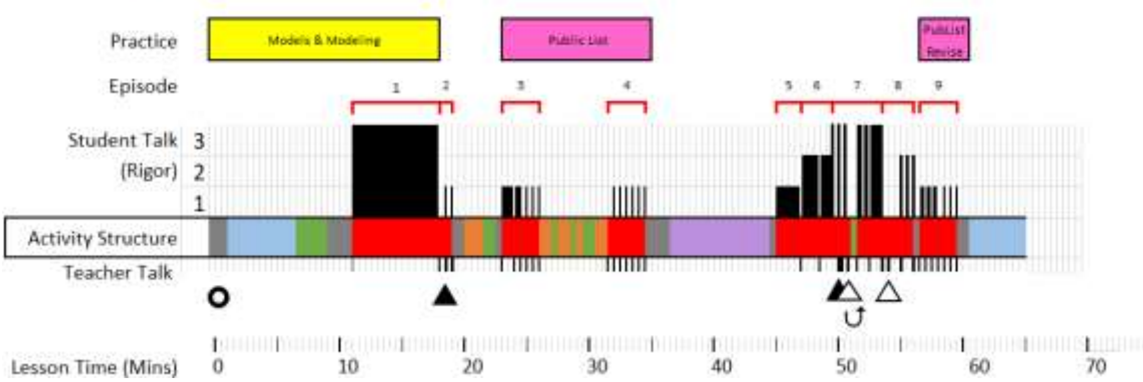
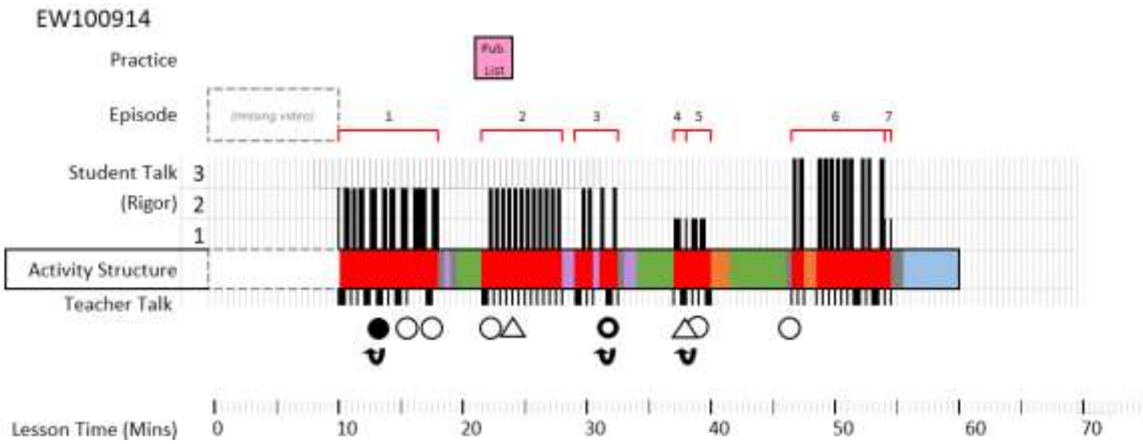
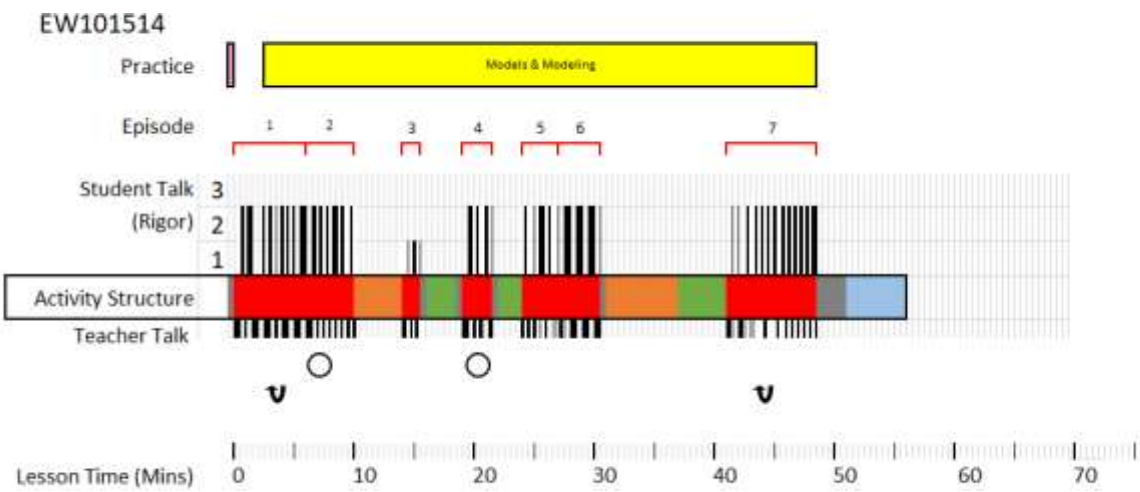
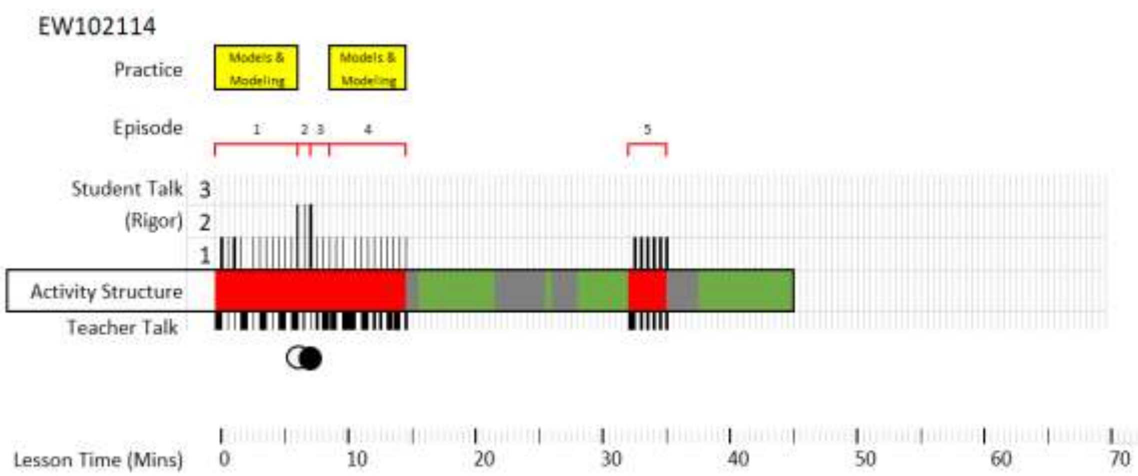


9 Lessons from Ellie's Classroom, Grade 5







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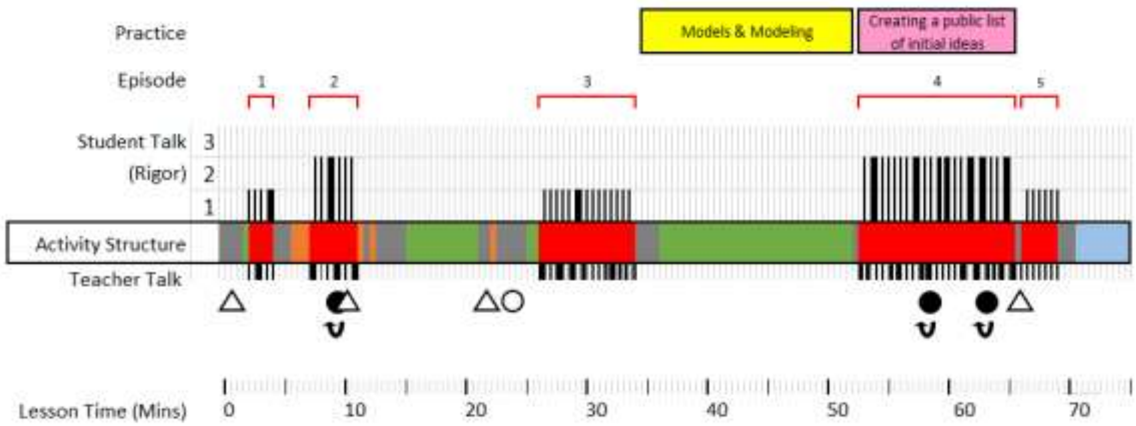

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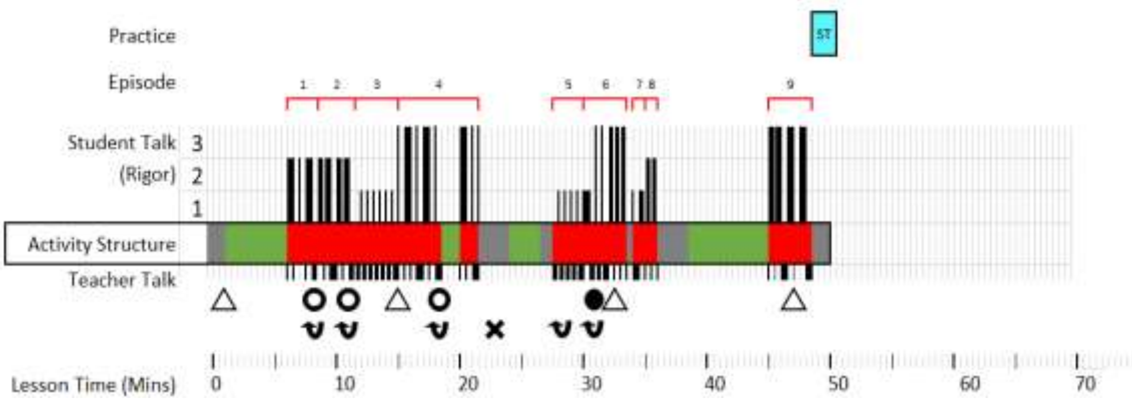

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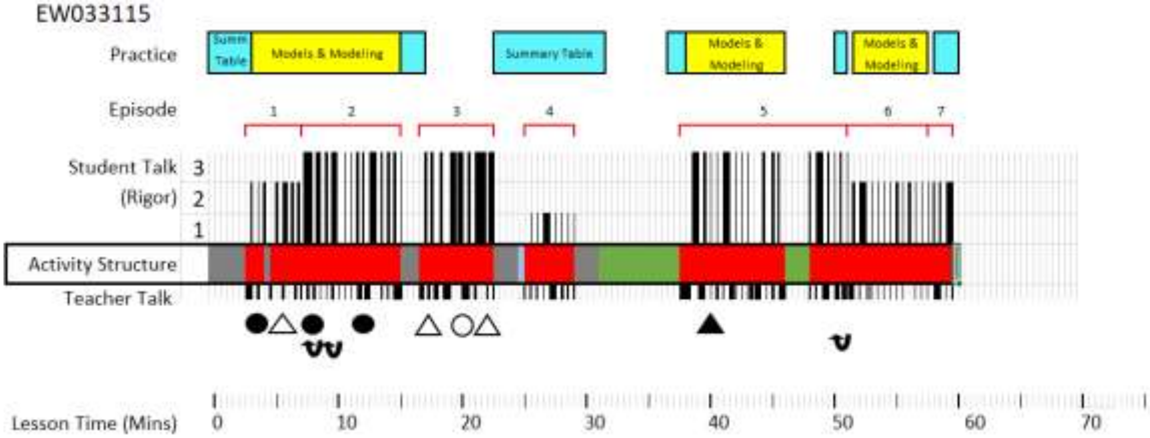

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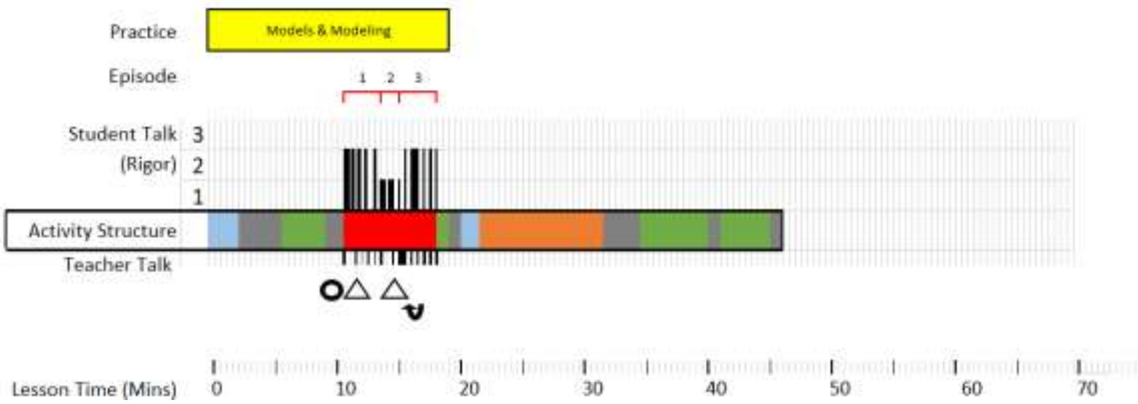

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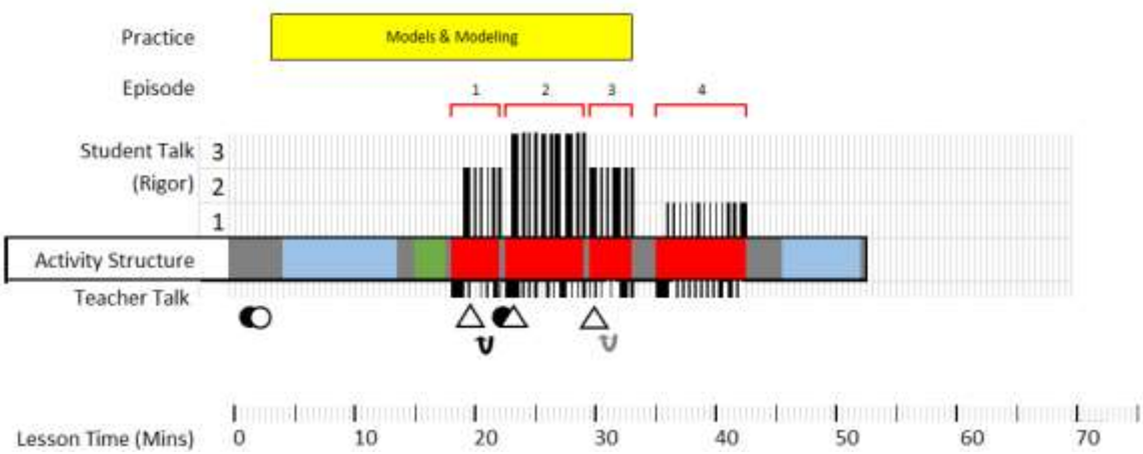

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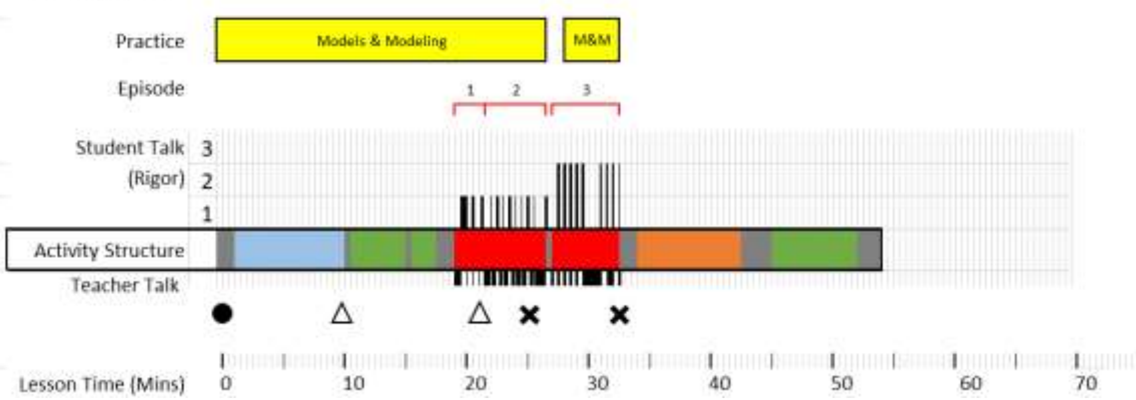


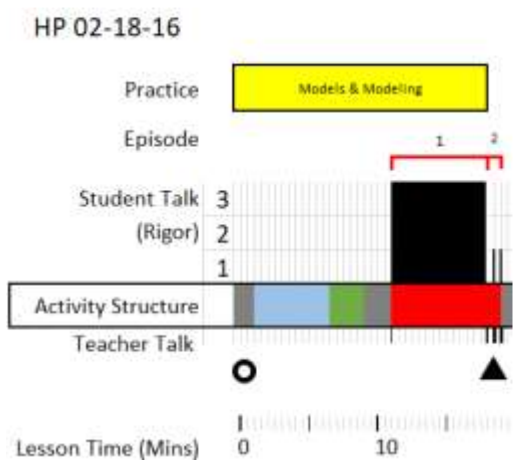
Appendix C

Henry's Entry Task Routine

I include a description of Henry's entry task routine because: 1) it was an essential routine to access students' ideas and consistently provided supported opportunities for rigorous talk; 2) it was featured in a studio day, which other teachers observed and many of whom, including Ellie, tried out later in the year.

Henry employed an entry task routine at the start of his lessons. First, he developed this routine in math lessons, then, with my coaching support, we adapted it for his science lessons. The unique quality of this routine was how consistently it supported higher rigor whole-class talk between students with little or no teacher intervention. Also, Henry often selected a scenario for students to model-to-explain, so in his class, it provided consisted opportunities to compare models and explanations.

Look at the barcode section below in minutes 0-18. The sequence for this routine included: the teacher providing introduction to the prompt which was projected on the front board (gray), several minutes of silent, independent work time to write and draw (light blue), a few minutes to turn-and-talk to a partner (green), transition for everyone move the front of the room (gray) and then student-led whole-class discussion about that students' response (red) projected from the document camera. Out of the 10 lessons analyzed in this study, 8 of them had this entry task sequence. It was also observed in other coaching visits that were not included in the barcode analysis.



Barcode from Lesson HP021816 cropped to the entry-task routine.

This particular entry task example began with an open-ended prompt and time for students to work independently by drawing and writing in their science notebook. This particular prompt was a scenario that Henry devised in hopes that students would use to connect to a recent lab activity and use data from that lab as evidence for their claims (coaching notes, 02-18-16). Photo below (left side) shows the prompt: *"Sanj and Mario were debating about the mold that grew on their potatoes after it was left in a bag for a week. Sanj believe that the dirtier the potato, the more mold it will have. Mario believes that the cleaner the potato, the more mold it will have."* Henry based this scenario on a debate that was starting up between students in small group conversations during the prior lesson about dirty versus clean hands (coaching notes, 02-

18-16). The data table on the whiteboard (Photo, right side) has data from the prior lab activity. The “nasty meter” is a scale of 1-4 to quantify the visual assessment of some potato slices which served as petri dishes about how much growth covered the slices. After Henry read the prompt out loud and gave brief directions, students had about five minutes of silent, independent time to think, write, and draw to respond in their science notebooks.

As students worked, Henry circulated looking at student work to select one or two students who would start-off discussion by showing and explaining their thinking. For this episode, Henry selected Student A because she made connections between the data in the experiment, the entry task prompt, and tied it back to the unit phenomenon story (coaching notes, 02-18-16).

For this whole-class discussion episode, all students came to the gathering area and sat on the floor to see the screen while Student A stood at the document camera with her notebook projected. Her partner sits next to her in the teacher’s chair. Below is a photo of the arrangement of people. From this physical location, Student A served as the initial presenter (lines 1-13) and then facilitator for this whole-class discussion of the entry task prompt, mostly by serving as turn-allocator (lines 18, 25, and 35) and also responding to others’ contributions (lines 34-35 and 41-42). Henry stands off to the side, physically distancing himself from the class of students who are seated on the floor. He stands near the ‘Habits of Mind’ posters which he uses to tag particular talk moves during conversations silently. In contrast to more traditional whole-class discussions that often feature the teacher to varying degrees, Henry does not participate verbally at all in this episode. After this episode, Henry facilitated the second whole-class episode to facilitate an explicit conversation to have students name and provide examples of what talk moves and what was said that constituted “making connections” or “justifying with evidence” as examples.

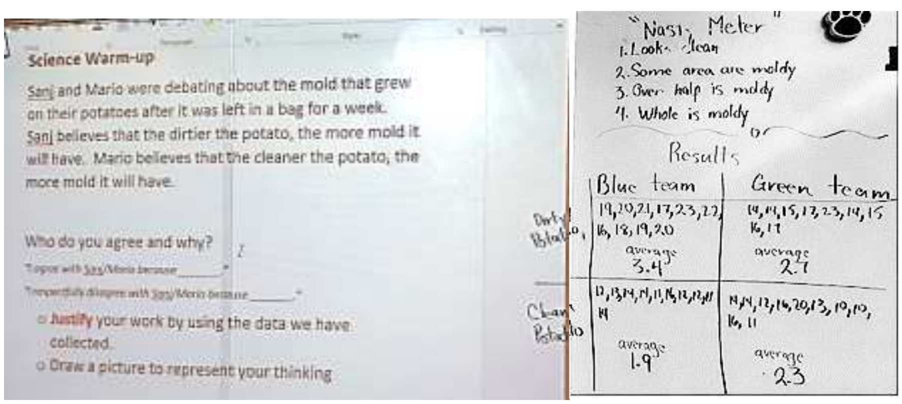


Photo of the entry task prompt with language scaffold and results table from prior lab.

Student arrangement during the student-facilitated, whole-class discussion.

Student-facilitated, whole-class discussion episode

HP021816-1 from 10:50-15:00

Student A: *(Displayed her notebook under the document camera to project her work)* So what I did was I - I agree with Sanj because much like-- Cuz like what we did with our experiment with the potatoes is I dirtied our hands and then we touched the potato and then a week later uh uh our potatoes got mold and our dirty potato got moldy and then the same things with Sanj and Mario's potato they got mold, the dirty potato, they left it, and it got mold. And I kinda get like the chicken cuz the chicken *(HP marks "connections" talk moves poster with a sticky note)* the chicken was sitting by the window and on a sunny day *(referring to unit phenomenon story)* and when you see the sun you can see the little dirt coming down and the dirt was like shining on the chicken and un there was just something on it like dirt on the chicken and [Mr. Henry] ate it *(referring to unit phenomenon story)* and he got sick and then side effects happened. Yeah. *(3 second pause)*

Student B: I agree with you, but I respectfully disagree with you because I agree how—That, um, that, um Sanj and Mario, I agree with Sanj and Mario because um the clean potato it got mold on it and the clean potato could still get mold because it's been touched.

Student A: [Student C]?

Student C: Um, I agree with um both of them because like on the clean one we, um, we had we had like for like some of the potatoes were moldy and for both classes some of the potatoes were moldy and there was 3s and 4s on the dirty potatoes *(pointing to data chart with 'nastimeter' scale to quantify growth)* so I think like maybe the hand sanitizer could affect the clean potato or something.

Student A: [Student D]?

Student D: I'd like to add on to what [Student C] said because both of them are correct because it just depends because, the dirt will create bacteria which will make mold on the dirty potato and then the hand sanitizer would affect the clean potato cuz it's not used to the thing the hand sanitizer is made of on the potato

Student E: I'd like to add on with [Student D] because on the potato like you read the ingredients for the hand sanitizer it affected the potato to cause mold -cause mold

Student F: I'd like to add on to [Student E] because I think hand sanitizer is (inaudible)

Student A: Yeah it had chemicals like they affected the potato and the potato got mold? I don't know. [Student C]?

Student C: I think there are all 3 like the bread, the potato, and the chicken are like *(Student A raises her hand enthusiastically)* like the bread got germs from the (inaudible short phrase), the potato got germs from our hands, and then the chicken um the chicken got, um, the salmonella, the salmonella germs from um outside from eating like the grass and stuff.

Student A: Now I agree with [Student B], [Student C], [Student D], [Student E] now I do because the clean potato was dirty and they both were dirty.

Student B: Uh I agree with you.