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EXPLORING THE TEACHER-STORYLINE RELATIONSHIP: CURRICULAR DESIGN AND ENACTMENT FOR COHERENCE FROM THE STUDENT PERSPECTIVE

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Abstract

Exploring the teacher-storyline relationship:

Curricular design and enactment for coherence from the student perspective

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Recent K-12 science reforms necessitate a shift in curriculum and instruction to support coherence from the students' perspective. This coherence emerges when students see their science work as addressing and making progress on their questions and problems. Storyline curricular units afford student coherence, but teachers need support to craft coherent instruction from storyline materials. This three-paper dissertation involved research into one teacher's storyline design work.

The first empirical paper explores how one expert teacher interpreted the storyline materials as he planned for enactment. I used interaction and thematic analysis to identify key sources of tension that the teacher engaged with as he made sense of the storyline materials for epistemic agency. Three key sources of tension were: curricular coherence and student coherence-seeking; equitable participation and incremental building of science ideas; and singular or different forms of epistemic agency in discussions. Over time, the teacher grappled more deeply with these tensions and learned to leverage them to share epistemic agency with students.

The second empirical paper documents how the same expert teacher designed instruction during enactment as students' sensemaking diverged from the storyline plans. I engaged in interaction analysis to identify and describe particular episodes of storyline

activity where the teacher shared epistemic agency with students in these divergences. The teacher engaged in principled improvisation related to the students' interactive role, the science ideas they raised, and the experimental errors they experienced. Each episode involved the teacher's efforts to work with students' divergences with an eye toward leveraging the storyline designs to share epistemic agency.

The third paper, which is conceptual, provides an initial image of the Teacher-Storyline relationship. This relationship involves the teacher's use of storyline materials to design and enact instruction with the goal to be coherent for students. The relationship concerns the teacher, the storyline materials, the participatory interactions between the two, and the subsequent planned and enacted storyline that is an outgrowth of this relationship. It has implications for 'opening up' curricular materials and for designing curriculum-based professional learning.

“Knowledge does not keep any better than fish. You may be dealing with knowledge of the old species, with some old truth; but somehow it must come to the students, as it were, just drawn out of the sea.”

― Alfred North Whitehead

“With my ears to the ground, listening to my students, my eyes are focused on the mathematical horizon.”

—Deborah Loewenberg Ball

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Section I

Introduction

The storyline approach offers a promising path to engaging students as powerful science knowers and doers because this approach supports teaching and learning that is coherent from the students' perspective (Reiser, Novak, & Fumagalli, 2015; Reiser, Novak, & McGill, 2017). This coherence arises when the classroom community sees their science work as addressing their questions and problems, rather than following the directions of the teacher or curriculum (Reiser, Novak, McGill, & Penuel, 2021). In general, a storyline is "a classroom unit designed with a trajectory from questions to investigations to ideas in which students are partners in developing and managing the knowledge building" (p.9, Reiser, et al., 2021). To facilitate a storyline in partnership with students, the teacher needs to adopt new instructional approaches and make intentional efforts to position students with epistemic agency as they seek coherence in the storyline (Ko & Krist, 2019; Hammer & Sikorski, 2017). Epistemic agency refers to *students being positioned with, perceiving, and acting on, opportunities to shape the knowledge-building work in classroom activity* (Miller et al., 2018).

Teachers require explicit backing from researchers and curriculum developers in their efforts to support students' epistemic agency in storyline units (Sikorski & Hammer, 2017: Manz & Suarez, 2018). Particularly, teachers need additional support to navigate and respond to students' emergent sensemaking within the enactment of storyline materials (Manz, 2015). Teachers must be able to support students' efforts to navigate their own arc of inquiry as they progress through the storyline (Reiser, Novak, & McGill, 2017). This emergent navigation involves responsive adaptations in planning for enactment, as well as improvisation in the midst of instruction (Drake, 2002; Heaton, 2000). These instructional decisions directly affect the epistemic goals, knowledge-building processes, and roles that students take up in the science classroom (Kang, Windschitl, Stroupe, & Thompson, 2016). This perspective on teaching with storylines points to an understanding of the teacher's work as a process of design (Remillard, 2005; Brown, 2009). The teacher engages in design-work when interpreting, planning, and enacting storyline materials to support coherence and students' epistemic agency (Ko & Krist, 2019). While it is important for teachers to consider students' epistemic agency in all design work, some key activities and lessons are particularly important because these learning experiences position students to powerfully shape the development and management of knowledge-building in the storyline (Reiser et al., 2021; Sikorski, 2015). It is vital that teachers recognize and design for these key learning experiences with the explicit goal of supporting students' epistemic agency as they seek coherence in the context of the storyline.

Lessons that feature whole group discussions are important epistemic levers because these lessons serve as one of the main venues for collective sensemaking in the storyline (Lowell, Cherbow, & McNeill, in review). These discussion-based lessons help students to share their ideas, communicate with one another, and engage in purposeful efforts to co-construct the storyline with the teacher. This three-paper dissertation involves the research of one teacher's curricular design work in a storyline unit for discussion-focused lessons. In what follows, I will first contextualize my dissertation within the larger field of science education by reviewing four areas of research that broadly ground all three of my papers (Section I). I will then provide a brief overview of each section of my dissertation before turning to the content of my three papers and my conclusion (Sections II-V).

Theoretical Background

The first area of the theoretical framework focuses on how I define *epistemic agency* and how I characterize the process of sharing epistemic agency with students in science learning. Second, I turn to *teaching for epistemic agency*, in which I articulate a form of emergent science instruction where teachers take up students' ideas as productive seeds to support their epistemic growth and conceptual understanding. Third, I discuss the *use of curriculum materials in teaching for epistemic agency*. This section focuses on how curriculum materials can serve as a powerful mechanism to support teachers to share epistemic agency with students in their science learning. I also characterize the structural barriers in schooling that make curricular enactment for epistemic agency difficult. Fourth, I turn to the *storyline approach to curriculum and instruction.* I highlight this approach to curriculum and explain how the coherent design of storylines supports teachers to share epistemic agency with students (Reiser, Novak, & McGill, 2017). Further, I discuss how the whole group discussions within these storylines are epistemically significant activities that can serve as productive levers to share epistemic agency with students. I then conclude this section by explaining how situated and responsive professional learning can support teachers' understanding and enactment of storylines for epistemic agency.

Epistemic agency

In education research, the term epistemic agency was first introduced by Scardamalia and Bereiter (1991, 2006) in their research on knowledge-building communities. In such communities, students were positioned to shape, evaluate, and build knowledge in the classroom (Scardamelia, 2002). This initial characterization highlighted that epistemic agency is not a trait of an individual, but rather an emergent characteristic of a group to make progress on a shared knowledge object (Damşa et al., 2010). I follow this initial characterization and do not conceive of epistemic agency as a binary property that one either has or does not have. Instead, I view epistemic agency as a dynamic and multidimensional construct that is negotiated through classroom interaction (Miller et al., 2018).

As such, I understand students' agency in classrooms as the ways in which students act or refrain to act, and the ways in which their actions contribute to the joint actions of the group (Gresalfi, Martin, Hand, & Greeno, 2009). I use the modifier 'epistemic' to highlight students' actions or inaction that are consequential to shaping, evaluating, and constructing a shared knowledge object (Ko & Krist, 2019). This notion of epistemic agency does not, however, account for the specific forms of agency made available to particular actors in particular settings. The structures for participation in the classroom community afford and constrain students' goals and behaviors (Gresalfi et al., 2009; Hand, 2012). Further, these community structures significantly impact students' perceptions of themselves as agents in the classroom (Holland, Lachicotte, Skinner, & Cain, 1998). Therefore, following Arnold & Clark (2014), I understand agency not only in terms of students' position in the classroom, but also in how they perceive that position. As a result, I define epistemic agency as *students being positioned with, perceiving, and acting on, opportunities to shape the knowledge-building work in classroom activity.*

Traditionally, power structures in K-12 science classrooms assign epistemic agency to the teacher rather than students (Apple, 2013; Varelas, Settlage, & Mensah, 2015). When science teachers retain this epistemic agency in instruction, there are few opportunities for students to be collaborators in the co-construction of knowledge (Stroupe, 2014). The positioning of students with epistemic agency requires an intentional redistribution of power (Carlone, Johnson, & Scott, 2015). For example, Hand (2012) showed that a teacher could redistribute power by opening up dialogic spaces for students to shape the construction of a shared knowledge object. This example demonstrates an effort to share epistemic agency with students in their learning. I will use this concept of 'sharing epistemic agency' (Damşa et al., 2010; Zivic et al., 2018) to describe the shift away from the current epistemic and power structures in K-12 schooling and toward an active partnership between teacher and students in knowledge-building (Reiser et al., 2021). In classroom activity, this sharing of epistemic agency requires continual negotiation between the teacher and students around the development of shared knowledge objects (e.g. Colley & Windschitl, 2016; Manz & Suarez, 2018; Ko & Krist, 2019).

Teaching for epistemic agency

Ambitious instruction involves setting intellectually meaningful learning goals, and then facilitating students' progress on these goals through interactions with each other, the teacher, and the material world (Lampert, 2010; Kang, et al., 2016). The moment-to-moment work involved in such ambitious teaching requires that the teacher be responsive to students in a manner that positions their ideas as resources in the development of conceptual understandings (Colley & Windschitl, 2016; Russ & Luna, 2013). Responsiveness requires teachers to occupy a pedagogical stance where they are reflective, engaged in practical inquiry, and able to improvise with productive instructional moves in response to students' ideas and experiences (Cochran-Smith & Lytle, 1993; Rosebery, Warren, & Tucker-Raymond, 2016). Such a responsive stance can be easier in some teaching situations than in others. For example, teachers generally find it easier to surface students' initial ideas than to facilitate the development of initial ideas into more systematic disciplinary understandings (Harris, Phillips, & Penuel, 2012). This facilitation of students' knowledge-building is difficult because it requires teachers to not only have a deep conceptual understanding of science ideas, but also knowledge of how to respond to students' ideas productively in real-time (Ball, 1993; Maskiewicz & Winters, 2012).

To advance and deepen students' conceptual understandings, teachers must navigate the 'emergent curriculum' (Hammer, 1997) and consider how students' contributions are related to disciplinary understandings (Leinhardt & Greeno, 1986). Teaching for epistemic agency requires attention to an additional layer in the curriculum:

students' ideas about where to go next. Therefore, teaching for epistemic agency requires teachers to also understand the 'emergent epistemic curriculum' (Elby, 2001), where teachers take up students' intuitions and ideas as productive seeds to support students' epistemic growth and conceptual understanding. Further, teaching for epistemic agency pushes firmly against the grain of how epistemic agency and power are shared in schools (Apple, 2013; Carlone et al., 2015). Therefore, teaching for epistemic agency must also serve the purpose of sharing epistemic agency with students. At the same time, sharing epistemic agency can create tensions and uncertainties due to shifting classroom power dynamics (Rodriguez & Berryman, 2002). Teaching for epistemic agency requires that teachers develop practices that scaffold students' epistemic learning while at the same time managing the contingent, uncertain, and perhaps discomforting nature of such instruction.

Use of curriculum in teaching for epistemic agency

Following Ko & Krist (2019), I contend that well-designed curriculum materials can serve as a productive lever to support teachers' efforts to share epistemic agency in science classrooms. Curriculum materials are a powerful mechanism for shaping instruction because they specify how activities and phenomena correspond to learning objectives and student performance. Several curricular features, like the investigation and explanation of phenomena and the use of discourse to publicly evaluate and construct ideas, have been shown to support students' engagement in science as practice (e.g. Krajcik, McNeill, & Reiser, 2008; McNeill & Krajcik, 2009). However, well-designed curricula that aim to share epistemic agency do not inherently relieve the tension that comes with class-wide efforts to shift power dynamics and epistemic agency during enactment. Without recognizing and responding to these tensions, teachers are likely to adopt a complacent approach to the enactment of exemplar curriculum. In such an approach, enactment would appear to share epistemic agency with students, but would merely re-instantiate students' position as the receivers of science ideas and practices (Miller et al., 2018).

Therefore, as a field, in addition to our emphasis on concrete features of curricular materials, we should emphasize curricular enactment. This enactment must involve constant design work related to responsive adaptations and improvisations to the materials (Remillard, 2005; Brown, 2009). A responsive enactment is important because it can directly influence the epistemic goals and knowledge-building work in which students engage (Kang et al., 2016). To do so, teachers must develop a lens in interpreting, planning, and enacting curriculum materials that focuses on addressing uncertainty and sharing epistemic agency (Manz & Suarez, 2018; Ko & Krist, 2019). Teachers require professional learning (PL) to support their curricular design-work for students' epistemic agency. This PL would focus on supporting teachers to plan, enact, and reflect on their use of storyline materials with the explicit goal of sharing epistemic agency with students. In turn, these PL experiences would likely help teachers to develop a broader instructional stance where they are able to recognize and respond to students' nascent ideas as productive knowledge-building resources in the conceptual space of the lesson and the unit (Hammer, 1997).

Storyline approach to curriculum and instruction

A central goal of the science storyline approach is to provide students with a coherent experience that is motivated by students' own desire to figure out natural phenomena or solve engineering problems (Reiser et al., 2021). In storyline units, students' motivations are grounded in the questions that arise from their interactions with phenomena (Reiser, Novak, & Fumagalli, 2015; Reiser, et al., 2017). Each step in the storyline is designed to empower students to make progress on their questions and current understandings of phenomena using science and engineering practices. Further, each step in the storyline exposes limitations in the class' current consensus understanding and supports students to generate new ideas and questions to explore these limitations in future lessons. As a process of questioning, investigating, and building understanding, a storyline provides a coherent path toward building a disciplinary core idea and cross-cutting concepts (NRC, 2012) grounded in students' own experiences and questions. This coherent design affords opportunities to teachers and students to share epistemic agency as they navigate and co-construct the storyline (Sikorski, 2015).

Therefore, these storyline materials represent a potentially powerful resource for teachers to draw on, adapt, and improvise as they design instruction that aims to share epistemic agency with students. I believe storyline units can also serve as an extremely productive leverage point for professional learning around teaching for epistemic agency because these materials are already structured to be coherent from the students' perceptive. The design of storyline materials alone does not ensure that enactments will share epistemic agency with students. Teachers need the capacity to design instruction from curriculum materials to support their students' purposeful sensemaking (Sikorski &

Hammer, 2017). PL should focus attention on understanding and developing teachers' use of curriculum materials to design coherent instruction for students' epistemic agency (Ko & Krist, 2019). Further, certain activities and lessons across storyline units have particular importance to the major arc of the storyline. As a result, it is especially important for the teacher to plan for and enact these key experiences with an eye toward sharing epistemic agency with students (Manz & Suarez, 2018).

Overview of three papers

The three papers in this dissertation addressed the Teacher-Storyline (T-S) relationship in different ways. Broadly, the T-S relationship involves the teacher's use of storyline materials to design and enact instruction with the goal to be coherent for their students. The first two papers were empirical and were concerned with the T-S relationship as it played out in one teacher's classroom. The third paper was conceptual and provided initial modeling of the T-S relationship. This third paper utilized findings from the first two papers to articulate the model. In what follows, I will address the purpose and research questions (when applicable) for each paper.

Section II - Paper #1: Planning for epistemic agency in storyline discussions: A revelatory case of student-informed curricular sensemaking. The purpose of my first paper was to explore how one expert teacher made sense of the storyline materials to support his students' epistemic agency during enactment. I employed a collaborative design approach with this teacher, and we worked together to interpret, plan, and reflect on storylines lessons that contained important whole-group discussions. We engaged in this discussion planning cycle (DPC) with the goal to design instruction that was coherent for his students and that supported their epistemic agency. The DPCs offered an opportunity to support and research the teacher's curricular sensemaking and instructional design in discussion-focused lessons and in the storyline more generally. My research questions for this study were: 1) How does the teacher make sense of epistemic agency as a pedagogical construct as the teacher and researcher co-plan and reflect on discussion-focused lessons across the storyline? 2) How does the teacher's curricular sensemaking for epistemic agency evolve across his enactment of the storyline unit?

Section III - Paper #2: Responsive instructional design for coherence-seeking: Documenting episodes of principled improvisation in storyline enactment. The purpose of my second paper was to investigate how an expert teacher (same from paper #1), designed moment-to-moment instruction to support his students' epistemic agency as they deviated from the plans in the storyline materials (i.e. engaged in divergent coherence-seeking). These are episodes of principled improvisation. They were principled because the teacher leveraged particular designed coherences in the materials to support students' coherence-seeking. They were improvisational because the teacher backgrounded other designed coherences in order to better address and work with students' divergent lines of coherence-seeking. This paper explored the interactive work involved in students' divergent coherence-seeking efforts and the teacher's instructional work in principled improvisation. The research questions for this paper were: 1) How do the students deviate from the designed coherences in the materials during each episode of discussion enactment? 2) How does the teacher's facilitation of these discussion episodes embody principled improvisation and support students to take up epistemic agency?

Section IV - Paper #3: Enacting curriculum to be coherent from the student perspective: Exploring the teacher-storyline relationship. The purpose of my third paper was to provide an initial model of the Teacher-Storyline (T-S) relationship. Broadly, this relationship entails the activity in which the teacher interacts with and uses storyline materials to design instruction that is coherent from the student perspective. This relationship concerns the teacher, the storyline materials, the participatory interactions between the two, and the subsequent planned and enacted storyline that is an outgrowth of this relationship. I then described each part of the Teacher-Storyline relationship model and explained how these components interact to support coherence from the student perspective. Finally, I used the information in the T-S model to offer strategies to support the design of curricular materials and curriculum-based professional learning.

Section V - Conclusion. Lastly, I will provide a brief conclusion where I draw connections between the findings in papers #1 and #2 and my model of the T-S relationship in paper #3. I end the section by posing two lingering questions concerning the T-S relationship. The first question involves the quality of students' opportunities to act with epistemic agency in planned storyline materials. The second question addresses the sociopolitical context in which the T-S relationship occurs in practice.

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Section II

Planning for epistemic agency in storyline discussions: A revelatory case of student-informed curricular sensemaking

Introduction

A central goal of the storyline approach and curricular materials is to position students to build and critique ideas in a manner that is coherent from their perspective (McNeill & Reiser, 2018). As a process of questioning, investigating, and building understanding, a storyline unit provides a coherent arc for students to construct science ideas that are grounded in their experiences and questions (Reiser, Novak, & McGill, 2017). However, the use of well-designed curricula like storylines does not inherently ensure students will be able to pursue their own arc of inquiry in the enactment of the curriculum (e.g. Ball & Cohen, 1999; Brown, 2009; Remillard, 2005). Teachers must design instructional episodes which share epistemic agency with students in their learning (Berland et. al, 2016). I define epistemic agency as, "students *being positioned with, perceiving, and acting on, opportunities to shape the knowledge building-work in the classroom community" (*Miller et. al, 2018, p.6). Teachers need support in developing their capacity to make sense of, and design curriculum materials for students' epistemic agency (Manz & Suarez, 2018).

Storylines units can potentially support teachers to develop this capacity for curricular sensemaking because the materials are already designed to be 'coherent from the student perspective' (Reiser, Novak, & McGill, 2017). I believe that teachers can reliably draw on, adapt, and improvise from these storyline materials as they design instruction for shared epistemic agency. In particular, whole-group discussions are crucial opportunities for curricular sensemaking and adaptation because these activities are the primary venue for class-wide knowledge-building across the storyline (Lowell, Cherbow, & McNeill, in review). I view storyline discussions as an important lever to develop teachers' capacity for curricular sensemaking and instructional design for shared epistemic agency in storyline units.

To leverage these discussions, I employed a collaborative design approach. One focal teacher and I collaboratively made sense of, planned, and reflected on storylines lessons that contained these whole-group discussions. This participating teacher was an ideal choice for this intensive form of professional learning because he was a veteran teacher with substantial experiences developing and using reform-based curriculum. As a result, the teacher was well-positioned to interpret and use the reform storyline materials to support coherence from the student perspective (Reiser, Novak, & McGill, 2017). We engaged in this discussion planning cycle (DPC) to co-design and support the teacher's efforts to share epistemic agency with his students in these discussion-based lessons and in subsequent storyline learning. This professional learning design was a potential vehicle to advance the teacher's sensemaking because it allowed him to plan for and reflect on problems of practice about epistemic agency that directly concerned his own classroom context and students (Reiser, et al., 2017). The DPCs offered a powerful opportunity to support and research the teacher's sensemaking and instructional design for epistemic agency in discussion and in the storyline more generally. Our research questions for this study are: *1) How does the teacher make sense of epistemic agency as pedagogical* *construct as the teacher and researcher co-plan and reflect on discussion-focused lessons across the storyline? 2) How does the teacher's sensemaking for epistemic agency evolve across his enactment of the storyline unit?*

Theoretical Framework

Epistemic agency as a pedagogical construct

In education research, the roots of epistemic agency as a pedagogical construct stem from work by Scardamalia and Bereiter (1991) on knowledge-building communities. In knowledge-building communities, students are positioned with agency to shape the shared knowledge of the classroom community (Scardamelia, 2002). This characterization highlights that epistemic agency is not a trait of an individual student, but rather an emergent characteristic of the classroom community as they engage in collective knowledge-building (Damşa et al., 2010). The character of this work is shaped by the structures of the classroom community and school which convey particular expectations about the epistemic roles of teachers and students (Stroupe, 2014). I follow these characterizations and view epistemic agency as negotiated in classroom interaction (Damşa et al., 2010; Hand, 2012) and located in activity systems which enable and constrain particular forms of agency (Holland, Lachicotte, Skinner, & Cain, 1998).

Epistemic agency in classroom activity involves the ways in which students act or refrain to act in knowledge-building, and the ways in which their contributions shape the knowledge-building work and structures of the classroom community (Gresalfi, Martin, Hand, & Greeno, 2009; Miller et. al, 2018). The structures for participation in the classroom community afford and constrain students' epistemic roles and practices (Hand, 2012). These community structures significantly impact students' perceptions of themselves as agents in the classroom (Holland, et. al, 1998). Therefore, I understand agency not only in terms of students' position in the classroom, but also in how they perceive that position (Arnold & Clarke, 2014).

In practice, power structures in K-12 science classrooms typically position the teacher and curriculum as the primary epistemic agents in science learning rather than students (Apple, 2013; Varelas, Settlage, & Mensah, 2015). When science teachers drive knowledge-building in instruction, there can be few opportunities for students to be meaningful collaborators in the co-construction of knowledge (Stroupe, 2014). Sharing epistemic agency with students in their learning involves a redistribution of power in the classroom (Carlone, Johnson, & Scott, 2015). For example, Hand (2012) showed that a teacher could share epistemic agency and power with students by opening up dialogic spaces in classroom interaction to allow students to help construct a knowledge object. I use the concept of shared epistemic agency (Damşa et al., 2010) in this study to describe the teacher's efforts to partner with students in the trajectory of knowledge-building in the storyline. Shared epistemic agency means that students take on part of the intellectual responsibility in developing and managing this trajectory (Berland et al., 2016; Ford, 2008; Manz, 2012). This storyline science work is guided and scaffolded by the teacher, but the students are always active partners in identifying what the class needs to work on, what they have figured out so far, and what gaps still need to be resolved in their explanations or models (Reiser, Novak, & McGill, 2017). As a result, teaching for epistemic agency with storylines involves negotiation between student ideas and questions and the trajectory and resources in the storyline materials (Reiser, et al., 2021).

Teacher planning for epistemic agency

Recent science education research has advocated for the design and enactment of learning environments where students are positioned as the 'doers of science' rather than as the receivers of scientific facts (e.g. Miller et. al, 2018; Sikorski & Hammer, 2017). For design, curriculum materials can be a productive support for teachers and students to engage in instructional activity that shares epistemic agency with students (Ko & Krist, 2019). However, the enactment of any curriculum is a function of the interactions between teachers, students, the curricular materials, and the institutional context (Remillard & Heck, 2014). As such, curricular enactments that support students as epistemic agents require teachers to engage in responsive adaptations and improvisations from the curricular materials to engage students' agency (Drake, 2002; Heaton, 2000). Teachers' decisions in planning, enacting, and reflecting on curricular enactment shape the formation of epistemic goals in instructional activity and the subsequent roles and practices that teachers and students are expected to take in the knowledge-building community (Arnold & Clarke, 2014)

Several papers have begun to articulate teachers' decision-making around knowledge-building during the enactment of reform curriculum materials. Stroupe, Caballero, and White (2018) depicted how teachers navigated various tensions while enacting a carefully-designed curricula and trying to position students as epistemic agents. They concluded that teachers navigate tensions differently based on their context and they would benefit greatly from increased capacity to make instructional decisions. Manz and Suárez (2018) documented how a workgroup of elementary science teachers made sense of the uncertainty inherent in scientific activity and engaged in principled instructional design work to support students' investigations of natural phenomena. In both studies, the researchers facilitated professional learning that focused on the development of teachers' capacity to craft principled and responsive instructional episodes from curriculum materials.

I contend that storyline materials have great potential to support teachers' efforts to share epistemic agency with students because they are designed to be 'coherent from the student perspective' (Reiser, Novak, McGill, 2017). This designed coherence powerfully organizes classroom activity to position students to explore their questions about phenomena and to incrementally build on these ideas by investigating their questions (Reiser, Novak, & Fumagalli, 2015). Therefore, storyline materials can serve as a powerful resource for teachers to interpret and use as they craft instructional episodes that share epistemic agency with students. In particular, discussions are particularly important opportunities for instructional design because these tasks serve as the main venue for collective sensemaking across the storyline (OpenSciEd, 2020). I contend that teachers should make epistemic agency an explicit target in their instructional design of these storyline discussions. As such, teachers would benefit from additional support in planning for epistemic agency in these storyline discussions.

Discussion planning as collaborative design and sensemaking

Our enactment of the discussion planning learning environment was guided by a situative perspective on teacher learning (Lave & Wenger, 1991; Putnam & Borko, 2000). This perspective acknowledges that learning is situated in particular contexts and distributed across participants, the informational structures and practices they enact, and the technical and material tools they utilize (Greeno, 2006). As teachers learn and enact their knowledge in the classroom, they draw on a collection of varied resources, such as curriculum materials, various classroom practices (e.g. existing teaching practices, district directives) (Horn & Little, 2010), and knowledge of the identities of their students. This perspective points to the importance of situating teacher learning opportunities in the negotiation and development of context-specific tools, practices, and classroom identities (Heredia, Furtak, Morrison, & Renga, 2016). Collaborative instructional design and reflection is a powerful setting for teacher learning (Horn & Little, 2010) and a window into teachers' sensemaking (Manz & Suarez, 2018). Further, teachers' representations of practice in collaborative design can advance teacher learning and serve as important subjects of analyses concerning teacher sensemaking (Hall & Horn, 2012; Heredia, Furtak, Morrison, & Renga, 2016).

Specifically, I investigated a discussion planning cycle (DPC) that involved one teacher and co-planner's efforts to plan, enact, and reflect on focal discussions across the storyline unit. DPCs were structured for collaborative sensemaking and design to support the teacher's efforts to share epistemic agency with his students in these discussion-based lessons. This professional learning environment was used to research and advance the teacher's sensemaking because it allowed him to plan for and reflect on problems of practice concerning epistemic agency in his own classroom context (Horn & Little, 2010). The enactment of these DPCs was not framed as an attempt to facilitate the direct translation of research findings on epistemic agency and the storyline curricular approach into classroom practice. Instead, this partnership activity is best viewed as a form of joint work (Penuel, Allen, Coburn & Farrell, 2015) requiring mutual engagement to create, implement, and study strategies in the discussion planning cycle for epistemic agency.

In general, teachers engage in sensemaking when they negotiate the meaning of classroom and school activity from a variety of often-conflicting messages (Coburn, 2001). Teachers attempt to resolve tensions within their school environment and make retrospective, as well as prospective sense of their classroom practices (Coburn, 2001). In general, tension can emerge from the presence of conflicting institutional goals, limited resources available to perform actions, lack of clarity on roles and responsibilities, or the absence of measures to assess the success of action (Allen & Penuel, 2015). In this study, I was interested in tensions that emerged between the teacher's interpretation and plans for storyline curriculum and their enactment with their students. The structures of the DPC were an important lever for this form of sensemaking because they provided a forum to uncover and resolve tension between discussion planning and enactment, and between storyline enactment and his institutional context.

Methods

I used a single case study approach in order to capture the complexities and particularity of a single case (Patton, 2001). A case study is suitable where (a) the focus of the study is answering "how" and "why" questions about (b) contemporary events (Yin, 2017). This single case study addresses how a teacher made sense of the storyline materials to plan and enact discussion-based lessons for epistemic agency. I view this study as a revelatory case of this form of curricular sensemaking. Generally, a revelatory case study involves the depiction of a case that reveals a phenomenon yet unexplored (Yin, 2017). I view this form of curricular sensemaking as largely unexplored, as these storyline units are some of the first curricula that are explicitly designed to be 'coherent from the student perspective' (Penuel & Reiser, 2018). The structures of the storyline materials were a valuable tool for making sense of storyline units and for engaging instructional design work for epistemic agency. Additionally, the participating teacher was an ideal choice for this revelatory case (Yin, 2017). He was a veteran teacher with experience teaching physical science concepts, using argumentation-based instruction, and facilitating incremental building of science ideas in a student-centered manner. The teacher was well-positioned to interpret and use the storyline materials to share epistemic agency with his students in enactment.

Curricular Context

This study took place during the field test of middle school storyline units. These units were designed to align to recent reforms in K-12 science education (i.e. NRC, 2012; NGSS Lead States, 2013). Specifically, the OpenSciEd Developers Consortium designed these curricula using the storyline approach. This approach anchors storyline units in students' own questions to figure out natural phenomena or their own solutions to address engineering problems (Reiser, Novak, & Fumagalli, 2015).

In particular, this study focuses on one teacher's pilot of a storyline unit titled: *How can a magnet move another object without touching it?* This unit is about forces that interact at a distance through fields that extend through space. It begins with students exploring the anchoring phenomenon concerning the vibration of a speaker when it makes noise. Students think about what causes this vibration. The anchoring phenomenon motivates students to dissect a variety of speakers to explore their inner workings. The unit then engages students in a series of investigations where they manipulate the speaker's parts to figure out how they work in the speaker system. Through these investigations, the students refine their consensus model about how permanent magnetic forces operate at a distance with electromagnets. This model is then applied to explain speaker technology and other phenomena that push or pull objects at a distance.

Three whole-group discussions within this storyline were selected for planning. Storyline units use discussions to help draw out student ideas, support students in communicating with one another in scientific ways, and facilitate student sensemaking (OpenSciEd, 2020). The three discussions were selected for planning because they were distributed in time across the storyline unit. They also represented each of the three types of storyline discussion, which are: 1) initial ideas; 2) building understandings; and 3) consensus discussions.

Initial ideas discussions involve students expressing their beginning ideas about phenomena publicly. These discussions provide students with the opportunity to make sense of partially formed ideas and to realize there are gaps in their understanding. This discussion type takes place when students are beginning the process of making sense of a phenomenon. *Building understandings discussion* allow students to share claims and reasoning based on evidence. These discussions involve students connecting, critiquing, and building on each other's ideas. They occur at the end of a lesson in which students discuss and arrive at tentative evidence-based conclusions about the lesson's question using data from investigations, simulations and/or reading materials. *Consensus discussions* involve the class coming to agreement on some important idea(s) that they have been working on over the period of multiple lessons. During these discussions, students put together ideas and come to agreement about what they have and have not figured out about the phenomenon of interest (see Table 1.1). These discussions occur when students collectively work towards a consensus explanation or model. The discussions chosen for this study took place in lessons 1, 5, and 9 across the storyline (12 lessons in storyline total, see table 1.2).

Table 1.1: Discussion types and goals

Discussion Type	**Goals**
Initial ideas discussion	● Get students' initial ideas and experiences on the table. ● Provide students the opportunity to make sense of what may not be fully formed ideas and to realize that there are gaps in their understanding. ● Promote curiosity and motivate what the class could do next to figure something out.
Building understanding discussion	● Share claims and reasoning based on evidence from investigations, simulations and/or reading materials. ● Connect, critique, and build on each other's findings, claims, evidence, and explanations. ● Conclude with the class arriving at tentative conclusions about a specific question or understanding from one lesson.

Consensus building discussion	● Come to agreement on some important idea that they have been working on over the period of multiple lessons. ● Put together multiple ideas built from experiences to come to an agreement on what is and is not known about a phenomenon of interest. ● Propose ideas for evaluation and/or discussion to decide if the class agrees on them.

The lesson 1 discussion is an "initial ideas" discussion. After the students explore the anchoring phenomenon (i.e. the vibration of the speaker), attempt to make sense of it, and identify related phenomena, they then gather in a circle for an initial ideas discussion. The main function of this discussion is for students to ask questions about the anchor, construct a public representation of their questions, (i.e. Driving Question Board), and develop initial ideas for investigation in the next lesson.

The lesson 5 discussion is a "consensus discussion." In this lesson, the class builds a consensus model of what they figured out in lessons 1-4 to explain how the alternating magnetic forces between a permanent magnet and coil of wire result in vibrations in the speaker system. The consensus discussion involves students coming together to share their individual models and explanations with the whole class to develop a consensus model for how the speaker works with magnetic forces.

Finally, the lesson 9 discussion is a "building understanding" discussion. In this lesson, the class continues to investigate the magnetic field around magnets. In this discussion the class comes together to share what they concluded from their investigations in Lesson 9 about the relationship between distance and magnetic force. Students use data from these investigations to explain in whole-group that the magnetic field around a magnet gets stronger when it is closer to another magnet.

Table 1.2: Focal Discussions

Lesson #	Discussion Description	Discussion Type
Lesson 1	Students gather in a circle to construct the Driving Question Board (DQB) around the 3 parts of the speaker system. The class then develops initial ideas for investigation and makes decisions about where to head in the next lesson.	Initial ideas discussion
Lesson 5	Students create a class consensus model about how the speaker works with magnetic forces using what they figured out in Lessons 1-4. After, the class engages in a consensus-building discussion to share limitations of the current model and brainstorm what needs to be addressed next.	Consensus discussion
Lesson 9	Students design and carry out an investigation to answer their questions about the effect of distance on magnetic forces. The class then examines the mathematical relationships that appear in their data and discuss their findings about the relationship between distance and magnetic forces.	Building understanding discussion

Discussion Planning Cycle (DPC) Context

The DPC involves the planning, enactment, and reflection on the three focal storyline discussions described above (table 1.2). A discussion planning tool and a video reflection protocol were used to organize the teacher's interpretation of and subsequent enactment of storyline discussions for students' epistemic agency. The *discussion planning tool,* created by OpenSciEd developers' consortium, (OpenSciEd, 2020) was used to plan and reflect on each focal discussion enactment (see appendix 1). The tool supported the teacher to intentionally plan, facilitate, and reflect on the focal discussions across the storyline (OpenSciEd, 2020). Each focal discussion was planned for and reflected on using this tool. This situated and responsive professional learning environment served the dual purpose of supporting the teacher's enactment of the storyline and also his efforts to share epistemic agency with students in the focal discussions.

Teacher context. The "DPC team" was made up of the teacher (Mr. Kelly) and co-planner (myself). Prior to the DPCs, I worked with Mr. Kelly when he was a participant in a multi-year, storyline-based professional learning series that I supported. Mr. Kelly was purposively selected (Patton, 2001) for this study based on those experiences, as well as my knowledge of his substantial experiences enacting reform science curricula. In the past he had both designed and enacted argumentation-based science curriculum (Knight & McNeill, 2015; Knight-Bardsley & McNeill, 2016). Further, he had significant expertise in physical science and engineering, which included a degree in engineering from an elite research university and professional work in this field. Mr. Kelly was also a veteran teacher with over 15 years of middle school science teaching experience (see table 1.3). Therefore, as mentioned above, I believed Mr. Kelly's classroom was a revelatory case (Yin, 2017) of productive curricular sensemaking and instructional design work for epistemic agency in storylines. At the onset of professional learning, I expected Mr. Kelly would already have greater-than-average capacity to decompress storyline ideas and find productive connections between target disciplinary understandings and students' thinking and arc of inquiry. In turn, I anticipated that Mr. Kelly would be better at attending and responding to students' emergent epistemic practices concerning science ideas during whole-group discussion.

Table 1.3: Teacher Background

Teacher	**Race**	**Education**	**Type of Teaching Credential**	**Years of Teaching Experience**	**Classes Taught**
Mr. Kelly	White	M.Ed. (Leadership) and BS (Engineering)	Middle school science and math (5-8)	15+ years	7th and 8th grade general science

Discussion planning. Each DPC planning session involved two steps. The DPC team, 1) navigated to and walked through the focal lesson; 2) discussed and completed the *planning* and *leading discussion* sections of the discussion planning tool for the focal discussion. First, prior to any explicit discussion planning, the teacher and co-planner walked through the teacher guide and slides for the focal lesson. In so doing, the DPC team discussed the previous lesson's contents, the teacher's enactment, and his navigation efforts to the focal lesson. Second, the DPC team discussed and completed the *planning* and *leading discussion* sections of the discussion planning tool for the focal discussion. To begin, the teacher and co-planner responded to the questions in the tool individually before meeting to discuss and complete a digitally-editable copy of the discussion planning tool together. The planning section of the tool asked the teacher to respond to questions related to preparing for the focal discussion (e.g. *what is the intended outcome of the discussion?).* The leading section asked the teacher to respond to questions connected to enactment of the focal discussion (e.g. *what are some things you will say to encourage your students to work with one another's ideas?*). For each section of the tool, the teacher typed his thoughts and responses to the questions in the shared copy of the discussion planning tool. The teacher developed a final response for each planning question one-by-one as the DPC discussed the question. Their collective response for each question was the culmination of the DPC's efforts to compare their individual work on the tool, and to co-develop final responses.

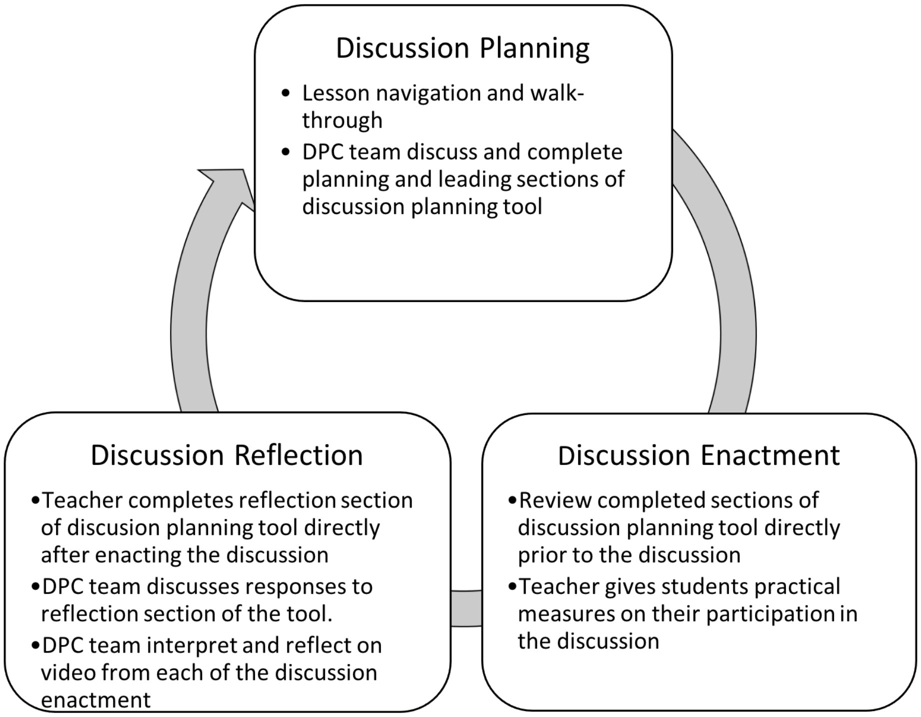
Discussion enactment. Before focal discussion enactment (i.e. night before or period before), the teacher reviewed the completed planning sections of the discussion planning tool to revisit his plans for the focal discussion. This review was not originally a part of the DPC structures, but the teacher elected to engage in this work prior to the first focal discussion. After the first DPC, this practice was accommodated into the structures of this learning environment because the teacher found benefit in this work. After review, the teacher then taught the discussion lesson, which was also video recorded. Following the enactment of the discussion, the teacher gave practical measures (Penuel & Watkins, 2019; Bryk et. al, 2015) to students to gauge the students' perceptions of their participation in knowledge-building work during discussion. These practical measures consisted of 8 check-off questions. The questions were designed to be answered by either checking *yes*, *no*, or *unsure* or by checking all the open responses that students thought applied to the question. These measures primarily surveyed how students were experiencing knowledge-building during the discussions (see appendix 2). For example, the first four questions asked if the student or their peers shared any ideas in discussion, and if they think their ideas or other students' ideas influenced the class. These practical measures were primarily employed to spark broader reflection from the teacher about their enactment and their efforts to share epistemic agency with students in storyline activity.

Discussion reflection. DPC reflection sessions after the enactment consisted of three parts: 1) teacher completed reflection section of the discussion planning tool directly after enactment; 2) DPC team discussed teacher's responses to the reflection section; 3) DPC team analyzed and reflected on focal discussion video of enactment. First, the teacher took stock about his discussion enactment by completing the reflection section of the tool. The reflection section of the tool asked the teacher to respond to questions to analyze and interpret what happened during the discussion (e.g. *what ideas and reasoning did you hear? How would you describe the group's understanding of the ideas you identified in planning?).*

Second, the teacher and co-planner discussed the teacher's completion of the reflection section of the discussion planning tool. This process consisted of the teacher recalling and elaborating on his responses on the tool. At this time, the co-planner asked clarification questions about the teacher's responses and probing questions to position the teacher to explain his responses further. Additionally, in discussing the tool, the DPC team also referenced the practical measure results from the students for the focal discussion. Discussions related to the practical measures were used to triangulate DPC team reasoning in the tool with students' perceptions of the discussion. Convergences and divergences between these two evidentiary sources sparked broader reflection on what went well and what was challenging in the focal discussion.

Finally, in reflecting on discussions, the teacher and co-planner also reflected upon video from each of the discussion enactments. For each DPC, the team co-analyzed one clip of the discussion video (typically 3-5 minutes) that the teacher felt went well according to their plans, and one clip that they thought was challenging. The DPC team collaborated on the selection and production of these video clips. Specifically, the teacher responded to questions in the discussion planning tool that specifically addressed "what went well" and "what was challenging" in the discussion. The co-planner then procured video from the discussion enactment footage that highlighted the successful and challenging portions of the discussion that the teacher alluded to in the tool. In reviewing the selected video clips, the teacher and co-planner each began by separately recording what they noticed from the teacher and students during discussion. These noticings included descriptions and time stamps of the occurrence in the discussion. After, the DPC team used their noticings to individually develop inferences about the effect of particular teacher moves and student activity on the occupied roles and trajectory for knowledge-building during discussion. Each member of the DPC then shared their individual noticings and inferences with one another. The teacher concurrently summarized these noticings and inferences in their shared planning tool.

Figure 1.1: Discussion Planning Cycle Overview



School Context

Mr. Kelly's school was a Title I public middle school. It enrolled 365 students in grades 6-8 and had a student-teacher ratio of 11 to 1. According to state test scores, 20% of students were at least proficient in math, 11% in reading, and 3% in science. The school was designated at the time by the state as requiring *Focused/Targeted Support* and was receiving assistance from the state to make progress toward improvement targets, accountability percentiles, graduation rates, and state testing participation rates.

In terms of demographics, the school primarily served students of color (Hispanic, 58.9%; African American, 28.5%; Asian, 3.8%) and had a significant proportion of students who were classified as economically disadvantaged (see table 1.4). The student body also enrolled a sizable population of students with disabilities and students who were classified as English Language Learners (ELLs). Mr. Kelly's class population reflected the broader school-wide trends in academic achievement and demography but his class represented the average class size at the school (21-25 students). Specifically, the target class for this study included 23 students. The teacher, students, and school names in this study were replaced with pseudonyms to protect the participants' anonymity.

Table 1.4: School and Classroom Context

School	Unit Piloted	Grade of Students	Class Size	% Free and Reduced Lunch	% Persons of Color	% EML	% with disabilities
Mary B. Talbert Middle School	Forces at a Distance	7th grade	21-25	73%	95%	30%	24%

Data sources

I utilized two main data sources in this study: 1) pre- and post-interview transcripts and 2) discussion planning cycle transcripts and artifacts. This study examined these data sources to identify the key sources of tension that Mr. Kelly wrestled with as he enacted the discussions and the storyline unit for epistemic agency and made sense of these tensions across the storyline. All interviews and DPC sessions were video recorded and transcribed in full.

The first data source was pre- and post-interviews with Mr. Kelly. These interviews bookended his participation in the three DPCs. Transcripts of these interviews were used to gauge the teacher's sensemaking for epistemic agency as a pedagogical construct before and after completing the three DPCs. The interview protocol addressed the teacher's conceptions about key storyline instructional elements and discussion practices in the context of the Forces at a Distance unit and for other units the teacher had previously taught (Appendix 3). The teacher's responses to these pre- and post-interview questions helped to characterize the bounds of the teacher's sensemaking for epistemic agency across the storyline.

The second data source was the transcripts and artifacts from the discussion planning, enactment, and reflection sessions (i.e. DPCs). Discussion enactments involved video recordings from whole-group discussion and from one focal student small group (when applicable). As discussed previously, the three discussions (initial ideas; building understandings; and consensus discussions) were selected for analysis because each involved different underlying epistemic goals and practices. Therefore, I could observe the variation in how Mr. Kelly's efforts made sense of and planned for epistemic agency in each of the discussion types and how this variation evolved across the storyline.

There were also a number of artifacts for the DPCs. Each focal discussion was planned for and reflected upon using the discussion planning tool (see appendix 1). Transcripts of planning and reflections sessions and all completed planning tools (planning, leading, reflecting sections) were analyzed to understand the teacher's sensemaking and learning around epistemic agency. Additionally, practical measures (Yeager et al., 2013) were given to students following the completion of each discussion. I adapted Penuel & Watkin's (2019) practical measures of instructional activity to focus exclusively on students' experience of their knowledge-building during the discussions (see appendix 2).

Data Analysis

The analysis was guided by a situative perspective on teachers' learning (Lave & Wenger, 1991; Putnam & Borko, 2000). From this perspective, the discussion planning setting functioned as a powerful venue for the negotiation and development of tools, practices, and ideas around discussion and epistemic agency. The analysis involved two phases to characterize the teacher's sensemaking for epistemic agency across the three discussions. In the first phase, I analyzed the pre- and post-interview transcripts to describe how the teacher's understanding of the key storyline instructional elements shifted across participation in the DPCs. Fidelity to the storyline instructional elements is integral to the coherent enactment of a storyline unit (McNeill, Marco-Bujosa, González-Howard, & Loper, 2018). Therefore, this teacher's discussion of these instructional elements offered a powerful window into his understanding of epistemic agency as a pedagogical construct. I examined the teacher's pre-and post-interview responses concerning these elements to characterize any shifts in his understanding of particular elements (e.g. coherence from the student perspective) or in the storyline approach more generally (i.e. understanding that cuts across elements). As a result, these interview transcripts were analyzed to initially characterize the progression of the teacher's sensemaking for epistemic agency across DPC participation.

In the second phase, I used interaction analysis (IA) to analyze planning and reflection sessions transcripts from each of the focal discussions. Specifically, I used interaction analysis (Jordan & Henderson, 1995) to characterize Mr. Kelly's 'knowledge in use' (Hall & Stevens, 2015) during DPC planning and reflection. Interaction analysis (IA) is grounded in the notion that teaching and learning as involving human and material interactions during concerted activities (e.g. classroom activity, Stevens, 2010). Further, IA gives analytic primacy to the social actor's point of view and to what is demonstrably relevant to those actors in interaction. Lastly, it involves making inferences about 'knowledge in use' that are grounded in the visible and audible traces of interactants' activity before appealing to hidden mental contents or mechanisms (Hutchins, 1995; Latour, 1987). In this analysis, I focused on identifying interactive episodes of pedagogical reasoning (EPRs) related to epistemic agency during the DPC planning or reflection. EPRs are instances of teacher talk in which teachers "describe issues in, or raise questions about, teaching practice that are accompanied by some elaboration of reasons, explanations, or justifications" (Horn, 2005, p. 215). For this study, EPRs for epistemic agency were defined as instances where *the teacher describes issues in, or raises questions about knowledge and/or epistemic practices, accompanied by some elaboration of reasons, explanations, or justifications.* After identifying all EPRs for epistemic agency, I sequentially and temporally organized them within and across DPCs to develop initial themes related to the teacher's sensemaking for epistemic agency. The compilation of all EPRs in DPCs revealed recurrent sources of tension between the teacher's plans for and enactment of the storyline for epistemic agency. Further, the manner in which this teacher grappled with these sources of tension evolved across his participation in the DPCs. In turn, Mr. Kelly's sensemaking concerning these key sources of tension informed and contextualized the shifts in his understanding of epistemic agency identified during the pre- and post-interviews.

I triangulated (Merriam, 2009) my analyses of each data source (i.e. EPRs, pre-post interview transcripts, practical measures) to develop themes of curricular sensemaking for epistemic agency. I then conducted a member check with the teacher to verify and extend these initial themes and enhance the validity of our analysis (Merriam, 2009). Prior to the member check, I provided the teacher with the study's results to review. During the member check, I shared the research questions, analytic methods, and findings and then the teacher and I discussed areas of agreement and disagreement in the findings, and any suggestions the teacher had for improving their accuracy. After the member check, the themes were revised and finalized. These themes directly concerned the key sources of tension Mr. Kelly wrestled with and how he made sense of these sources across his participation in the DPCs.

Results

Mr. Kelly wrestled with three key sources of tension during his participation in the discussion planning cycles (DPCs). Specifically, Mr. Kelly made sense of tension between: *1) Curricular coherence of ideas and student coherence-seeking; 2) Equitable participation and incremental building of science ideas; and 3) Singular or different form(s) of epistemic agency in discussion (see Table 1.5).* Mr. Kelly's sensemaking to resolve these tensions was grounded in disparities between his discussion planning and students' subsequent knowledge-building during these discussions and in the Forces at a Distance storyline more generally. In what follows, I will present each of the three sources of tension in detail, and will track how Mr. Kelly's sensemaking concerning these sources changed across his participation in the DPCs. To best capture his sensemaking around these sources of tension, I organized each results section temporally. This sequencing allowed me to describe the trajectory of Mr. Kelly's engagement with emergent sources of tension, and the ways he made retrospective and prospective sense of these tensions and his teaching practice during the DPCs.

Table 1.5: Key sources of tension over time

Source of Tension	**Description**	**Shift Over Time**
Curricular coherence of ideas and student coherence-seeking	The teacher made sense of a tension between the premeditated coherence of ideas in the storyline and students' coherence-seeking in the construction of ideas.	● Identified initial tension between premeditated coherence and student coherence-seeking. ● Shifted to use divergent moments between curricular and student coherence to open up space for students' epistemic agency. ● Shifted to make convergent moments between coherences less transparent to students to insulate their arc of inquiry.
Equitable participation and incremental building of science ideas	The teacher made sense of a tension between his goal for equitable participation in science learning and the incremental, public construction of science ideas across the storyline.	● Identified initial tension between equitable participation and the incremental construction of disciplinary understanding. ● This tension became more acute as the teacher tried to promote the equitable construction of science ideas in a time-efficient manner. ● The teacher productively wrestled with this tension to promote equitable participation across the unit.

Singular or different form(s) of epistemic agency in discussion	The teacher made sense of a tension between his initial perception of a singular epistemic agency for different discussion types and his actual enactment of these discussions as designed with different epistemic purposes.	● Initially the teacher viewed epistemic agency in all discussion types as similar. ● The initial ideas discussions remained focused on getting student ideas out. ● The consensus discussion became more focused on incremental model building over time as a classroom community. ● The building understanding discussions became more focused on evidence use and greater conceptual rigor.

1. Curricular coherence and student coherence-seeking

Identifying initial tension between premeditated curricular coherence and student coherence-seeking. Across participation in the DPCs, Mr. Kelly consistently voiced concern about a tension between the coherence that was planned and designed for in the storyline materials and his enactment of these materials in a manner that is coherent from the student perspective. In his pre-interview, Mr. Kelly said, *"nothing is introduced prior to someone saying that. And that's the thing that's totally mortifying. What if nobody says this? Did we waste all that time? What do I do then?"* In this quote, Mr. Kelly said he would feel distressed if there was a lack of overlap between his students' ideas and the premeditated coherence of the storyline.

Mr. Kelly mentioned this concern again when planning for the initial ideas discussion in lesson 1. In planning, he had the following interaction with the co-planner:

Mr. Kelly: *Right. It's funny that in teaching it has to feel like the least scripted curriculum I've ever taught, but it also like the most scripted. Right?*

Co-planner: *Yeah, it's kind of bizarre.*

Mr. Kelly: *I mean I think it's great because there's a very specific way you've got to do this to make it happen.*

Co-planner: *It's interesting, right?*

Mr. Kelly: *My big worry is" like Oh my God, what if I say the wrong thing? What if I mess up?" Then it's like as long as it's headed down the pathway-*

Co-planner: *Exactly.*

Mr. Kelly: *As long as we're steering in the general direction and in the style that we're hoping to teach this in.*

In this second interaction, Mr. Kelly highlighted a tension he felt between the substantial premeditated coherence in the storyline and differing lines of inquiry that students want to pursue. Specifically, he stated that the storyline is supposed to be enacted as the 'least scripted curriculum' for students, so they feel their emergent ideas and practices are driving their progression. At the same time, Mr. Kelly acknowledged that the curriculum, from his perspective, is highly scripted in terms of the sequence and goals for activities and idea development. Similar to his concern in the pre-interview, Mr. Kelly perceived a tension between student coherence and curricular coherence. In the second quote, he added a greater degree of nuance to his conception of this tension by offering an interpretation of storyline enactment that included divergence from curricular procedures when necessary to provide space for student coherence-seeking. However, he still maintained the importance of the 'general direction' and 'style' of the premeditated storyline. This sensemaking displayed understanding of coherence as a useful pedagogical construct in their practice.

In further planning and reflection, Mr. Kelly experienced several instances where there was tension between the premeditated coherence of the storyline and the way students' emergent coherence-seeking occurred. In the lesson 5 reflection, Mr. Kelly returned to the issue of coherence in the context of an investigation they previously completed. In this investigation, students were to design and carry out three investigations to determine whether or not air particles affect the forces between two magnets. The first investigation involved putting a barrier (e.g. cardboard) between the magnets and observing if they still interacted with one another. In this quote, Mr. Kelly described an issue that emerged:

> *"That specific worksheet was all about the barrier, and what's it going to be like with that and without that barrier… And it is like, okay, this is what we want to do. Great. And here's the worksheet that's already printed up about your idea and what you just told me. And that's a danger to this because I don't know, that was my idea. How did you print that up? Is this not really my idea? And that could be a really toxic thing. "Oh my God, all my trust in my teacher is gone now." "*

In this case, the students' emergent ideas for investigation aligned with the arc of inquiry designed into the storyline and into the investigation handout. Mr. Kelly perceived that students could take issue that their ideas for investigation aligned with the contents of the investigation handout that Mr. Kelly had printed before class. He worried that the premeditated design of the investigation handout would signal to students that they in effect did not have the epistemic agency to truly pursue their ideas and lines of inquiry. Further, the premeditated design could show students their efforts to shape knowledge-building in the storyline were minimal and authority was ultimately positioned with Mr. Kelly and the curriculum. He went on to describe how this alignment of curricular and student coherence can come off as disingenuous and can therefore be a breach of trust between teacher and students.

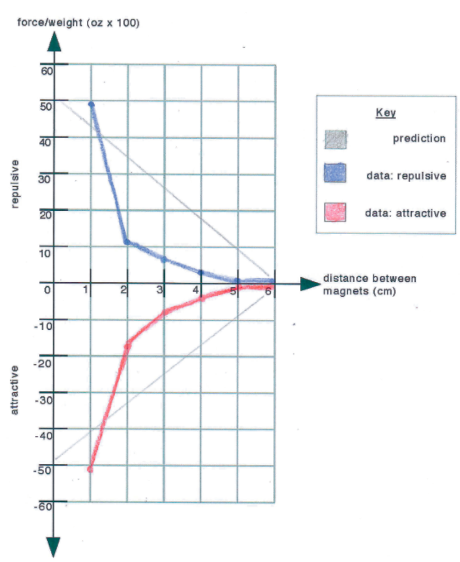
This concern bore out in the classroom. For example, in planning for the building understandings discussion in lesson 9, Mr. Kelly mentioned how one student had recently picked up on the alignment between the class's coherence-seeking and the designed activities in the storyline. In this quote, Mr. Kelly described how he engaged his students in navigation from lesson 6 to lesson 7. Here, he facilitated a brief discussion about what was happening around the magnet and then students decided to engage in an investigation using a magnet and iron shavings to visualize the space around a magnet:

> *"You know what happened yesterday? We were talking about-- We were talking about the kinds of questions they had about the forces around a magnet and then we went to this one, right [concerning the magnet and iron shavings]? And Glen, the boy who talks the most in the class you observed, he was like, "Oh, you were ready for that one, weren't you?" "*

The student acknowledged that the idea for investigation they had just come up with was also going to be present on the investigation handout that Mr. Kelly had previously printed. Mr. Kelly did not convey whether the student thought it was a bad thing that he was 'ready for that one'. However, this tension was identified by Mr. Kelly on other occasions in the DPCs as his students continued to notice a convergent pattern between their emergent sensemaking and the substance of the pre-made storyline materials.

Using divergent moments between curricular and student coherences to open up epistemic space for students. While Mr. Kelly worried about the disingenuousness of both convergences and divergences between curricular and student coherences, he also learned to leverage these sources of tension to better share epistemic agency with his students. Across the DPCs, Mr. Kelly began to more flexibly utilize moments of student divergence from the curriculum to 'open up' the storyline to the students' emergent arc of inquiry. Specifically, Mr. Kelly became more comfortable responding to a myriad of student ideas and sources of uncertainty that cropped up during learning. For example, in planning for the lesson 9 building understanding discussion, Mr. Kelly argued the need to push students to dive deeper to explain why their graphs of the relationship between magnetic force between two magnets and distance never crossed zero. The students produced two graphs to plot the effect of the distance between two magnets (x-axis) for both the strength of repulsive and attractive magnetic forces (y-axis). These graphs were supposed to show that as the distance between the magnets increased, both the repulsive and attractive magnetic forces decreased. At further distances, the forces between the two magnets approached zero (i.e. no force), but never crossed the x-axis to switch from repulsive to attractive forces or vice versa (see figure 1.2 for example graph).

Figure 1.2: Example graph of distance by magnetic force



In the reflection for this discussion, he discussed how one student's unexpected graphing issue due to instrument error actually opened up space for students to grapple with the meaning of the numbers in the graph.

> *"Yeah. Well I, especially even before the discussion kids were saying that they noticed it wasn't really linear that it was wavy. You know it was interesting we heard Albert was saying that it went into negatives. Because I wouldn't have thought they would have said that, but on a reflection of course they're going to say that because it's going down. It goes to zero, and if we keep going, it's going to go past zero-and I thought that was really great because that opened an opportunity to tie the day-to-day concepts…And so to tie that back to, does this make sense? If that happens, I think that really helped them see the link between the numbers and the graph and then the actual situation."*

In this example, Mr. Kelly was able to leverage variability in students' experimental results to open up epistemic space for discussion of the scientific ideas behind the graph. Albert's graphing issue led to a conversation about why it was a physical impossibility to get these results. Mr. Kelly embraced divergence in coherence in the building understanding discussion and the students were in turn positioned with the agency to reason and build science ideas about the relationship between distance and the magnetic force between two magnets.

Trying to make convergent moments between coherences less transparent to students to insulate their arc of inquiry. Mr. Kelly also voiced plans in the post-interview to make convergences between planned curricular coherence and student coherence less transparent to students. Specifically, Mr. Kelly stated the following plans concerning the 'dilemma' of when students catch on to premeditated nature of the storyline:

> *"I think they were kind of shocked by that, you know, that I had maybe seen or the unit had seen where we're headed and had something printed out for*

them…That's a dilemma, by the way. I was talking with the science director for the district the other day. And I was telling her that we should not print physical books for the kids. And she was saying that another teacher thought that we should because they've got nice color diagrams and visuals for the kids. Which I think is a valid point because we certainly don't have any color copiers at the school. But if there's a book, I feel like for the kids it takes away from that point."

In this quote, Mr. Kelly stated that these work books, while valuable as resources for learning (e.g. for color diagrams), are counter-productive for student coherence. When given these books, students can see exactly where the curriculum is designed to have them go across the unit. As a result, Mr. Kelly worried his efforts to 'open up' the storyline for students' epistemic agency could be easily undermined. Given that the students in fact shared epistemic agency in many activities during Mr. Kelly's enactment, the presence of the book could lead to the unwarranted perception among students that they are not the primary drivers of knowledge-building. Mr. Kelly made plans to insulate the students' epistemic and conceptual arc from curricular convergences that could wrongfully undermine their ownership of their arc by not using the books in the future.

Overall, Mr. Kelly's sensemaking concerning this source of tension shifted across his participation in the DPC. Across the storyline, Mr. Kelly grappled with the tension between premeditated and student-based coherence in more complex, experience-dependent ways. Further, he began to make sense of this tension in practice as productive resources for sharing epistemic agency with his students.

2. Equitable participation and incremental building of science ideas

Tension between equitable participation and disciplinary understanding began at the onset of the storyline. Across the DPCs, Mr. Kelly regularly articulated concern about tensions between his efforts to equitably involve all students in knowledge-building and his facilitation of students' incremental conceptual understanding across the storyline. From the beginning, Mr. Kelly consistently voiced the importance and challenge of equitable student participation in knowledge-building. For example, in the pre-interview, Mr. Kelly said:

> *"You know, I see you got to take the kid who's being quiet about everything and asking what their ideas are. Sometimes that's the kid who thinks they're totally wrong, but actually has got the most profound statement. Yeah. I feel we've got a decent classroom culture here, but I think obviously that's something that's going to be challenging and, a lot of times we have to stop and we have to talk about what are we really doing here, what's really the goal? And yeah, I'm sure if you're in here you'll see a couple of moments like that, where it's like, no, stop. Let's step back for a moment"*

In this quote, Mr. Kelly described the importance of drawing out more reserved students' ideas into the learning community. He also voiced the need to pause instruction and refocus the classroom community's attention in learning to support equitable participation in the storyline. He aptly foreshadowed the challenge of equity in knowledge-building that subsequently emerged and was addressed by Mr. Kelly over the course of the DPCs.

In planning and reflection, Mr. Kelly regularly addressed the challenge of equitable participation. Beginning in lesson 1, Mr. Kelly raised concern about the challenge to promote equitable participation while also promoting students' conceptual learning. In this lesson, students were introduced to the anchoring phenomenon: a speaker vibrating using a magnet and a coil of wire. Students explored and initially modeled this speaker phenomenon to explain what forces caused the speaker to vibrate. After modeling, they came up with examples of related phenomena that involved magnets or electromagnets. The students then asked questions about the speaker system and related phenomena. After publicly posting their questions, the students were to organize their questions into groups that they would then investigate further. Mr. Kelly said the following about this process:

> *"Yeah, you know it was that connection. I think a lot of kids didn't know. I think in retrospect, they were thinking well mine says cone, but does that really mean it's connected or is it too shallow of a connection. I think that was really the issue that we had the most. The last class of the day, I definitely allowed very shallow connections and I was clear about that, and I worried because maybe the connections they made were really shallow because yeah, "my question's about the cone, too." "Yes, my question's about the cone, too." "Yes, my question's about the cone, too." And it's like everyone was like that. It was like, well, okay. You know, I guess those are connected, but you know it doesn't deeply."*

In this quote, Mr. Kelly explained how he negotiated equitable student participation and the depth of conceptual connection between students' questions. In the first class (the one filmed), he perceived students were reserved in sharing connections because they were worried their connections were not deep enough (i.e. connecting beyond both the questions referencing a speaker part). As a result, only a few confident students regularly participated to share deep conceptual connections among questions. In response, in the final class, he addressed this equity concern by explicitly launching the discussion in a manner that framed any connections between questions as appropriate. As a result, the students more equitably participated in the activity, but the connections had less conceptual depth. This example illustrates that this tension between conceptual rigor and equitable participation was relevant even at the onset of the storyline.

This tension became more acute as the teacher tried to promote the equitable construction of science ideas in a time-efficient manner. Mr. Kelly described several instances in the subsequent planning where there was tension between his efforts to promote equitable participation and students' incremental conceptual understanding in a time-efficient manner. In lesson 5, Mr. Kelly described student participation during their discussion of the consensus model of the speaker system. In this lesson, students developed a checklist of criteria for a model (Windschitl, Thompson, & Braaten, 2020) based on what they figured out in lessons 1-4. Students constructed initial models independently and in small groups, and then developed a consensus model as a whole class in discussion. During this consensus discussion, students suggested parts of their models that should be included in the class consensus model. Mr. Kelly described this discussion as follows:

> *Mr. Kelly:* *Especially with the class you've seen. I wish I was having more voices. It's really tough because that table of there, it's Mya who has her moments, but she's really resistive to being a full-fledged member of the community.*
>
> *Co-planner:* *Exactly.*
>
> *Mr. Kelly:* *There's another kid there who I won't get into, but she's got a lot of trauma going at home, and so she probably gets two hours of sleep a night, and if she comes into school ready to participate, it's fantastic, but nine times out of ten she's not ready to really be here. And Darryl, who can get involved, and really wants to be supportive and a good friend and talking here and there... I don't know. And then we've got the girl who doesn't really talk outside of writing.*
>
> *Co-planner:* *Yes, but she has great written responses.*
>
> *Mr. Kelly:* *Right. We've also got Ana who's starting now to come back into science class, thank God, because she shut down recently.*
>
> *Co-planner:* *I do remember that, yes.*

Mr. Kelly: *And so she started now to come back a little bit more into class, which is good. There's so many quiet kids in that class that it's just…I don't know how to do it without just torturing the class by staying on ideas.*

In this interchange, Mr. Kelly explained how several students in his class had substantial in-school and out-of-school considerations that logically constrained their capacity or desire to participate in knowledge-building. Mr. Kelly went on to describe his concern in trying to draw out these quiet students' voices and their ideas, when other students had already expressed understanding of these science ideas and desired to move forward. Mr. Kelly used the term 'torturing' to describe his perception of how the class must feel when he attempted to draw out ideas from reserved students.

The teacher productively wrestled with this tension to promote equitable participation across the unit. Starting in lesson 1, Mr. Kelly faced challenges in his attempts to facilitate equitable knowledge-building with students. As a result, Mr. Kelly readily planned to accommodate the challenges in subsequent enactments of the same discussion with other classes:

> *"I think I tried to push through all the questions and categorize them on that day versus the other classes, we got the questions up and I went to the following day to categorize them and move on, and I just wanted to spend a little extra time putting the questions in and not feel like I had to continue, you know? Like it's sometimes is the first time you teach something, it's like oh, okay, well let me pace that differently with the rest of the kids, you know? I knew then that I really wanted to take the time in the second class to hear everyone share at least one question before we even started thinking about organizing the board."*

In his first class, Mr. Kelly felt the time he allocated to this discussion was insufficient for all students to ask at least one question and to equitably participate. As a result, he adapted subsequent instructional design of this initial ideas discussion to give students more time to participate in the construction of their public record of their questions.

The negotiation of equitable participation and incremental conceptual learning remained a persistent challenge and an area for planning during the DPCs. In reflection on lesson 9, Mr. Kelly discussed when students were planning the investigation for that lesson. During that time, Mr. Kelly noticed that only one table group was sharing ideas to investigate the relationship between magnetic force and the distance between two magnets. To address this equity issue, the teacher allowed this group to start the experiment in the hallway and then regrouped with the rest of the class. He described the consequences of this move as follows:

> *Mr. Kelly:* *I mean when we set those guys in the hallway to do the experiment, everyone else piped up when those guys were gone which is great. But I feel like they sort of take the backseat with those guys, and I don't feel like everybody except for maybe who's the girl with her head down always right there is truly checked out. Because then some kids started opening up.*
>
> *Co-planner:* *That was a good move.*
>
> *Mr. Kelly:* *But I definitely, I mean there was more space after for sharing and working with science ideas.*

In this account, he explained how this move served both the ends of equitable participation and conceptual learning. Specifically, in moving the most vocal table group, Mr. Kelly felt that he had opened up space for students to both share and work on science ideas. Mr. Kelly was able to productively leverage an instance of tension between participation and conceptual learning as an opportunity for more students to share in communal knowledge-building.

The challenge and necessity to productively address these tensions was summed up by Mr. Kelly in the post-interview:

> *"I think towards the end the content got so complex that a couple kids started getting lost in exactly what was going on. You know, I think that's to be expected when we're talking about fields and drawing them and talking about the strength of these invisible forces and everything. But you know, every time where I'd stop and say, you know when the kids were getting lost and waiting for me to answer I'm like, "This is not what I say, this is what you say. There's nothing up here that came from me. Everything's coming from you guys." And you know, even there was one time I said that and one kid was like, "Na-uh." I'm like, "What came from me?" You know? And the other kids are like, "Oh yeah. Yeah, no. Those are all our ideas." Which was good. You know? So first of all the power that comes from the kids."*

Here, Mr. Kelly thoughtfully explained why the promotion of equitable participation in incremental conceptual learning is important for positioning students with real epistemic ownership over the construction of ideas in the storyline. Mr. Kelly's maintenance of the norm of equitable participation positioned him to authentically respond that the students in fact drove the development of ideas across the storyline. Across the DPCs, Mr. Kelly maintained a sophisticated sense of the importance of equitable participation in students' conceptual learning. Additionally, similar to his sensemaking concerning coherence, Mr. Kelly began to frame and address this persistent tension in sensemaking and enactment as a productive resource to share epistemic agency with his students.

3. Singular or different form(s) of epistemic agency in discussion

Initially the teacher viewed epistemic agency in all discussion types as similar. In the DPCs, Mr. Kelly regularly made sense of the different forms of epistemic agency available to students in the discussions. Mr. Kelly displayed increased understanding over time about how the knowledge-building work differed in initial ideas, building understandings, and consensus discussions. Initially, Mr. Kelly employed more generalized notions of the role of discussions. For example, during the pre-interview, Mr. Kelly was unclear about the different forms of discussion in the storyline:

> *Co-planner:* *Do you envision there being different types of discussion?*
>
> *Mr. Kelly:* *What do you mean by different types of discussions?*
>
> *Co-planner:* *I guess maybe just discussions that would have different goals to them, or students would be doing a different thing in talking to each other.*
>
> *Mr. Kelly:* *I'm not sure if I would see that necessarily across from lesson to lesson. I know that there's going to be parts where they're going to figure out, well, what should we do with these materials, what can we test out? How are we going to ... what does that mean? You know, and you might have designed an experiment and they find out the end, oh, that doesn't really mean anything. Let's go back and let's figure out what we can do that's going to tell us something.*

In this example, Mr. Kelly equated all discussion types as similar in the 'figuring out' process of the storyline, and focused on the knowledge-building work that occurred around investigations in particular. While some initial ideas and building understanding discussions are based in concrete investigations, these discussions have different epistemic goals and practices in knowledge-building. Further, consensus discussions involve a distinct set of epistemic goals and practices not acknowledged in this response (e.g. synthesizing ideas and coming to consensus on a shared knowledge object like an explanatory model).

The initial ideas discussions remained focused on getting student ideas out. In planning for different discussion types, Mr. Kelly became more well-versed in the goals and practices involved. For example, in planning for the initial ideas discussion in lesson 1, Mr. Kelly made sense of the intended outcome of this discussion as such:

Mr. Kelly: *It's weird because they're not really trying to answer that question necessarily.*

Co-planner: *No.*

Mr. Kelly: *They're just trying to figure out how we can initially answer that question.*

Co-planner: *Right, kind of like questions about that question.*

Mr. Kelly: *Right. Okay. So the intended outcome of the discussion is basically they're figuring out- they're sort of breaking that big question down to smaller pieces, they're sort of finding related questions to it, right? Questions based on their initial ideas about the anchor and related phenomena.*

In this interchange, Mr. Kelly described this discussion involving students asking questions that addressed different ‘pieces’ of the broader driving question for the unit. He went on to mention how these questions should be grounded in students’ initial experiences with the anchoring phenomena. Further, Mr. Kelly went on to describe the importance of having students connect their questions to one another’s in the construction of a public record of their questions (i.e. Driving Question Board (DQB)):

> *“Right, and it's [student questions] got to be connected. I wrote that down because I think that's really strong about how can you connect. Not only does it need to be connected, but you don’t raise your hand if it's not connected. So raise your hand if you think yours connects to that in some way. I think that's really important. Because the idea is that they're relating and that, by putting up there, they're almost making categories a little bit. Because they're putting up there too. So that it's not just me categorizing. So like, okay well you guys all said it was, you had a lot of questions about this. We'll explore this first.”*

Mr. Kelly explained that it was important for students to find connections between questions because such a practice would afford students greater agency in the construction and organization of categories in the public record. Additionally, he predicted that this activity would position the class to navigate to the next lesson in a manner that is coherent from the student perspective (e.g. *…you had a lot of questions about this. We'll explore this first”).* This sort of sensemaking involved both sophisticated understanding of the purposes of the initial ideas discussion and of strategies (e.g. raise your hand if your question connects; student-driven category development) to share epistemic agency with his students in this discussion and in navigating to the next lesson.

The consensus discussion became more focused on incremental model building over time as a classroom community. Mr. Kelly also showed a more sophisticated sense of the forms of epistemic agency in consensus discussions during and after planning for such a discussion in lesson 5. In planning for this discussion, Mr. Kelly described specific strategies he would use to launch the discussion and the construction of the consensus model:

> *“Yeah, so I think I would say “you know we've figured a lot about the magnetic field now. We've got to bring that knowledge to update our model”. I think also maybe reframing it around, just like we did last time and we started with the basic model, and we took a major conceptual step up. Time to take that step again, to discuss how we should revise the model of the speaker system. To agree on the important things, we need to add to this model about fields.*”

In this quote, Mr. Kelly described the manner in which he would frame the consensus model activity to collectively work toward a revised consensus model. In his view, consensus discussions center on taking stock of what has been collectively figured out (e.g. *“agree on important things”*) and on the public revision of earlier models (e.g. *“we need to add to this model about fields”)*. Similarly, in the post-interview, Mr. Kelly explained the value and the difficulty in constructing consensus models with students:

> *"In discussion I think that's really hard [making a consensus model]. And that's one that I've looked at over the years and tried to develop, like I've got a plate tectonics unit that every day we come back to a model and they make a model of what we learned that day. But it's not necessarily the same model, maybe it's building on, maybe it's a piece over here or whatever. I think it's really hard to make a consensus model and come back and change it…To come up with and discuss consensus models that works until we learn more about it, and then we come up with and discuss a better model that explains more."*

Mr. Kelly expressed the difficulty of developing a consensus model in class-wide discussion. To explain this difficulty, he compared the quality and use of consensus models in a previous unit (plate tectonics unit) with his current enactment of the Forces storyline. He thought that the models students developed in the plate tectonics unit were meaningfully different in that the class was developing various, loosely connected models across lessons that built and found coherence between ideas in haphazard manner ("*a piece over here or whatever").* In comparison, Mr. Kelly felt the public revision of consensus models in the storyline were substantially more difficult to facilitate because this involved problematizing what does not work about the current iteration of the consensus model ("*discuss consensus models that works until we learn more"*) and revising the model to provide a new explanatory account *("come up with and discuss a better model that explains more.")*. In both quotes, Mr. Kelly described multiple forms of epistemic agency for consensus discussions: 1) taking stock of what ideas the class has figured out, 2) asking students to come to agreement about modifications to the consensus model and, 3) incremental revising previous models with new science ideas. Across DPC participation, Mr. Kelly made more complex sense of the epistemic practices and purposes for consensus discussion and the development of class-level models.

The building understanding discussions became more focused on evidence use and greater conceptual rigor. Similarly, Mr. Kelly showed greater specificity about the epistemic purposes and practices involved in building understanding discussions. For example, in the post-interview, Mr. Kelly clearly articulated some of these differences between building understanding and initial ideas discussions:

> *"Yeah, I mean certainly I think when we're coming to an understanding, they've got to be asking more about what's the evidence. Like what did we learn? Think back to the experiment we did. Versus in the beginning there's not much to draw on, so it's like, "What do you think is going on? What are the pieces that you have a hunch that are working?" And that's where everybody starting drawing towards the magnet and the coil to sort of show us what direction we needed to investigate, you know?"*

In this example, Mr. Kelly discussed how building understanding discussions differed from initial ideas discussion, because they primarily involved students working with evidence to make sense of ideas in investigations. In an initial ideas discussion, though, knowledge-building primarily involved students putting their initial ideas on the table to motivate and navigate to subsequent investigations. Further, he went on to say:

> *"In initial ideas discussions any idea is going to fly, right? Like, "Maybe, great let's write that up, let's put up a question." But when we build understanding, I mean they were still coming up with questions, but they were more explaining what happened in the lesson with evidence to back it up. So they were able to have deeper more specific thoughts."*

Mr. Kelly again showed greater understanding of the purpose of the building understandings and initial ideas discussions than prior to his participation in the DPCs. This same level of understanding was present in Mr. Kelly's planning for the building understandings discussion in lesson 9.

> *"In terms of using evidence, it's going to be like what do we try during investigations that would support that idea? Or is that supported by what we found out? Or even just how do we know that? I just need to get the kids talking about how patterns in their force data relates to the strength of the magnetic field between two magnets. It will flow from there. Students will be able to make sense of the graphs."*

In this quote, Mr. Kelly was discussing how he would lead the building understandings discussion with his students. He mentioned a series of open-ended questions he could use to prompt his students to use investigation evidence to build science ideas in the lesson. In positioning students to make these evidence-reasoning connections, Mr. Kelly felt the discussion would then 'flow from there'. Mr. Kelly's sensemaking concerning this discussion exhibited a complex conception of the instructional design work that goes into facilitating this discussion. His sensemaking was more concerned with positioning students to interact in a particular conceptual space rather than focused on explicit instructional procedures to get to particular class-wide explanations. He also expressed trust in his students because he sincerely believed that, in occupying this conceptual space, the discussion would 'flow' and students would be able to drive the construction of science ideas from the lesson. Rather than strict fidelity to curricular procedures, Mr. Kelly discussed the conceptual space in which he sought to position his students so they could interact and build ideas. This depiction of facilitation focused on fidelity to the goal of making the discussion coherent from the student perspective as it entrusted students to lead knowledge-building from that conceptual space.

Discussion

This study depicts one teacher's efforts to make sense of different sources of tension as he enacted a storyline for students' epistemic agency. I posit that the form of sensemaking which Mr. Kelly engaged in can support other teachers' efforts to interpret and enact curriculum for their instructional goals (e.g. for epistemic agency, for equitable participation, etc.). In what follows, I will detail this form of sensemaking I call, *student-informed curricular sensemaking*. Then, I will consider how the storyline materials and the structures of the DPC environment can support student-informed curricular sensemaking. Finally, I will highlight potential implications that stem from this new understanding of curricular sensemaking.

Student-informed curricular sensemaking

Teachers enactment of curriculum is a design activity in which they interact with, interpret, and use curricular materials to craft instructional episodes (Brown, 2009). Mr. Kelly engaged in instructional design when he interacted with, interpreted, and used the storyline materials to craft instruction episodes of discussion for students' epistemic agency. Across the DPCs, Mr. Kelly developed capacity to make sense of the tensions between his instructional plans for epistemic agency and his enactment of the storyline with his students. I call this type of sensemaking, *curricular sensemaking*, as it involves the interaction between the teacher and the curriculum and how subsequent planned and enacted curriculum was an outgrowth of this participatory relationship (Remillard, 2005). Curricular sensemaking involves a teacher making sense of tension between their interpretation and instructional design of curriculum and their subsequent enactment with their students in their local context.

I term Mr. Kelly's unique engagement in this work, *student-informed curricular sensemaking.* In general, student-informed curricular sensemaking involves a teacher's efforts to attend, interpret, and respond to students' emergent ideas and participation in subsequent design plans for storyline activity. In this form of sensemaking, students are the catalyst for subsequent curricular sensemaking and instructional design. As a result, the teacher's sensemaking is not driven by the goal of making student experiences parallel with the design of storyline activities in the written curriculum. Instead, it is driven by the goal of shaping storyline activity to support students' search for connections and consistency between ideas in the curriculum and their own experiences and ideas (Sikorski & Hammer, 2017). This is consistent with the storyline instructional approach and the goal to support coherence for students in enactment (Reiser et al., 2021). However, this stands in contrast to other views of curriculum-use that prioritize fidelity of implementation in which teachers' enactment closely follows prescribed procedures or activities (O'Donnell, 2008; Seraphin et al., 2017) and power structures that position the teacher and curriculum as the primary epistemic agents in science learning (Apple, 2013; Varelas, et al., 2015). Instead, student-informed curricular sensemaking highlights that a multiplicity of enactments can both align to the overarching goals of the curriculum and be responsive to the students' arc of inquiry in science learning (Buxton et al., 2015).

Mr. Kelly's engagement in student-informed curricular sensemaking supported his efforts to share epistemic agency with his students in the storyline. Mr. Kelly learned to leverage tensions to position students with epistemic agency in storyline activity. As a result, engagement in this curricular sensemaking enhanced his capacity to interpret and leverage storyline materials in teaching for epistemic agency. This capacity represents Mr. Kelly's 'pedagogical design capacity' (PDC) (Brown, 2009) for epistemic agency, or his capacity to mobilize storyline resources for epistemic agency in instructional design. Future research should investigate whether rigorous engagement in student-informed curricular sensemaking can develop teachers' pedagogical design capacity (PDC) for storyline materials.

Supporting student-informed curricular sensemaking

Storyline curricular materials and professional learning supports can be used to productively support teacher engagement in student-informed curricular sensemaking. For storyline materials, the 'coherent from the student perspective' design to storyline materials powerfully organizes teacher's instruction and students' learning. This focus on student coherence is different from many previous science curriculum, which have instead focused on building science ideas from a disciplinary perspective (Sikorski & Hammer, 2017).

The coherent underlying structures of the storyline systematically organize the community's knowledge-building efforts across the storyline. Therefore, I view the storyline as a guardrail for teachers' student-informed curricular sensemaking. In this context, teachers make sense of tensions and engage in instructional design work from the starting point of the storyline materials and their coherent structure. These structures allow teachers to offload some agency to the materials to guide coherent instructional activity (Brown, 2009). As a result, the teachers' efforts in curricular sensemaking are freed up to focus more on the students' current and prospective coherence-seeking while making sense of the storyline materials (i.e. be student-informed). Teachers can diverge from this structure to support students' epistemic agency and then can return to this structure as they facilitate students' efforts to find connections and consistency between their ideas and the science ideas built into the storyline. To share epistemic agency with students, teachers need the capacity to support students' divergent coherence-seeking from the arc of the storyline. Teachers also require the capacity to support students' convergent coherence-seeking in order to co-construct the storyline together. Both capacities are vital for teachers' use of storyline materials to craft coherent instruction with students.

In addition, teachers would benefit from professional learning that concerns their planning and reflecting on their storyline enactment for their goals and for fidelity to the storyline approach. Teachers should participate in professional learning that directly addresses and supports their engagement in student-informed curricular sensemaking and use. I believe the structures of the discussion planning cycle were productive for Mr. Kelly's student-informed curricular sensemaking. In the DPC setting, the teacher and co-planner jointly analyzed tensions between instructional planning and Mr. Kelly's subsequent enactment of the storyline materials. This discussion planning cycle involved an assemblage of conversational routines (e.g. stimulated recall) and material resources (e.g. discussion planning tool, practical measures) (Horn & Little, 2010) that productively structured and supported the teacher's capacity to make sense of, and respond to these tensions in their design of storyline instruction. For example, the teacher and co-planner engaged with the discussion planning tool and in stimulated recall to plan and reflect on instructional episodes of storyline discussion. This tool and conversational routine primed (Windschitl, Thompson, Braaten, & Stroupe, 2012) Mr. Kelly to consider how his students would engage in knowledge building during the discussions. In turn, this priming supported Mr. Kelly to identify tensions between his plans for sharing epistemic agency and his enactment, because he could readily detect when student participation ran incongruent with the responses he anticipated in discussion planning and reflection. Across participation in the DPCs, the teacher and co-planner were able to unearth, discuss, and plan in a manner that aligned to their goals for instructional design and with fidelity to the storyline approach. As a result, I am also interested in leveraging this professional learning environment to support teachers' curricular sensemaking and storyline enactment more broadly as it is accomplished in schools.

Implications

There are several implications that stem from our conception of student-informed curricular sensemaking and our efforts to develop this form of sensemaking. First, I argue that revisions to the storyline curriculum materials could support teachers' student-informed curricular sensemaking and enactment. I contend that storyline curriculum materials need to better amplify for teachers, the epistemic, conceptual, and interactive coherences embedded in the storyline materials. These epistemic, conceptual, interactive coherences are reflected in a variety of activity structures in the storyline materials. Therefore, in reading the materials, the teacher should be able to quickly interpret in the activity how students will engage knowledge-building practice (i.e. investigations, sensemaking), disciplinary understandings (i.e. targeted explanations, models, solutions), and talk with one another (i.e. dialogic/interactive structure). One suggestion to amplify these coherences is to reduce the degree of scripting in the storyline materials. Mr. Kelly expressed difficulty in enacting highly scripted storyline activities in a manner that felt non-scripted and coherent for his students. In its place, storyline designers could make explicit note of the epistemic, conceptual, and interactive coherences in the teacher-facing lesson materials. For example, teacher-facing materials already often include examples of the consensus models, explanations, and solutions that the classroom community might develop in enactment. Developers could bolster this support by providing additional representations that depict different degrees of conceptual or representational sophistication, but still possess the same underlying causal mechanism. The developers could highlight the basic pieces of the causal account in each representation. This support would focus the teacher's attention to the conceptual coherences in constructing the representation as a classroom community. Instead of scripting this key activity, the teacher is afforded the agency to consider how to plan for and enact a local representation of this mechanism in negotiation with their students' coherence-seeking efforts.

Together, these supports could serve as an important educative feature for teachers to reference and use as they build instructional designs around these coherences.

These coherences would communicate to teachers the epistemic, conceptual, and communal rationale for student engagement in particular activities across the storyline (e.g. for discussions). This is an important goal for educative curriculum because this rationale can enhance teachers' understanding of the goals and practices of curricular activity and support teachers to adapt curricular materials to meet the needs of their students (Beyer, Delgado, Davis, & Krajcik, 2009). More explicit focus on these designed coherences in the materials will "speak to" teachers about the goals of the storyline activity rather than trying to speak these goals through them with scripting and intensive direction (Davis & Krajcik, 2005). As a result, I think these educative supports can give teachers a greater sense of professional discretion in their storyline enactments. Future research should explore how variations in the curricular design inform teachers' understandings and enactment of the curriculum.

The professional learning structures of the DPCs can be adapted to support student-inform curricular sensemaking for storyline units from a more school-wide perspective. This perspective involves the functions of teaching a storyline as they are realized in schools (Cobb, McClain, de Silva Lamberg, & Dean, 2003). The functions of storyline teaching include teachers' instruction with students, as well as functions related to organizing and supervising storyline teaching (Cobb et al., 2003). The 1-on-1 structure of the DPCs was beneficial for exploring one teachers' curricular sensemaking and enactment, but did little to address the other functions of science teaching. Therefore, I suggest mobilizing the general structures of the DPC environment in school-wide professional learning communities (PLCs) (Hord, 1997) consisting of teachers, instructional leaders, and other school professionals. These PLCs can develop goals and address tensions in storyline enactment based on the contours of their institutional context and on their collective vision for science teaching at their school (Penuel, 2019). In turn, these PLCs can attempt to resolve these tensions through distributed activity. In this process, the storyline teacher would develop their capacity for student-informed curricular sensemaking and instructional design and the other PLCs members would develop their capacity to provide congruent support to storyline teaching in the form of instructional leadership, cross-discipline collaboration, etc. This form of PLC would collectivize efforts to improve storyline teaching across the various systems and actors in the school. Future research should explore how the conversational routines and material resources used within the DPCs can be taken up and adapted for other professional learning contexts, such as PLCs.

The vision for instruction has shifted to one in which all students are known, heard and supported as they engage in knowledge building-work in their classroom communities, not only in science but across disciplines. Curriculum materials are important resources to support teachers in this work; however, to align with this vision the enactment of those materials requires teachers to attend, interpret and respond to students' emergent ideas and participation. Student-informed curricular sensemaking offers a lens to design curriculum materials and professional learning experiences to better support teachers in this important work of negotiating and sharing epistemic agency with students.

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Appendix 1: Discussion Planning Tool

Discussion Planning and Reflection Tool

Before the discussion (Analyzing and reflecting on the lesson in the teacher guide):

1. What is the question students are trying to answer through this discussion?

2. What is the intended outcome of the discussion? (coming to consensus on something we just experienced? Figuring out improvements to our model? Designing an investigation? Getting students to realize they have new questions?)

3. What are the key elements of the model or explanation you want the students to grapple with? (create an explanatory model for this phenomenon for yourself)

4. What other ideas might students have? What questions might they ask?

Leading the Discussion (Considering talk moves and strategies in teacher guide)

1. What will you say to launch the discussion?

2. What are some things you will say to encourage your students to work with one another's ideas?

3. If students seem to think they have explained the phenomenon but you know they need to go deeper, what kinds of questions could you ask to help students see the need to extend or revise their explanations?

4. What will you say to help close the discussion to synthesize what it is you all agree on and/or what new questions you have?

Taking Stock Reflective Notes

After the discussion (spend 10-20 quiet minutes writing)

1. What ideas and reasoning did you hear? How would you describe the groups' understanding of the ideas you identified in question 3 of your planning?

2. What went well in the discussion?

3. What was challenging?

4. Describe a moment when you weren't sure what to do. What *did* you do and why? And what was the result?

5. Anything you would do differently if you could do it over?

Appendix 2: Practical Measures

1. Did you share your ideas out loud today to the whole class, a small group, or a partner? (**check one only**)
   - Yes
   - No
   - Unsure

2. If you answered yes to the last question, did any of your ideas influence the class or help others? (**check one only**)
   - Yes
   - No
   - Unsure

3. Did any other students share ideas out loud today to the whole class, a small group, or a partner? (**check one only**)
   - Yes
   - No
   - Unsure

4. If you answered yes to the last question, did you learn more in class today because other students shared their ideas or opinions? (**check one only**)
   - Yes
   - No
   - Unsure

5. I have ideas about what questions we should investigate next. (**check one only)**
   - Yes
   - No
   - Unsure

6. Whose questions or ideas did you mostly explore in class today? (**check all that apply**)
   - The teacher's
   - My own
   - The class
   - My small group's
   - The curriculum's
   - My community's
   - We did not explore any questions or problems

7. I understand how today's class ties to the bigger picture for what we're studying in this unit. (**check one only**)
   - Yes
   - No
   - Unsure

8. What we did in class today matters to because (**check all that apply**):
   - I think what we did today will be useful to my everyday life or future.
   - I care about this because it will help me get a good grade.
   - I think the material is interesting.
   - What we did today doesn't matter to me

Appendix 3: Pre- and Post-Interview Protocol

1. Now think back to the OpenSciEd winter PD. We discussed the key OpenSciEd elements for these units. How do you think each of these elements is reflected in the Forces at Distance unit? (how is this element supported in the curriculum)?
    - Centered around student questions and ideas about phenomena or problems
    - Students incrementally build and revise ideas based on evidence.
    - Student driven and coherent from the student perspective
    - Collaborative-WE figure out ideas together
    - Requires a classroom culture that values all ideas
2. How do you think these elements are and are not reflected in other science units you have taught in the past?
3. What do you see as the role of discussions in the Forces at a Distance unit?
4. Take a moment to look over the storyline. Do you envision there being different types of discussion that occur across this unit?
    - If so, what do you think these types might be? What purpose does each serve?
    - If not, what makes all these discussions similar?
5. What, if anything, do you think is different about the role of discussions in Forces at a Distance unit and the role of discussions compared to other science units you have taught?
6. Now think about your district & school context. What opportunities or challenges do you envision from your context in enacting this unit? Think specifically about opportunities and challenges related to:
    - Instructional leadership and evaluation
    - Science state testing and accountability systems in your school
    - District and school-level initiatives (e.g. pacing demands, curriculum or technology use)
    - Resources in your school (time, materials, technology)
    - Other areas?

<u>**Section III**</u>

Responsive instructional design for students' coherence-seeking: Documenting episodes of principled improvisation in storyline enactment

Introduction

A shift from students 'learning about' science ideas to students 'figuring out' science ideas using science practices is a key element of recent reform efforts in science (NRC, 2012; Schwarz, Passmore, & Reiser 2017). Teachers can be supported in this reform shift by providing them with curricular materials that both organize classroom engagement in 'figuring out' (Penuel & Reiser, 2018), and help them to discern the underlying purposes and structures of the materials (Davis & Varma, 2008). Storyline curricular materials support students 'figuring out' of ideas as these materials are designed to be coherent from the student perspective (Reiser, Novak, McGill, & Penuel, 2021). Each unit is designed as a sequence of learning activities that are driven by students' own desires and efforts to figure out natural phenomena (McNeill & Reiser, 2019). As a result, these curricular materials are valuable resources to organize and support students' efforts to seek coherence or make progress on their questions and problems about natural phenomena in the storyline (Reiser, Novak, & Fumagalli, 2015).

However, these curricular materials are not the main driver of coherence-seeking efforts during enactment. Fostering coherence from the student perspective in the enactment of these materials requires that teachers provide space in the curriculum for students' epistemic agency in their coherence-seeking (Reiser, et. al, 2021; Sikorski &

Hammer, 2018). This requires responsive adaptation and improvisation of the materials, sometimes in the midst of instruction to address both expected and unexpected knowledge-building work by the classroom community (Brown, 2009; Remillard, 2005). In moment-to-moment enactment, teachers must deviate from the premeditated coherences of the storyline materials to address and productively mediate student epistemic agency in their coherence-seeking efforts. In this study, I will investigate what enactment looks like when students deviate from these curricular coherences during different discussions in a storyline unit.

Theoretical Framework

In what follows, I will first explain how teachers' use of storyline curriculum can support their teaching for students' epistemic agency. I will then explain the notion of principled improvisation to highlight one form of teaching for epistemic agency in storyline enactment. Finally, I will provide theoretical grounding for my descriptions of episodes of principled improvisation (EPI) in this study. Specifically, I describe EPIs using the construct of teacher attention and responsiveness. I focus on the way teachers attend to epistemic, conceptual, and interactive substance in students' talk over the course of the EPI.

Storyline enactment for epistemic agency

Teachers' enactment of curriculum is always a design activity in which they interact with, interpret, and use curricular materials to craft instructional episodes (Brown, 2009). In storyline units, teachers craft instruction from materials that are designed to be 'coherent from the student perspective' (Reiser et. al, 2021). That is, the units are designed for students to see their efforts as making progress on questions and problems their classroom community has committed to address, rather than simply following directions from textbooks or teachers (Reiser, Novak, & Fumagalli, 2015). The coherent design to the storyline materials organizes classroom activity so students act with epistemic agency in the direction and management of knowledge-building across the storyline (Damşa, Kirschner, Andriessen, Erkens, & Sins, 2010; Ko & Krist, 2019). In general, I define epistemic agency in this study as students being positioned with, and acting on, opportunities to shape knowledge-building work in their classroom community (Miller et. al. 2018; Ko & Krist, 2019). As a result, the premeditated coherence of the storyline powerfully shapes and supports teacher facilitation of the storyline materials for students to act with epistemic agency in their coherence-seeking efforts (Reiser et. al, 2021).

From this perspective, storyline materials are a powerful resource for teachers to draw on as they design and enact instruction for students' epistemic agency. However, teaching for epistemic agency from storyline materials is never fully identical with the designed coherences in the materials (Sikorski & Hammer, 2017). Storyline enactments for epistemic agency require adaptation and improvisation of the materials (Drake, 2002; Heaton, 2000; Lampert, 1986). Teachers need to engage in the 'emergent epistemic curriculum' (Elby, 2001) with their students. This curriculum involves teachers taking up and cultivating students' emergent ideas as productive resources for subsequent knowledge-building and science learning (Elby, Macrander, & Hammer, 2016; Redish & Hammer, 2009; Sandoval & Reiser, 2004). In this emergent curriculum, students can act with epistemic agency to seek coherence in the storyline in a manner that converges or diverges from the premeditated or designed coherences in the curricular materials (Sikorski & Hammer, 2018). Therefore during moment-to-moment enactment, teachers must be willing and able to deviate from and leverage the storyline's premeditated coherences to address and productively mediate students' efforts to act with epistemic agency (Ko & Krist, 2019; Manz & Suarez, 2018). One form of this instructional process is represented in the idea of Principled Improvisation.

Principled improvisation in storyline enactment

Teachers' success in enacting a curriculum is a product of their efforts to interpret and mobilize the routines and activity structures in the materials in a creative and improvisational fashion to meet the needs of their students (e.g. Sawyer, 2004; Berliner, 1987; Leinhardt & Greeno, 1986). In storyline design, the teacher engages in creative and improvisational work when they foreground and background particular designed coherences in the materials to meet students coherence-seeking. This moment-to-moment instructional design work is referred to as principled improvisation. This construct of principled improvisation is primarily grounded in Robertson, Richards, and Elby's (2015) idea of meta-responsiveness. Meta-responsiveness refers to a teacher "being responsive about which facets of student thinking to foreground, in addition to his noticing and responding to the substance of student thinking in the first place" (p.17). The key connective tissue between meta-responsiveness and PI is that teacher engagement in both of these practices requires that the teacher make principled attentional decisions as to which facets to try to foreground (or background) in moment-to-moment classroom activity in pursuit of their instructional goals.

PI represents a more specific iteration of meta-responsiveness concerning instances in curricular enactment when the classroom community's efforts to deviate from the premeditated coherences of the curricular materials. In this context, the teacher addresses and mediates divergences between students' moment-to-moment coherence-seeking and the premeditated curricular designs for how students are expected to engage in knowledge-building work (epistemic coherence), disciplinary understandings (conceptual coherence), and dialogic and interactive activity with one another (interactive coherence). These episodes are considered *principled* when the teachers' talk and instructional moves address these divergences with an eye toward foregrounding particular designed coherences to support students to act with epistemic agency in their coherence-seeking. These episodes are considered *improvisational* as the teacher backgrounds other designed coherences and attends to emergent and varied forms of students' coherence-seeking.

Teacher attention in episodes of principled improvisation

Teacher attention and responsiveness. To describe the teacher's efforts in these EPIs, I will utilize a teacher attention framework. Teacher attention or noticing as an analytic framework stems primarily from the work of Sherin and her colleagues (e.g. Sherin, Jacobs, & Philipp, 2011). Teacher noticing as a practice involves two main components: (1) attention to particular occurrences in a classroom setting and (2) sensemaking around these noticed occurrences (Sherin & van Es, 2009). Following this work, other researchers have developed a third component of teacher noticing that characterizes how teachers actively respond to these noticings in the instructional setting (Grossman, Hammerness, & McDonald, 2009; Hammer, Goldberg, & Fargason, 2012). The substance of students' thinking is not only their speech and actions that employ canonical concepts and vocabulary but also the meaning they intend to convey from their point-of-view (Robertson, Richards, & Elby, 2015). The substance of students' ideas can be embedded with conceptual, epistemic, interactive facets.

Conceptually, teachers must attend and respond to how students' contributions relate to disciplinary understandings so as to advance and deepen students' conceptual understanding (Leinhardt & Greeno, 1986). Epistemically, teachers must attend and respond to student intuitions and knowledge-building efforts as resources for the communal development of productive epistemic criteria for engaging in science practices (Elby, Macrander, & Hammer, 2016). Interactively, teachers need to attend to the participant roles and relationships in *talk directed to* students and in *talk about* students (O'Connor & Michaels, 1996). This includes either explicitly talking about the configurations of interactional rights and responsibilities teachers expect for classroom activity (i.e. participant structures, Goodwin, 1990) or actively depicting students in these participant roles and social identities (i.e. animation, Goffman, 1981). In attending to substance, teachers can foreground and shift between conceptual, epistemic, and interactive facets of students' talk to encourage disciplinary understandings, promote epistemic agency, and facilitate dialogic interaction (Elby, 2001; Robertson, Richards, & Elby, 2015). These attentional shifts involve teachers embedding fine-grained noticings into coarser-grained attentional patterns that drive the framing of classroom activity (Robertson Richards, & Elby, 2015).

Attention and responsiveness in episodes of principled improvisation. In the context of this study, I will mobilize the teacher attention framework (Sherin, Jacobs, & Philipp, 2011) to describe how the teacher attends and responds to the conceptual, epistemic, and/or interactive facets in student talk during these EPIs. Conceptually, the teacher attends and responds to student talk that employs disciplinary understanding (both accurately or inaccurately) of science ideas. Interactively, the teacher attends and responds to the configurations of interactional rights and responsibilities in the substance of students' talk. Epistemically, the teacher attends and responds to clarity, consistency, and causality in the substance of students' talk. These three epistemic facets are drawn directly from Berland, Russ, & West's (2020) epistemologically responsive science teaching (ERT) framework. First, science teachers should attend to the clarity of students' talk of their science ideas. Clarity is important because the classroom community cannot collaborate on constructing knowledge unless students each understand the knowledge being discussed (McNeill & Berland, 2017). Second, science teachers should attend to the consistency of students' science ideas with evidence and other ideas. Consistency is important because science sensemaking requires the constant checking of ideas against relevant phenomena asking whether the idea being constructed aligns with nature (Kuhn, 1989). Finally, science teachers need to attend to causality in students' science ideas. Causality is important because constructing causal stories is fundamental to describing underlying mechanisms that cause phenomena (Nersessian, 1992).

The ERT framework is a powerful analytic tool to describe how the teacher attends to the unanticipated substance of students' talk with a principled focus on these epistemic criteria. This framework will be used to address the following research questions in this study: *1) How do the students deviate from the designed coherences in the materials during each episode of discussion enactment? 2) How does the teacher's facilitation of these discussion episodes embody principled improvisation and support students to take up epistemic agency?*

Methods

I used a single case study approach in order to capture the complexities and particularity of a particular classroom (Patton, 2001). A case study is suitable where (a) the focus of the study is answering "how" and "why" questions about (b) contemporary events (Yin, 2017). This single case study investigated how a teacher's facilitation of different storyline discussion embodied principled improvisation and supported students' epistemic agency. The participating teacher was purposely selected for this case study because he was uniquely suited to explore this instructional phenomenon. Specifically, he was a veteran teacher with a deep conceptual knowledge-base and substantial experience engaging students in science practice-based learning and the incremental building of science ideas. Therefore, this teacher was well-positioned to engage in principled improvisation with his students in these discussions.

Curricular Context

This study took place during the field test of middle school storyline units. These units were designed to align to recent reforms in K-12 science education (i.e. NRC, 2012;

NGSS Lead States, 2013). Specifically, the OpenSciEd Developers Consortium designed these curricula using the storyline approach. This approach provides students with a coherent experience that is motivated by students' own desire to figure out natural phenomena or solve engineering problems (Reiser et. al, 2021).

In particular, this study focuses on one teacher's pilot of a storyline unit titled: *How can a magnet move another object without touching it?* This unit is about forces that interact at a distance through fields that extend through space. It begins with students exploring the anchoring phenomenon concerning the vibration of a speaker when it makes noise. Students think about what causes this vibration. The anchoring phenomenon motivates students to dissect a variety of speakers to explore their inner workings. The unit then engages students in a series of investigations where they manipulate the speaker's parts to figure out how they work in the speaker system. Through these investigations, the students refine their consensus model about how permanent magnetic forces operate at a distance with electromagnets. This model is then applied to explain speaker technology and other phenomena that push or pull objects at a distance.

Three whole-group discussions within this storyline were selected for the case study. Storyline units use discussions to help draw out student ideas, support students in communicating with one another in scientific ways, and facilitate student sensemaking (Reiser et. al, 2021). The three discussions were selected because they were distributed in time across the storyline unit. They also represented each of the three types of storyline discussion, which are: 1) initial ideas, 2) building understandings, and 3) consensus discussions. Initial ideas discussions involve students expressing their beginning ideas about phenomena publicly. These discussions provide students with the opportunity to make sense of partially formed ideas and to realize there are gaps in their understanding. This discussion type takes place when students are beginning the process of making sense of a phenomenon. Building understandings discussions allow students to share claims and reasoning based on evidence. These discussions involve students connecting, critiquing, and building on each other's ideas. They occur at the end of a lesson in which students discuss and arrive at tentative evidence-based conclusions about the lesson's question using data from investigations, simulations and/or reading materials. Consensus discussions involve the class coming to agreement on some important idea(s) that they have been working on over the period of multiple lessons. During these discussions, students put together ideas and come to agreement about what they have and have not figured out about the phenomenon of interest. These discussions occur when students collectively work towards a consensus explanation or model.

The discussions chosen for this study took place in lessons 1, 5, and 9 across the storyline (12 lessons in storyline total, see table 2.1). The lesson 1 discussion is an "initial ideas" discussion. After the students explore the anchoring phenomenon (i.e. the vibration of the speaker), attempt to make sense of it, and identify related phenomena, they then gather in a circle for an initial ideas discussion. The main function of this discussion is for students to ask questions about the anchor, construct a public representation of their questions (i.e. Driving Question Board), and develop initial ideas for investigation in the next lesson. The lesson 5 discussion is a "consensus discussion." In this lesson, the class builds a consensus model of what they figured out in lessons 1-4 to explain how the alternating magnetic forces between a permanent magnet and coil of wire result in vibrations in the speaker system. The consensus discussion involves students coming together to share their individual models and explanations with the whole class to develop a consensus model for how the speaker works with magnetic forces. Finally, the lesson 9 discussion is a “building understanding” discussion. In this lesson, the class continues to investigate the magnetic field around magnets. In this discussion, the class comes together to share what they concluded from their investigations in Lesson 9 about the relationship between distance and magnetic force. Students use data from these investigations to explain in whole-group that the magnetic field around a magnet gets stronger when it is closer to another magnet.

Table 2.1: Focal Discussions

Lesson #	**Discussion Description**	**Discussion Type**
Lesson 1	Students gather in a circle to construct the Driving Question Board (DQB) around the 3 parts of the speaker system. The class then develops initial ideas for investigation and makes decisions about where to head in the next lesson	Initial ideas discussion
Lesson 5	Students create a class consensus model about how the speaker works with magnetic forces using what they figured out in Lessons 1-4. After, the class engages in a consensus-building discussion to share limitations of the current model and brainstorm what needs to be addressed next.	Consensus discussion
Lesson 9	Students design and carry out an investigation to answer their questions about the effect of distance on magnetic forces. The class then examines the mathematical relationships that appear in their data and discuss their findings about the relationship between distance and magnetic forces.	Building understanding discussion

Participants & Context

The teacher, Mr. Kelly, was selected for this study as part of the larger pilot of this storyline unit in a Northeastern state. In the past, he had both designed and enacted argumentation-based science curriculum (Knight & McNeill, 2015; Knight-Bardsley, & McNeill, 2016). Further, he had significant expertise in physical science and engineering, which included a BS in engineering from an elite research university and professional work in this field. Mr. Kelly was also a veteran teacher with over 15 years of middle school science teaching experience, middle school science and math (5-8 teaching credential, and a M.Ed in Leadership). I had also previously worked with Mr. Kelly when he was a participant in a multi-year, storyline-based professional learning series that I supported. Therefore, he was purposively selected (Patton, 2001) for this study based on my experiences with him, as well as my knowledge of his substantial work enacting reform science curricula with his students. As a result, I felt that Mr. Kelly was uniquely qualified to embody principled improvisation in his enactment of each focal storyline discussion. In particular, I believed he had substantial instructional capacity to decompress storyline science ideas and find productive connections between target disciplinary understandings and students' thinking and arc of inquiry.

Mr. Kelly's school was a Title I public middle school. It enrolled 365 students in grades 6-8 and had a student-teacher ratio of 11 to 1. According to state test scores, 20% of students were at least proficient in math, 11% in reading, and 3% in science. The school was designated by the state as requiring Focused/Targeted Support and was receiving assistance from the state to make progress toward improvement targets, accountability percentiles, graduation rates, and state testing participation rates. In terms of demographics, the school primarily served students of color (Hispanic, 58.9%; African American, 28.5%; Asian, 3.8%) and had a significant proportion of students who were classified as economically disadvantaged (see table 2.2). The school also enrolled a sizable population of students with disabilities and students who were classified as English Language Learners (ELLs). The school's average class size was 21 to 25 students. The target class for this study was a seventh grade class with 23 students. The class population reflected the broader school-wide trends in academic achievement, demography, and class size. The teacher, students, and school names in this study were replaced with pseudonyms to protect the participants' anonymity.

Table 2.2: School and Classroom Context

School	Unit Piloted	Grade of Students	Class Size	% Free and Reduced Lunch	% Persons of Color	% EML	% with disabilities
Mary B. Talbert Middle School	Forces at a Distance	7th grade	21-25	73%	95%	30%	24%

Data sources

I utilized three main data sources in this study: 1) curricular materials from target lessons 2) focal discussion video and transcripts and 3) related classroom artifacts. Concerning the first source, the curricular materials consisted of the teacher guide, class slides, and student handouts involved in each focal discussion. The teacher guide provides direction to teachers as to how to enact each storyline lesson and its embedded activities. The guide also contains 'educative boxes' that are embedded in each teacher guide and provide specific and just-in-time support to teachers (OpenSciEd, 2020). The class slides and student handouts are designed for teachers to use with their students to guide each moment-to-moment enactment of each storyline lesson. These curricular materials were used to determine the interactive, epistemic, and conceptual curricular coherences present in each focal discussion. Concerning the second source, all three focal discussions were video recorded and transcribed in full. The lesson 1 - initial ideas discussion was 40 minutes and 29 seconds, the lesson 5 - consensus discussion was 19 minutes and 36 seconds, and the Lesson 9 - building understanding discussion was 7 minutes and 16 seconds. Concerning the third source, whole group classroom artifacts were collected for each focal discussion. These artifacts represent the collective knowledge objects that were co-constructed in the course of each discussion (i.e. Driving Question Board, Consensus model, Class Graph). Consistent with a situative perspective on teacher and student practice, I viewed these public representations as important subjects of analysis of teaching and learning (Hall & Horn, 2012). Public representations produced in discussion provided a window into how a classroom community represents knowledge-building and conceptual learning during activity (Bannister, 2015). The final public representations in each discussion (i.e. knowledge objects) were used to derive students' epistemic agency and conceptual contributions (Ko & Krist, 2019).

Data Analysis

This analysis involved documenting the teacher's patterns of attention involved in each discussion and the co-construction of each shared knowledge object. I drew on interaction analysis (IA) (Jordan & Henderson, 1995) to document the shifts in the teacher's attention to multiple facets in the substance of students' talk. Further, I drew on Goodwin's (2007) notion of environmentally-coupled gestures. I mobilized this construct to describe how the teacher's attention sometimes involved language moves (González-Howard & McNeill, 2020), physical gestures to construct the knowledge object, and orientation to specific parts of the knowledge object (Goodwin, 2007). To capture teacher attention, I focused on documenting visible and audible traces (Jordan & Henderson, 1995) in the teacher's talk and embodied behavior that displayed attention to epistemic, conceptual, and interactive substance in student talk. This embodied interaction analysis allowed me to make more persuasive inferences about the teacher's 'knowledge in use' (Hall & Stevens, 2015) in his efforts at principled improvisation and his support of his students' epistemic agency.

I began by analyzing the curricular materials (i.e. teacher guide, slides, and student handouts) for each focal discussion. In reviewing the materials, I pulled quotes and information from the teacher guide that explicitly or implicitly described how the classroom community would engage in knowledge-building work (epistemic), science ideas (conceptual), and interaction with one another (interactive) in the discussion. I then logged this textual evidence and provided initial summaries of the epistemic, conceptual, and interactive coherences designed into each in each discussion. I completed this textual analysis to determine and be able to use these premeditated coherences as lenses for analyzing the video and transcripts of the discussion enactments. My initial pass of the discussion transcripts and videos involved two efforts. The first effort was to annotate the transcript by marking the places during discussion where the class added to, and revised the shared knowledge object. This included any explicit changes made to the writing and drawing on the public knowledge object over the course of the discussion.

I used numerical notation to insert mention of change to the knowledge object in the discussion transcript to mark the point of the change in interaction. Additionally, I developed a visual log of the corresponding images for each change to the knowledge object and marked these images with the related notation from the transcript text. This analysis allowed me to describe how the shared knowledge object developed over the course of each discussion and who in the class mobilized each change to the object. The second effort was to deductively flag instances in the discussion transcript where students' coherence-seeking efforts (i.e. agency) diverged from the planned coherences previously identified in the materials. To deduce these divergences, I focused on visible and audible traces (Jordan & Henderson, 1995) in students' talk and embodied behavior that depicted an epistemic, conceptual or interactive divergence from the pre-planned coherences for the discussion.

After this initial analysis, I focused on the flagged episodes of divergence for each discussion in a second pass of the discussion video and transcripts. This pass was used to document teacher attention in these discussion segments and to finalize the episode of principled improvisation chosen in each discussion type. To begin, I characterized how the teacher attended to, and shifted between different epistemic (i.e. talk about epistemic clarity, consistency, and causality; West, Berland, & Russ, 2020), conceptual (i.e. talk about content of science ideas), and/or interactive (i.e. talk about how to participate in the discussion) facets in the substance of students' talk in the EPI. This analysis provided a window into how the teacher handled the students' divergent agency in each discussion. I was able to characterize the facets (i.e. epistemic, conceptual, interactive) of student talk that the teacher flexibly foregrounded to address the divergence. I was also able to track the facets in student talk that he principally maintained focused on throughout the course of the divergence.

To answer research question one, I provided a descriptive account of how the students' coherence-seeking deviated from the curricular coherences in each discussion-based EPI. For each of the EPIs, I provided: 1) descriptions of the premeditated coherences in the discussion and 2) a descriptive account of teacher and student talk in the EPI and the co-construction of knowledge objects. For the description of coherences, I mobilized and reworked my initial summaries of the curricular coherences for each discussion to populate this section. For the account of the EPI, I provided classroom exchanges from the launch of the discussion, as well as across the course of the EPI. After the launch, each EPI involved a sequence of events where students diverged from the coherence of the discussion. The teacher, in turn, flexibly attended to this unanticipated substance with a principled focus on the goals and designed coherences for the discussion. Taken together, these details provided a comprehensive description of the coherences designed into the materials and the classroom community's efforts to deviate from these coherences in enactment.

To answer research question two, I interpreted how the teacher's efforts in the episode embodied principled improvisation and supported students' epistemic agency in the construction of each collective knowledge object. This interpretation was broken down to explain how the teacher's facilitation in the EPI was 1) principled, 2) improvisational, and 3) supported students' epistemic agency. To explain the teacher's embodiment of PI, I will focus on his patterns of attention (i.e. attentional coherences, Robertson et. al, 2015) and the related instructional moves that exhibited improvisation to students' coherence-seeking and/or principled focus on designed coherences and students' epistemic agency. Mr. Kelly's efforts in these EPIs were classified as principled if they were undergirded and observably worked toward specific goals and coherences in each discussion. This was evidenced when the teacher attended to, or foregrounded particular designed coherences in the substance of students' talk in order to mediate their coherence-seeking. His efforts were classified as improvisational if they attended to emergent and varied forms of students' coherence-seeking during the enactment of each discussion. This was evidenced when the teacher shifted their attention away or backgrounded particular designed coherences in the substance of students' talk in order to attend and respond to students' divergent lines of coherence-seeking. Finally, to interpret students' epistemic agency in the EPIs, I explained how the teacher's patterns of attention and related instructional moves positioned the students to build and revise the collective knowledge object in real time. Additionally, I provided annotated images of the completed knowledge objects to highlight and explain where the students acted with epistemic agency to co-construct specific parts of each knowledge object.

Results

Mr. Kelly engaged in episodes of principled improvisation in his enactment of each storyline discussion type. Mr. Kelly's efforts at principled improvisation in each discussion worked to position students with discussion-specific forms of epistemic agency in enactment. The findings in this study do not encompass all the different sources of student divergence or teacher agency in PI that are relevant to, or possible in storyline enactment. However, these findings demonstrate the regularity in which students' coherence-seeking can deviate from premeditated coherence of the storyline during enactment. In what follows, I will describe one episode of principled improvisation from Mr. Kelly's enactment of each of the three focal discussions. First, I will provide context for the focal discussion. This will include context from the curriculum, particularly focusing on the conceptual, epistemic, and interactive coherences designed into the curricular materials for the discussion. Second, I provided a description of the Episode of Principled improvisation (EPI). This section will describe how Mr. Kelly attends to his students' emergent coherence-seeking, when it deviates from the coherences of the discussion materials. Finally, I will explain how Mr. Kelly embodied principled improvisation in each episode and supports the classroom community to take up epistemic agency in construction of the public knowledge objects in each discussion.

1. Principled improvisation in the Initial Ideas discussion - Interactive structures

1.1. Curricular coherences for discussion

The focal initial ideas discussion for this study takes place near the end of lesson 1. At this point, the students gather in a circle to share their questions about the speaker phenomenon and to collaboratively construct a Driving Question Board (DQB) around the 3 parts of the speaker system (magnet, wire coil, speaker cone) and how they work together.

***1.1.1. Interactive coherence**.* To construct the DQB, the materials provide specific directions for teachers to share with their students. To begin, the materials state that one student should go to the DQB and share one of their questions about the speaker phenomenon with the group. After, the student should post the question (on a sticky note) onto the DQB, and then call on a student volunteer to share a related question. The second student should then read the related question to the group and post it to the DQB. Additionally, the teacher guide for this discussion asserts that the second student should say *"what other question on the board it relates to and why or how*." The guide then states that the second student should then select the next student with a related question and the "*process continues until everyone has had a chance to post a question*". Once students have finished sharing questions, the teacher guide directs teachers to ask students to identify the categories of questions and to write these categories near each cluster of questions.

1.1.2. Epistemic coherence. The same directions for participation in the discussion also emphasize particular knowledge-building work. Specifically, these curricular directions are designed for students to share their initial question ideas and to link these questions to other questions. An educative support from the discussion materials also highlights the importance of students explaining the connections between their questions. This support provides instructional strategies for facilitating this connection-work with students. The curricular support emphasizes that effective facilitation of this work is "*a key way to emphasize the importance of listening to and building off each other's ideas and to help scaffold student thinking*". In turn, the materials ask teachers to "*press students to try to talk through their thinking*" related to these connections. Further, in organizing the DQB, students will engage in connection-seeking work when clustering their questions "*into smaller parts of the model or similar-type questions*."

1.1.3. Conceptual coherence. Conceptually, the materials foreground particular topics of questions for the students to grapple with and generate questions about. The discussion materials give explicit directions for students to generate questions that are either *"1) speaker related, (2) about specific parts of the speaker (like magnets), or (3) about other related phenomena that they believe would be similar to the speaker."* Students should have previously figured out that the magnet, the coil of wire, and the speaker cone were important parts to the speaker system and that these parts worked together in some way to produce vibrations and sound. The students would have also brainstormed related phenomena that use wires, electricity, and magnets to begin to think about how different objects use electromagnets. Further, when organizing the DQB, the teacher guide provides examples of potential categories of questions that students might come up with: "*magnet, the wire, the speaker cone, the space between, or other similar phenomena".*

1.2. Description of episode of principled improvisation

1.2.1. Launch of discussion. To launch this initial ideas discussion, Mr. Kelly explicitly stated the directions from the curricular materials regarding how students should participate in the discussion. The following exchange represents this beginning of this interaction with his students:

Table 2.3 Excerpt 1: Conveying interactional and epistemic expectations for discussion

Mr. Kelly:	So, you see the board up there that's blue, it says "driving question board"? In a second, we're going to go around and we're going to have people start sharing their questions. What's going to happen is you're going to say your question, you're going to put it up there. Now, if you have a question that turns out it's exactly the same as someone else's question ... you've got to join us in the circle ... then, you just put yours right on top of theirs, and we'll know that because there's multiple post-it notes, we'll know that several people had that question. That's a good thing, right?
Class:	Yeah.
Mr. Kelly:	But in order to make you make sure that we're listening really well, make sure that we're connecting our questions to other people, you cannot say a question unless you can relate it to the previous person's question. So let's say if I had Student 1 go up first, and put hers up there. She's going to call on the next person, and you're going to have to raise your hand if you think your question is related to her question.
Student 1:	Oh, so you mean like -
Mr. Kelly:	-So if she calls on Student 1 after she's put hers up there, Student 1's got to say not only his question, but also how it's related to Student 2’s. And then Student 1 will call on the next person who's got a question related to Student 1's.

In providing these directions, Mr. Kelly attended to establishing the interactional rights and responsibilities or participant structures (Goodwin, 1990) that he hoped students would take up in the discussion. Mr. Kelly framed these roles in terms of a series of environmentally-coupled gestures related to the construction of the DQB. He asked students to share their ideas (i.e. questions) by reading them to the class in the scientist circle and then physically posting them on the DQB (lines 2-4). He also asked them to connect their questions to one another's questions by first raising their hands if they had a related question, and then explicitly stating the connection to the previous student's question in their talk (lines 14-17 & 19-21). Further, Mr. Kelly also told his students to place their question sticky notes directly on top of other questions on the DQB if their question was "*exactly the same as someone else's question*" (line 5-9). These participant structures involved environmentally coupled gestures because they included student talk about questions, physical gestures, and specific locations on the DQB. These gestures comprised the bulk of the interactive work that materials envisioned for students in constructing the DQB. Finally, Mr. Kelly coupled the practice of "*listening really well*" with the students' efforts at "*connecting our questions to other people*" (line 11-12). Mr. Kelly also attended to students finding epistemic consistency between their questions by requiring students' participation to embody this epistemic practice (i.e. "*you cannot say a question unless you can relate it to the previous person's question*") (lines 13-14).

1.2.2. Students contest participant structures in discussion. As the discussion ramped up, Mr. Kelly tried to maintain attention to the epistemic and interactive roles he worked to establish in the launch of the discussion. Particularly, Mr. Kelly attended to consistency between questions and related gestures in the substance of his students' talk and behavior. Mr. Kelly regularly pushed the students to share related questions (e.g. *"Do you have one [a question] that's related?")* and to explain how their question connected to the previous question (e.g. "*and how is yours related?").* However, students almost immediately began to contest these embodied participant structures in the course of the discussion activity. At one point early in the discussion, Mr. Kelly asked one student who raised his hand whether he knew the last stated question. In response, the student struggled to identify that question. The student had raised his hand to share his question, but had not done so specifically to make a connection to the previous question. In response, Mr. Kelly attended to repairing the contested participant structures before moving on with the discussion.

Specifically, Mr. Kelly attended to consistency between questions in the substance of students' talk. He stressed that students have "*to understand what these connections are*". He also foregrounded the gestures that he felt showed students' readiness to make and share these connections in discussion ("*we're not just randomly calling on people. We're asking people to think if theirs is related or not, and they're raising their hands*"). In addition to this attention, Mr. Kelly also provided rationale for engagement in these participant structures:

> *"Now listen, if this scientist circle takes three days, if we take five days, if we take three weeks and we don't get to do any experiments because we just can't focus and be respectful of others and listen to their ideas, then we just won't do those labs. Because I don't have any labs because that's the next thing we'll do. We'll figure out how to answer these questions. But if we can't even ask the questions, we'll never get to that part. This is an important step, so we've got to be respectful. It's getting boring because we're taking forever because I don't know if we're seeing the connections yet. Make sure you're listening for connection."*

He connected the use of these structures with the community's efforts to effectively ask questions about, and subsequently investigate, the speaker phenomenon. Mr. Kelly concluded this interchange by explaining that the discussion was "*getting boring*" and "*taking forever*" because the students were not actively engaged in the epistemic (i.e. "we're *not seeing the connection yet*") and interactive roles (i.e. "*make sure you're listening for connection")* that were outlined in the launch. This repair attempt was a top-down directive from the teacher that focused on upholding their specified norms for participation in the discussion. This repair attempt was also largely ineffective as students contested the use of these embodied gestures in subsequent discussion activity. In turn, Mr. Kelly again attempted repairs at several other junctures during the discussion. These repairs also involved Mr. Kelly pausing discussion activity to refocus the students on engaging with the established embodied participant structures.

1.2.3. Teacher attempts shift to the students' interactive role. Following these unsuccessful repairs, Mr. Kelly attended to shifting the participant structures for the discussion.

Table 2.4 Excerpt 2: Shift in participant structures for sharing and connecting questions

Mr. Kelly:	Let's go around real quick. Let's do ... Here's what we're going to do. We're going to go around and see if we can think of a connection between questions that already exist. You've shared, you've shared, you've shared. You've shared, you've shared. Student 4?
Student 4:	Well it has to relate to hers?
Mr. Kelly:	Just say your question. We're going to see if we can relate it to some of the questions.
Student 4:	Will it still make a sound without the cone?
Mr. Kelly:	Will it still make sound without the?

Student 4:	Cone.
Mr. Kelly:	Without the cone. Okay. Does that relate to any of the questions we had.
Student 2:	Yeah.
Student 4:	I don't know.
Mr. Kelly:	Which question do you think that relates to a lot?
Student 5:	Does the cone help it make sound? *[student 2's initial question]*
Student 6:	If it was a bigger cone does it ... *[student 4's initial question]*
Mr. Kelly:	So Student 4's question and Student 2's question, right?

At this juncture, Mr. Kelly now asked the students to share around the scientist circle "*real quick*" and to "s*ee if we can think of [a] connection between questions that already exist*." (lines 1-5). Here, Mr. Kelly de-coupled the epistemic practice of connecting questions from the established interactive practices for participating in the discussion. Now, students would share one-by-one around the scientist circle, no matter if their question was related to the previous question. Further, the onus for finding connections between questions was now redirected to the class (e.g. *"we're going to see if we can relate it to some of the questions*). The result of this shift was more equitable participation in the sharing of questions and a more generative interactive setting for students to seek consistency among their questions. For example, following Mr. Kelly's explicitly stated shift, we see both a new student sharing a question (student 4) and other students (students 5 and 6) inter-animating this question with discussion of other related questions.

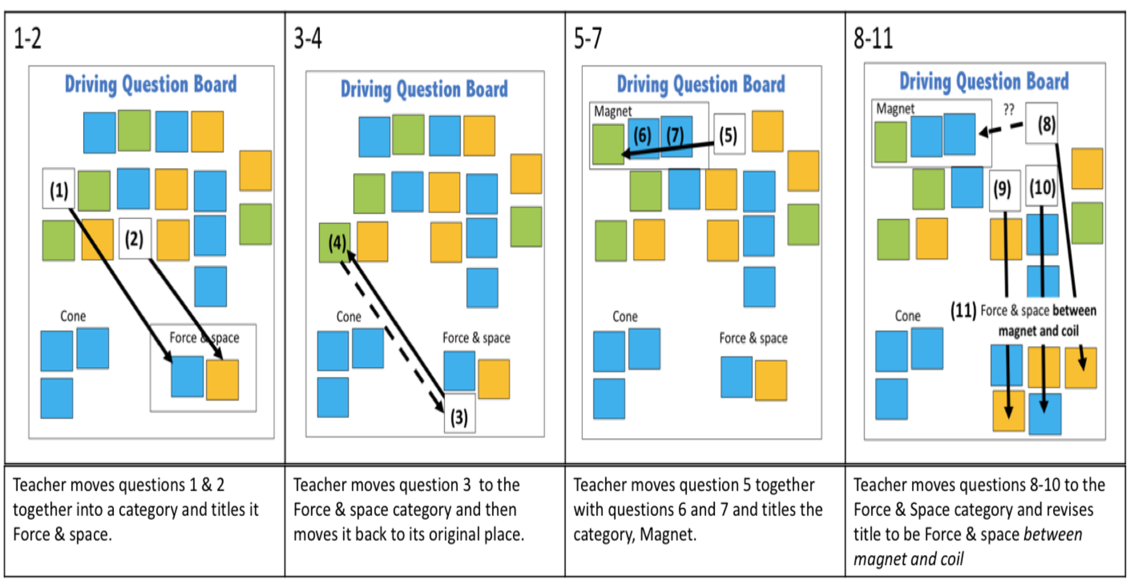
Finally, this shift to the participant structures also extended to the class' efforts in organizing their questions on the DQB. Mr. Kelly maintained less strict interactive expectations for student's participation in that portion of the discussion. Mr. Kelly worked from the DQB board, reading off students' questions and asking them about the categories for their questions. Mr. Kelly more loosely solicited students' ideas for the DQB's organization. Specifically, he positioned the students to name the question categories, and also to order and dispute each question's placement into these categories. In listening to his students, Mr. Kelly moved around the question sticky notes and labeled the question categories with a sharpie marker. As a result of this effort, Mr. Kelly completed 11 distinct moves to construct and reshape the organization of the DQB based on the students' directions (see figure 2.1).

Table 2.5 Excerpt 3: Continued shift to participant structures in organizing of questions

Mr. Kelly:	Can I put down a category that says like, "forces and empty space"? Does that sound okay?
Student 2:	Is that the cone?
Mr. Kelly:	Not the cone, a different one. Right?
Student 7:	Say force and space.
Mr. Kelly:	Okay I will call it force and space. Okay? (1) Did we have any others that ... oh, what type of force is in the field? (2) How about this one? Can this go in here? (3) [Force & Space] How does the coil transfer electricity and cause vibrations or is that different?
Student 5:	Different.
Mr. Kelly:	Different, okay. (4) Does more magnet make the sound play louder? Is that here [Force & Space] or is that in a different category?
Student 8:	Different category.

Mr. Kelly:	All right. What should I call that?
Student 6:	Magnets.
Mr. Kelly:	Magnets. All right. (5) Also up here, what happens if the magnets are facing the opposite direction? (6) Does all speakers need magnets? (7) What happens between the magnet and the coil? Is that here [magnet] or here [force & space] (8)
Student 2:	Magnets. Oh no. Space between. Yeah (8)
Mr. Kelly:	Does the magnetic force help the coil make sound? Is that here? Okay. (9) What type of magnetic force is between the magnet and the coil? Is that here?
Student 2:	Yeah (10)
Mr. Kelly:	So this is force and space between ...
Student 7:	Magnet and coil.
Mr. Kelly:	Okay. (11)

Figure 2.1: Replication of the class organization of the DQB



Across this interchange, the class community came up with two categories of questions (1. magnet and 2. force & space) and populated these categories with a total of 8 questions (1. magnet- 3 Qs; 2. force & space- 5 Qs). Furthermore, one student revised the question category *force & space* to *force & space between the magnet and coil* (line 26) after Mr. Kelly asked "*so this is force and space between...*" Mr. Kelly attended to clarity in asking this question, and student 7 responded by adding conceptual specificity to the category with her answer. The interchange then concluded with Mr. Kelly revising the question category on the DQB to fit student 7's response. Overall, Mr. Kelly's effort here allowed the community to drive the organization of the DQB and positioned the students to come to a broad understanding of the conceptual topics they focused on with their questions (see figure 2.3 for final organization).

1.3. Interpretation: How did this episode embody principled improvisation and support students' epistemic agency?

Throughout the discussion, Mr. Kelly's attention cohered around two goals in facilitating the discussion: 1) equitable participation in the sharing of questions and 2) finding consistency among the ideas embedded in questions. In launching the discussion, Mr. Kelly coupled his attention to these facets with particular interactive and physical gestures in the construction of the DQB. For example, students 'listening' and 'raising their hand' were coupled to their efforts to share questions and find connections. Mr. Kelly repeatedly tried to maintain these epistemic and interactive participant structures and 'animate' (Goffman, 1981) students with these roles in discussion. However, regardless of their motivations, the students clearly contested this participant framework at multiple points in the course of the discussion.

1.3.1. Improvisational facilitation in the initial ideas discussion. In response, Mr. Kelly demonstrated improvisation by explicitly working to shift the participant structures away from the designed interactive coherences and toward his students' present interactive practices. Specifically, Mr. Kelly shifted his expectations for students' interactive role in sharing questions. Instead of raising their hands when they had a connected question, Mr. Kelly told the class that they would simply move around the scientist circle to hear questions from students who had not shared. These questions did not need to be related to a previous student's question. This move generated a more free-flowing and equitable sharing of the students' questions because each student was no longer restricted from participating if their question was not related to the previous question. Additionally, Mr. Kelly flexibly redirected the locus of connection-building work from the individual student who was sharing a question to the entire classroom community. This instructional move opened up dialogic space for other students to draw connections between questions. This move also resulted in a productive redistribution of epistemic agency away from the student sharing the question. These same improvisational and productive interactive structures were again utilized by Mr. Kelly and the classroom community as they collectively organized the questions on the DQB.

1.3.2. Principled facilitation in the initial ideas discussion. Mr. Kelly's response in this episode was also principled in relation to the designed epistemic coherences in the discussion materials. These materials were designed with the goal of equitable participation in the sharing and connecting of questions. The materials' directions for discussion participation and a related educative feature both emphasized having students connect questions to one another. Mr. Kelly's attention cohered around both equitable participation and epistemic consistency over the course of his facilitation, including when he flexibly worked to shift the interactive participant structures for the discussion. This principled focus resulted in more equitable and connection-rich discussion of each question as it was posted on the DQB. Similarly, Mr. Kelly's principled attention to consistency continued in the class' organization of the DQB. He positioned anyone from the classroom community to comment on the organization and labeling of each category in the DQB. Ultimately, Mr. Kelly's principled attention in this episode positioned more students to add and connect questions on the DQB and involved more students in making sense of the categories and organization of the DQB.

1.3.3. Students' epistemic agency in the initial ideas discussion. This EPI improved students' participation in this discussion and in the co-construction of the DQB (i.e. the shared knowledge object). About two thirds of the time in the discussion had already elapsed prior to the onset of the EPI. In that time, the classroom community shared and posted 8 questions to the DQB. At the onset of this episode, students began to more quickly and equitably build out the DQB knowledge object. In the EPI, more new students shared their questions and the community quickly populated the DQB with thirteen more questions in the final third of time in the discussion (figure 2.2). Mr. Kelly's principled and improvisational attention to equitable participation resulted in the quicker population of the DQB with students' questions. Further, Mr. Kelly's efforts in the EPI resulted in more students engaging in connection-seeking work. This was indicated in the classroom community's efforts to organize and label categories on the

DQB. Mr. Kelly positioned students with the epistemic agency to drive the organization of the DQB knowledge object. As a result, the classroom community was able to think through the DQB authentically to find the common topics they had questions about and wanted to investigate further (figure 2.3).

Figure 2.2: DQB before and after episode of principled improvisation

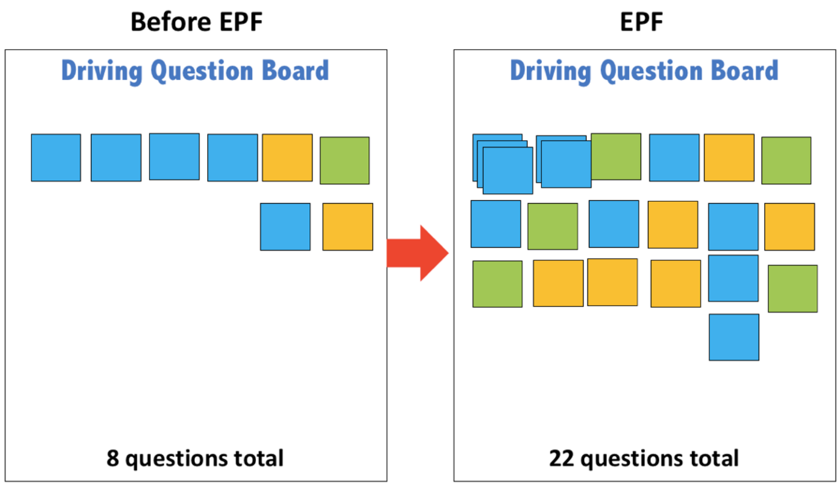
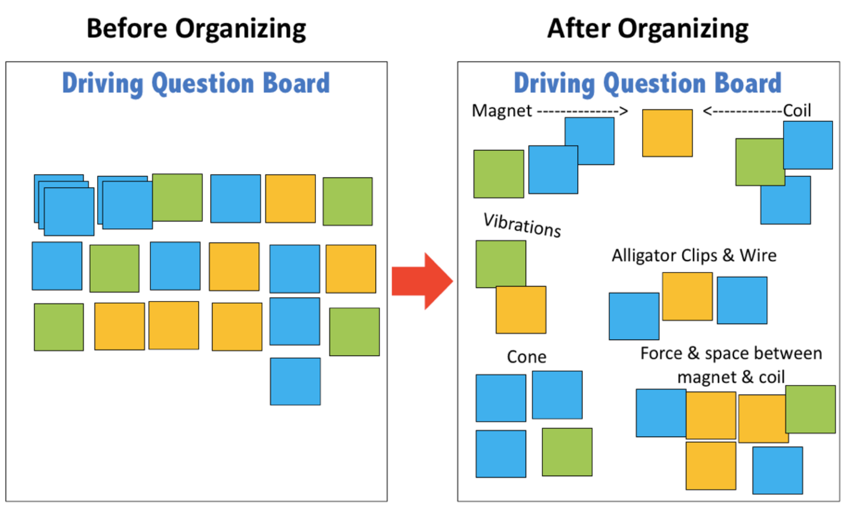


Figure 2.3: DQB before and after organizing the questions



2. Principled improvisation in the consensus discussion - Unanticipated science ideas

2.1. Curricular coherences in the discussion

The focal consensus discussion takes place in lesson 5. At this point, the students come together in a scientist circle to develop a class consensus model for how the speaker works with magnetic forces. The purpose of this discussion is to piece together the ideas students have figured out in lesson 1 through 4 about the speaker phenomenon.

2.1.1. Interactive coherence. The discussion materials provide some general description for how the teacher and students should participate in this consensus discussion. The curricular materials ask the teacher to prompt students to share and explain ideas for inclusion in the consensus model. Further, the materials provide question prompts for teachers to elicit, probe, and challenge students' ideas to help them come to consensus. These prompts suggest a teacher-mediated and student-directed construction of the consensus model in this discussion. However, differently from the initial ideas discussion, there are not strict directions as to how and when to interactively engage in the discussion.

2.1.2. Epistemic coherence. The curricular materials describe the epistemic roles that the teacher and students should take up in this consensus discussion. An educative support describes the teacher's role as, "*to prompt students to share what needs to be in the model, evidence they have to support their ideas, and how to represent it*". Further, it describes students' role as, "*to offer proposals for ideas to include in the model and how* *to represent those ideas, to support or challenge proposed ideas from peers, and to come to consensus about what should be included in the model*."

2.1.3. Conceptual coherence. The curricular materials highlight key ideas that the model should include. These include science ideas related to the attractive and repulsive magnetic forces between the magnet and coil of wire, the switching of magnetic poles and current direction, and the vibration of the speaker cone. These are key science ideas figured out in lessons 1-4 from the unit that explain how magnetic forces can cause vibrations in the speaker. These science ideas are to be included in the community's revision of the previous consensus model (from lesson 1) in order to show how the coil of wire is a magnet that can be controlled by changing the direction of the current running through it.

2.2. Description of episode of principle improvisation

2.2.1. Launch of discussion. To launch the consensus discussion, Mr. Kelly again attended to equitable participation in discussion. Here, Mr. Kelly made a connection back to the importance of one student's question (student 9) from initial ideas discussion in lesson 1:

> *I want to remind you guys some of our expectations here. When we're doing this, we gotta make sure we're respectful and listening to one another's ideas. You have some amazing ideas…First time we did this, I remember Student 9 had a question. I think I brought this up once or twice since, remember? That you didn't want to share with us at all going into that copper, about that copper coil, right? And it turns out investing in that copper coil was really important, wasn't it?*

Mr. Kelly went on to reason that "*sometimes the best questions come from ideas that people who maybe don't think they want to share them*" and that these questions can "*sometimes lead to the most learning*".

Following, Mr. Kelly then outlined the epistemic roles that he wanted students to take up in their co-construction of the consensus model. He asked his students to "*come up with ideas to put in the model*" that were "*supported by evidence from what we figured out*". Further, he mentioned that students would have to decide on "*how they were going to represen*t" these model ideas. In turn, these directions required the teacher to attend to particular epistemic facets in students' talk to promote these epistemic roles. These included: attention to the clarity of students' model ideas, attention to the consistency between these model ideas and related evidence, and attention to causality in explaining how the speaker phenomenon (and its associated components) worked to produce vibrations and sound. Interactively, students were positioned to participate in the scientist circle formation, but Mr. Kelly gave no strict direction as to how and when to participate. Conceptually, the development of the consensus model was framed as answering the following class question: *How do the magnet and wire work together to move the speaker?*

2.2.2. Teacher works with students on unanticipated ideas for the consensus model. Near the beginning of the discussion, students' model ideas moved beyond the premeditated conceptual coherences in the curricular model. Here, one student suggested that the consensus model include a 'battery' and another student suggested including an 'iPad'. Both components were not included in "*key ideas that the model should include*" or mentioned in any capacity in the curricular materials for this lesson. Similar to his initial launch, Mr. Kelly flexibly attended to these students' ideas and their causal implications for the speaker system.

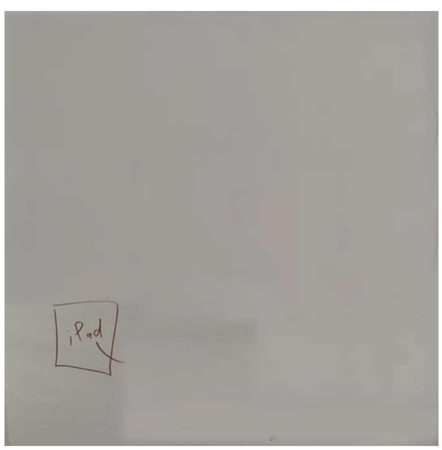
Table 2.6 Excerpt 4: Class discusses whether to include the battery or iPad in their model

Mr. Kelly:	I'm still hearing battery and iPad. Why should it be battery and why should it be the iPad?
Student 7:	iPad cause it is switching the currents.
Mr. Kelly:	What's that?
Student 2:	It switches currents?
Student 7:	Yeah.
Mr. Kelly:	Right, remember from the reading?
Student 2:	But I thought. No cause Student 3 said something about...
Student 3:	When? I said what-[crosstalk]
Student 2:	Oh never mind that makes so much sense now, yeah.
Mr. Kelly:	All right. And why is it important that the iPad switches the currents? Why does that matter?
Student 2:	Vibrations.
Student 7:	The vibrating.
Mr. Kelly:	Hold on, you are skipping step one and step two, and you're going straight to step three. I agree that switching the current gets the vibration, but how? What are the steps in between?
Student 10:	So, that would be the repulsive forces and attractive forces.
Mr. Kelly:	So it switches between repulsive and attractive forces. Which causes…
Class:	Vibrations.

Mr. Kelly:	..vibrations which causes perfect. All right. So I'm going to draw an iPad in here. I'm just going to put it over here. Does that sound okay? I know what you guys are thinking, that looks exactly like an iPad.

In this excerpt, Mr. Kelly redirected the question of whether to include the battery or the iPad to the whole group (line 1-2). Student 7 then suggested including the iPad because it switched current directions (line 3). Before adding it to the model, Mr. Kelly pushed the community to consider “*why is it important that the iPad switches the currents?”* (line 11) and how the “*switching of currents gets the vibration*”*?* (lines 16-17). Here, Mr. Kelly attended to the causal implications of the iPad in the speaker system from the students’ talk. As a result, students 2, 7, and 10 were able to inter-animate the iPad idea with related causal claims for the speaker system (i.e. iPad switches current; switching the current reverses the magnetic forces, the attractive and repulsive forces produce vibrations in the speaker). Following this interchange, Mr. Kelly then added the iPad to the consensus model. It was the first component added to the model (see figure 2.4).

Figure 2.4: Consensus model after addition of iPad component



2.2.3. Class revisits their unanticipated ideas and further integrates them into the model. After adding the magnet, coil, and speaker cone to the consensus model, the class returned to the iPad component again. In the excerpt below, Mr. Kelly re-focused students' attention to the iPad and its visual representation in the consensus model.

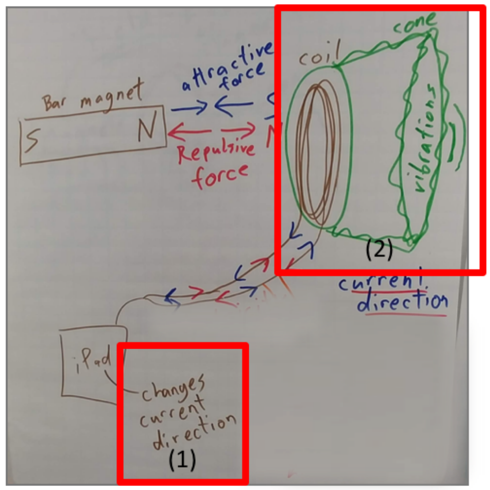
Table 2.7 Excerpt 5: Revisiting the iPad idea and representation

Student 2:	So we should have the current as changing. Can we show how it makes sound-[crosstalk].
Mr. Kelly:	And what changes the current, by the way?
Student 11:	The iPad
Class:	The iPad.
Mr. Kelly:	Okay, so can I write that here. (1) [*writes: changes the current direction]* So the iPad changes the current directions. Okay? Sorry now go ahead.
Student 2:	You know how, he said they can show how it's causing vibrations.
Mr. Kelly:	Where? The iPad vibrates?
Student 2:	No, not the iPad.
Student 7:	I mean, it could.
Student 2:	Going back to the current. So the current is changing. It's going back and forth, which causes vibrations. Can we show that?
Mr. Kelly:	Student 10, where should I be showing that?
Student 10:	The cone.
Mr. Kelly:	In the cone. How can I show that on here? What's the best way?
Student 11:	Going through the ...
Class:	[crosstalk]

21	Student 7:	A squiggly line!
22 23 24	Mr. Kelly:	I'm gonna do this on here so I'm not messing it up. Here's the cone. I know it's not as beautiful up here. Are you saying like that? *[draws two forms of squiggly lines]*
25	Student 7:	No
26	Class:	No!
27	Mr. Kelly:	Are you saying like that?
28	Class:	Yes! (2)

Mr. Kelly again asked the class what was causing the current to switch in the speaker system (line 3). Following the students' answer, he then attended to clarity by asking and receiving affirmation from students to write, "*changes the current directions*" next to the iPad drawing in the model (line 6-7). Following this addition, student 2 suggested that the class include more information related to how the current change caused vibrations in the speaker (lines 9-10; lines 14-15). Mr. Kelly positioned the class and then student 10 specifically to identify the location of the vibrations (lines 11-16). He also attended to clarity when he enlisted the students to choose how to represent the vibrations in the speaker system (lines 16-21). Based on student 7's request for squiggly lines, Mr. Kelly drew a couple squiggly line variations on the side of the model that depicted vibration. He then had the class decide on the final choice for the consensus model (lines 22-28) (see figure 2.5).

Figure 2.5: Revisiting the iPad and representing vibration in speaker cone



2.2.4. Class adds explanatory power to unanticipated ideas in the model. At the end of the class, Mr. Kelly asked if there was anything else that should be added to the model. This exchange followed:

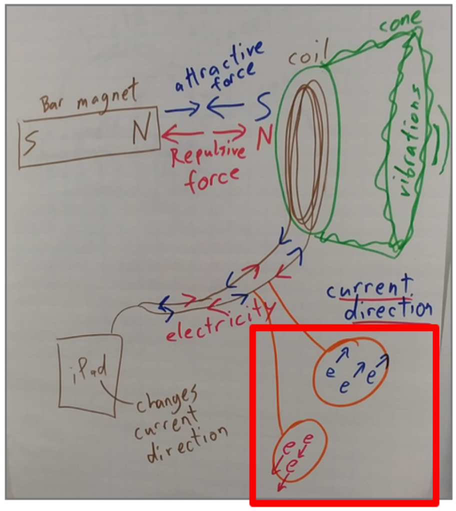
Table 2.8 Excerpt 6: Class adds electrons to their model

1 2	Mr. Kelly:	Are we missing anything from what we have on your checklist? Are we missing anything? …We have everything then?
3 4 5	Student 7:	Oh can you show, like what I did, with the line and the circle and the electrons. And then another with electrons going the other direction.
6 7 8	Mr. Kelly:	All right, so Student 7 is saying let's add in the electrons. Can I do, remember in the reading when they had sort of like a zoom in?
9	Student 7:	Yes, that's what I am saying.
10 11 12 13	Mr. Kelly:	Okay. So, we will zoom in a couple different ways because we'll make one for the blue and one for the red. So, if I'm drawing with blue on the bottom wire, which way should the electrons be going?
14	Student 7:	Up and down.

Mr. Kelly:	For the blue, if it's the blue way, which way are the electrons headed?
Student 12:	Up.
Mr. Kelly:	This way, right?
Class:	Yes.
Mr. Kelly:	All right, and if it's red, which way should the electrons be headed?
Class:	Down.
Mr. Kelly:	Down this way. Does that look okay?
Student 13:	Yeah.

In response to Mr. Kelly’s question, student 7 suggested adding a representation for the movement of electrons through the wire in the speaker model (lines 3-5). Mr. Kelly attended to consistency between Student 7’s idea and their previous evidence when he asked if student 7 remembered a related diagram from the reading in lesson 4 (line 6-8). Student 7 stated that the diagram Mr. Kelly mentioned was the one she was referring to, and then Mr. Kelly agreed to add the movement of electrons to the speaker model. In the remaining portion of the excerpt, Mr. Kelly attended to clarity by soliciting the community’s perspective on how to represent the electrons’ movement through the wire in both current directions (lines 10-24). This addition to the model was also beyond the key ideas mentioned for the model in the curricular materials (see figure 2.6). Further, this addition extended the explanatory power of the model by showing what was happening at the atomic level in the wires when the current switched from the iPad.

Figure 2.6: Consensus model with electron movement added



2.3. Interpretation: How did this episode embody principled improvisation and support students' epistemic agency in this discussion?

Mr. Kelly again launched the discussion describing the importance of students' equitable participation. In this discussion, equity manifested in the sharing, explaining, and representing of ideas in the consensus model. He further highlighted that students' ideas would drive the direction of the discussion and the construction of the consensus model. Mr. Kelly's focus on equity in this EPI allowed him to solicit a wide range of student perspectives on what should be included in the model and how it should be represented. Mr. Kelly also constantly attended to the causal implications for the speaker in the substance of students' talk. He even extended this attentional focus to students' science ideas that moved beyond the planned conceptual coherence for the curricular model.

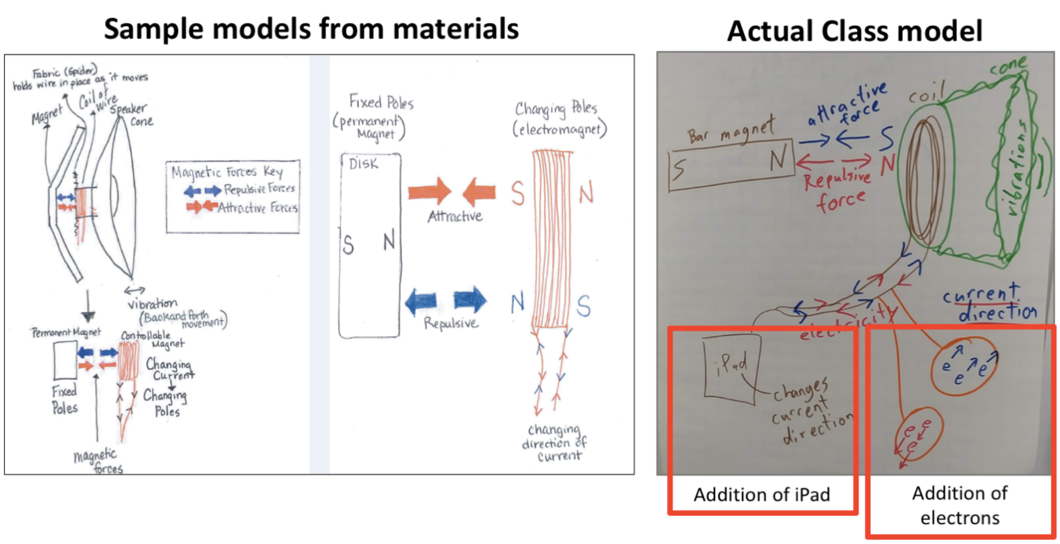
2.3.1. Improvisational facilitation of the consensus discussion. Mr. Kelly demonstrated improvisation in this episode in the manner he responded to students' science ideas for the consensus model. These student ideas were not anticipated in the materials and were therefore a divergence from the designed conceptual coherence. For example, after soliciting ideas about both the battery and the iPad, Mr. Kelly then attended to the causal implications of each component through his questioning efforts. He could have dismissed these ideas out-of-hand or directed the students to focus on the magnet, speaker, and coil, but instead, he flexibly followed and probed his students' thinking. Mr. Kelly also displayed improvisational attention when he re-focused the discussion on the iPad after one student brought up the effect of current switching on vibration in the speaker. Mr. Kelly's efforts showed improvisation as he was able to follow his students' line of thinking back toward the iPad component of the model and positioned them to explain the causal story of the speaker system including this component. Similarly, Mr. Kelly showed improvisation when he solicited an idea from a student about electron transfer and worked with the class community to incorporate this idea and its representation into the model. The inclusion of electrons was not premeditated in the materials, but rather represented another unanticipated extension to the community's model.

2.3.2. Principled facilitation of the consensus discussion. Mr. Kelly's response in this episode was also principled in relation to the epistemic coherences designed into the storyline materials for discussion. These materials ask for students to share their model ideas with evidence, agree and disagree with one another about the inclusion of these ideas in the model, and decide how to represent them in the model. Mr. Kelly attended to each of these practices in students' talk about unanticipated ideas for the consensus model. Mr. Kelly's principled attention to these practices positioned the classroom community to authentically incorporate the iPad component into the consensus model. Mr. Kelly also displayed principled attention when he worked with his students to further incorporate the iPad into the model. This effort made the iPad component not just an idea in the model, but an idea integrated into the causal mechanism of the model. Lastly, he showed principled attention to causality when he worked with the class to add electron movement to the consensus. Here, Mr. Kelly's attention to causality resulted in an addition to the model that better explained what was happening at the atomic level in the wires. Mr. Kelly's principled attention to causality ultimately extended the explanatory power of the community's consensus model beyond the pre-meditated coherences in the materials.

2.3.3. Students' epistemic agency in the consensus discussion. This EPI positioned more students to share more ideas in the construction of the consensus model. Mr. Kelly's principled attention to equitable participation resulted in roughly three quarters of the class contributing unique utterances in the discussion (17 out 23 students). Further, the majority of class was involved in call-and-response, yes-or-no responses around the representation of model ideas and the categorizing of questions. Further, his inclusion of unanticipated science ideas to the consensus model resulted in the co-construction of a consensus model with components and interactions not included in the designed coherence of the curricular materials (see figure 2.7). These additions of the iPad and electrons to the model (i.e. knowledge object), were solicited, explained, agreed upon, and represented through direct student input. As a result, Mr. Kelly's efforts in this

EPI positioned students with epistemic agency to co-construct the consensus model authentically with their own ideas and representations. By extension, the students were able to work with Mr. Kelly to make sense using the consensus model. The class community was able to work with the consensus model to identify areas of agreement and disagreement and to discuss their importance to the functionality of the speaker system.

Figure 2.7: Sample vs. actual consensus model



3. **Principled improvisation in the building understanding discussion - Unanticipated data from an investigation**

3.1. Curricular coherences in the discussion

The focal building understandings discussion takes place in lesson 9. Directly prior to this discussion, students worked in small groups to record data and plot data points on a graph to identify the relationship between distance and magnetic force for repulsive and attractive forces. After this investigation, the students come together in the whole group to discuss the mathematical relationships that appear in their graphed data and to explain the relationship between distance and magnetic force.

3.1.1. Interactive coherence. The discussion materials provide some general description for how the teacher and students should participate in this building understandings discussion. First, the materials direct the teacher to give the students 2-3 minutes to work with their groups on the first two questions at the bottom of their investigation handout. These questions ask students to describe the relationship between distance and magnetic force when repulsive and attractive forces are involved. After discussing in their small groups, the teacher should bring the groups together "*to share what they concluded about the relationship between distance and magnetic force based on the first two questions on the handout.*" The materials do not ask teachers to organize their students in a scientist circle to engage in this discussion. Following the discussion of these questions, the materials prompt the teacher to ask, "*As X-values increase, what happens to Y-values? Is this a linear or non-linear relationship?*" The directions for this discussion suggest that its facilitation is both teacher-mediated and student-directed because it involves the teacher prompting students and the students driving sensemaking with their responses to each question. However, similar to the consensus discussion, there are not strict directions as to how and when to interactively engage in the discussion.

3.1.2. Epistemic coherence. The curricular materials only generally describe the epistemic roles that the teacher and students should take up in this building understandings discussion. First, the materials state that students should discuss their ideas to each question in the investigation handout. These ideas involve claims about the relationship between distance and magnetic force when either repulsive and attractive forces are involved. These ideas should be consistent with the evidence from the students' investigation of magnetic force and distance. Specifically, these ideas should use patterns from their graphs of distance by magnetic force. Further, these interpretations of the graphs should be consistent with "*descriptions from math class where appropriate*".

3.1.3. Conceptual coherence. The curricular materials highlight the key science ideas that students should make sense of using their graphs. By the end of the discussion, students should be able to explain that "*as distance between magnets and between magnets and test objects increases, the magnetic force decreases. Thus, when the distance between the two magnets is small, as in our speaker, the magnetic force is greater.*" Finally, students should recognize this relationship in their graphs "*as an inverse square relationship or at least a non-linear relationship*."

3.2. Description of episode of principle improvisation

3.2.1. Launch of discussion. To launch the building discussion, Mr. Kelly expressed his desire to "*showcase a couple real nice graphs*" from students. This interchange followed.

Table 2.9 Excerpt 7: Launching discussion and public use of graph

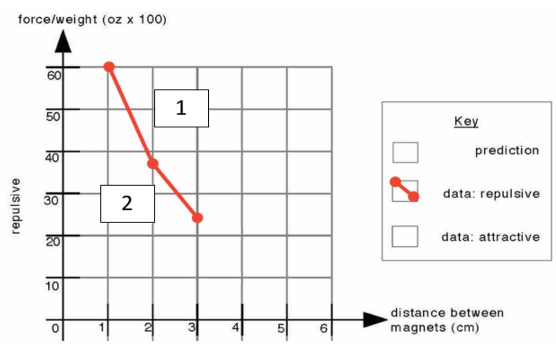
Mr. Kelly:	So we're taking a look up here, I think most people have got a graph done. I wanted to showcase a couple of real nice graphs. Who had a nice graph over here? Alright we've got some nice graphs. Now you all know that we did some predictions on here as well, correct? And so I'm seeing some nice graphs here. These guys were able to graph both the attractive and the repulsive forces. This one as well, really nice graph. What did you guys notice about the graphs?

Student 10:	They go up and down.
Mr. Kelly:	They go up and down? Did everyone's go up and down?
Student 10:	Yeah.
Mr. Kelly:	All right let me draw a picture of what I think you're telling me. And I think you're telling me on the graph because I figured out what they look like, I think you're telling me…actually I think I have a graph here, right? I think, oh, cool, look at this, I think when you're telling me it goes up and down that it maybe starts here and goes up and then goes back down.

After expressing the desire to showcase some students' graphs, Mr. Kelly then walked around the class and positively commented on several graphs from students who "*were able to graph both the attractive and repulsive forces*". He asked the class "*what did you notice about the graphs?*" Interestingly, in launching the discussion, we see that Mr. Kelly did not frame the discussion as specifically answering the two questions on the students' investigation handout. One student then stated "*they [the lines on the graph] go up and down*". Mr. Kelly then attended to clarity as he re-voiced this notion in the form and question and directed it to the whole group, "*did everyone's go up and down?*" After the initial student affirmed that his graph went up and down, Mr. Kelly decided to depict the graph ("*draw a picture*") of what he thought the student was telling him. Specifically, Mr. Kelly drew on one slide from the curricular materials that had a blank version of the graph.

3.2.2. Teacher co-constructs a public representation of the graph with his students. At this point in the discussion, the class had already begun co-constructing their shared line graph of the effect of distance between two magnets on the strength of the repulsive force between them. They had already co-developed two extensions of the line in the graph at this point: 1) an extension with a steep negative slope from 1 cm and 2 cm distance apart and 2) a connected extension with a less steep, but still negative slope from 2 cm to 3 cm distance apart (figure 2.8).

Figure 2.8: Line extensions 1 and 2 on the repulsive forces graph



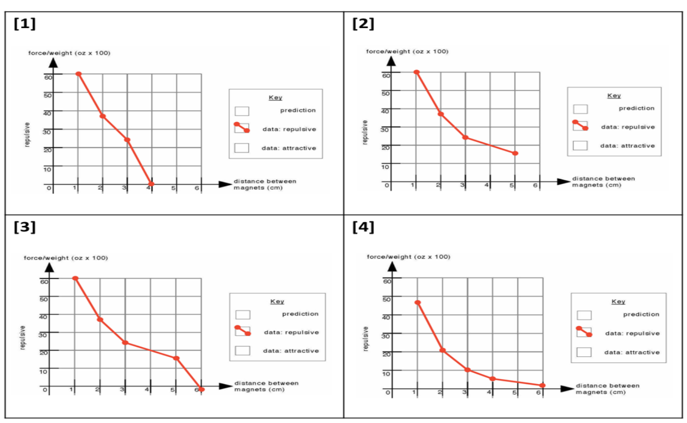
Following these additions to the shared graph, Mr. Kelly briefly highlighted what the change of slope meant in the context of the graph. Specifically, he explained that the repulsive force is initially "*decreasing here a lot*", and then starts "*decreasing a little bit*" as the magnets move further away from one another (lines 1-4). This explanation involved environmentally- coupled gestures, as Mr. Kelly talked about the slope of each portion of the line while both: pointing to these parts on the graph and gesturing to the paths of each line segment to indicate their differential slopes.

Table 2.10 Excerpt 8: Co-constructing the repulsive forces by magnet distance graph

1 2 3 4	Mr. Kelly:	So it's not that it turns that the force is decreasing as you move further away from the magnets, that force is decreasing here a lot [gestures to first line extension], here it's decreasing a little bit [gestures to second line extension], all right, how about here?
5	Student 10:	Down.
6	Mr. Kelly:	Down, like that? (1)

7	Class:	No.
8	Mr. Kelly:	No. Like, that, right? Something like that. (2)
9	Student 10:	And then down.
10	Mr. Kelly:	And then it went down? (3)
11	Student 10:	Yeah.
12	Mr. Kelly:	Did it go straight down for everyone?
13	Class:	No.
14	Mr. Kelly:	I don't see it on there [gesturing to student 3's graph]
15	Student 2 & Student 3 :	Turns to the side. [in unison]
16 17 18	Mr. Kelly:	It looks like maybe I drew too far, it looks like maybe it's like this. Is that about right? Is that about, kind of what most people got? [4]
19	Class:	Yes.

Figure 2.9: Line extensions to public graph of repulsive forces



In asking about the next segment of the line, Student 10 responded that it goes "*down*" (line 5). Mr. Kelly followed by drawing a line that traveled from 3-4 cm on the X-axis and plunged below the zero on the y-axis (see [1] in figure 2.9). Next, in attending to clarity, he asked if the line drawn was what Student 10 intended ("*Like, that, right?*", line 8). Before Student 10 could respond, however, several students in the class stated that this extension was not correct, likely due to this extension being incongruent with their own line graphs (line 7). Mr. Kelly then erased that portion of the line and then extended the line from 3-5 cm on the x-axis with a more gradual negative slope (see [2] in figure 2.9). Again, Student 10 responded that line would go further down (line 9). Mr. Kelly then drew a line extension with a steeper negative slope from 5-6 cm on the x-axis (see [3] in figure 2.9). He attended to clarity in Student 10's talk when he asked if "*it went down*" like he had drawn on the public graph (line 10). Student 10 agreed (line 11) and Mr. Kelly then redirected the question to the whole group, "*Did it go straight down for everyone?*" Several students verbally stated no to this question and Mr. Kelly commented that he did not see this same line extension on Student 3's graph. In response, Students 3 and 2 said "*it turns on its side*" in almost unison. Mr. Kelly responded by returning to the graph once again. He stated that he made an error in initially depicting their ideas on the graph ("*It looks like maybe I drew too far*", line 16) and decided to erase the line entirely to better match what students 3 and 2 had said. He then redrew the line to better match the 'turn' he viewed in these students' graphs ("*it looks like maybe it's like this*", line 16-17) (see [4] in figure 2.9). Finally, he again attended to clarity as he asked the students if this depiction is "*kind of what most people got*" (line 17-18) and several students replied affirmatively.

3.2.3. Class works to explain unanticipated trends in one student's line graph. At this point, Student 10 once again voiced his idea that the repulsive force line in the public graph crosses the x-axis and becomes a negative force measurement. He stated "*it will go in the negative*" after the line approaches zero on the y-axis (i.e. no force). This idea did not align to the designed curricular coherences for this graph and its related discussion because it was inconsistent with expected data and interpretation for the investigation.

Table 2.11 Excerpt 9: Class grapples with unexpected trends in one students' graph

Mr. Kelly:	Ignore the numbers for a second. Do you think it will turn from repelling to attracting if it moves far enough away? Or not?
Student 10:	Yes.
Mr. Kelly:	You think it will? Okay. What do you guys think? Do you guys agree?
Student 7:	No.
Mr. Kelly:	What do you guys think? Do you think that when you are taking…because according to this it does keep going lower and lower, but do you think if you go far enough away it will go negative and start attracting? What do you think?
Student 3:	No, I think actually because even if you're repulsing or if you're attracting eventually you're going to be too far away you can't you're not doing anything at all. So it's not like to a point where if it's attracting and then it's attracting less and less and less, and it's not going to start, it's not going to start pushing it away, it's just going to start, like it's not going to do anything.
Mr. Kelly:	Let me ask you guys this. Let's make sure this is repelling, hold it up so it is repelling. All right, so it's repelling and so we know that the force is going to be lower and lower. If I moved it this far away, is it going to be attracting there?
Class:	No.
Student 7:	It doesn't do nothing.

23 24	Mr. Kelly:	What do you think if we put a scale on that right now it would measure? How much of a force would it be?
25	Student 7:	Zero.
26	Mr. Kelly:	Zero? So you think eventually this would lead to zero, right?
27	Class:	Yes.

Mr. Kelly flexibly responded that Student 10 should "*ignore the numbers*" and asked if "*it will turn from repelling to attracting if it moves far enough away? Or not?*" These questions attended to the causal effect on force of moving two magnets further and further apart. This effort pushed the student to consider the physical consequences of the data points he plotted. In turn, Student 10 stated, "*yes*" to Mr. Kelly's question, implying the student believed his line graph was correctly plotted (line 3). Mr. Kelly responded by re-directing this question to the whole group (lines 4-5). When met with verbal disagreement, Mr. Kelly attended again to the causal effects of students 10's idea for the line graph. His questioning here conceded to Student 10 that the trend of the graph does seem to "*keep going lower and lower*". However, he asked the whole group to really consider the material effects of Student 10's idea for the relationship between the distance and magnetic force (lines 7-10). Student 3 then explained that as the magnets move further away from one another they will attract "*less and less and less, and it's not going to start, it's not going to start pushing it away*."

Mr. Kelly attended to causality further when he probed Student 3's explanation. He took a pair of magnets and gave one to Student 3. Mr. Kelly then held the other and the two oriented their magnets so the same poles faced each other (repulsive force). Mr. Kelly then began to move away from Student 3 and asked, "*If I moved it this far away, is* *it going to be attracting there?*" Several students voiced "*no*", that there would be no attractive forces at that far distance. Another student said "*It [the magnets] doesn't do nothing*". To cap this line of questioning, Mr. Kelly brought back the force measurements they had previously discussed. In attending to consistency, Mr. Kelly asked, "*What do you think if we put a scale on that right now it would measure? How much of a force would it be?*" These questions positioned the class to connect force measurement evidence (i.e. lead to zero) to their explanatory ideas about the previous demonstration (e.g. "*attracting less and less and less*").

3.2.4. Class discusses extrapolations of the lines in their consensus graph. After populating the attractive forces portion of the graph, Mr. Kelly directed the class to analyze the shape of the lines in their shared graph. He also asked the class if they "*graphed lines in math class?*"

Table 2.12 Excerpt 10: Class discusses extrapolations to their public graph

Mr. Kelly:	What kind of shape is that? Is that a line? Have you graphed lines in math class?
Student 2:	It looks like a volcano on it's side.
Mr. Kelly:	It kind of looks like a volcano maybe a little bit. What do you think that will be eventually if you get far enough out?
Student 3:	Probably meet at zero.
Mr. Kelly:	Probably meet at zero? Let me ask you this, if we put them, so that they were touching each other, there's no distance, so you know how hard that was at one centimeter, right? What if it went to a half a centimeter? What do you think the force would be there?
Student 2:	Less, no more, more.

Mr. Kelly:	It would be more force?
Student 2:	More, no be like more-
Mr. Kelly:	So it would be up here? What about a quarter centimeter? About like that far? An eighth of a centimeter? Or a millionth of a centimeter? What do you think that force would be?
Student 2:	It would be higher.
Mr. Kelly:	Let's say-
Student 2:	That would actually be higher.
Mr. Kelly:	Let's say if we put them, instead of one centimeter let's say half a centimeter or a quarter.
Student 10:	I don’t think you could do that with your hands.
Mr. Kelly:	Why couldn't I do that with my hands?
Student 10:	Because there's too much, too much force.

As specified in the materials, Mr. Kelly’s questions looked to highlight the mathematical relationship (i.e. inverse-square and/or non-linear) in the line graphs. However, Student 2 responded by commenting on its shape (“*a volcano on it’s side*”, line 3). Mr. Kelly validated this idea and then went about publicly thinking using their consensus graphs. He first asked, “*What do you think that will be eventually if you get far enough out?*” This question attended causality as students were asked to explain what would happen to the strength of magnetic force when two magnets got far enough away from each other. Student 3 correctly responded it [the line] would “*meet at zero*”. Mr. Kelly then asked about the other side of the graph and had his students extrapolate what would happen when the magnets were less than 1 cm apart from one another. Student 2 concluded that there would be more force between the magnets at 1/2 cm than at 1 cm. Mr. Kelly responded by asking about the force between two magnets at smaller and smaller distances, thus directing the students to extrapolate the lines even further. Following this probing, Student 2 correctly answered that the force would be higher between the magnets at closer distances, and Student 10 added that it is likely impossible for hands to hold magnets at this distance "*because there's too much, too much force*". These final turns by Student 10 correctly ended a chain of causal thinking that had begun with his initial unanticipated contributions.

3.3. Interpretation: How did this episode embody principled improvisation and position students' epistemic agency in this discussion?

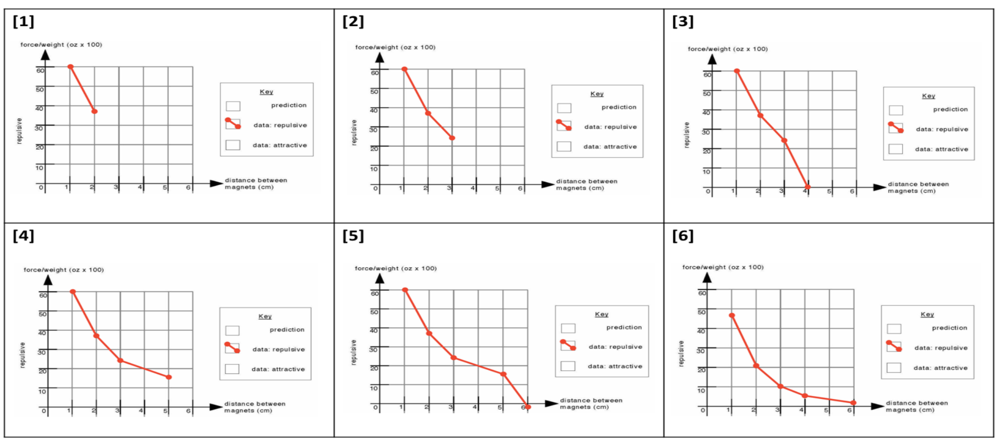
Mr. Kelly launched this building understanding discussion by simply asking the students "*What did you guys notice about the graphs?"* This request did not describe any strict participant structures that students would have to embody to answer this question or engage in the discussion more generally. Further, in asking this question, Mr. Kelly did not attend specifically to the relationship between distance and force but more simply to the descriptive trends in the line graph. The lack of explicitly stated participant structures and the conceptual and epistemic openness of the question positioned the classroom community to freely discuss their interpretations of their graphs. Mr. Kelly attended to different epistemic facets of student talk at different points in the discussion and in the co-construction of the shared graph.

3.3.1. Improvisational facilitation of the building understandings discussion. Mr. Kelly demonstrated improvisation in this episode in the manner he responded to Student 10's unanticipated and recurrent idea for the shared graph. Student 10 mentioned on two occasions that he believed the repulsive forces line would eventually cross the x-axis. Student 10 had obtained inaccurate data due to an instrumental error in his measuring of force during the investigation. Thus, his graph was inaccurate and diverged from the designed conceptual coherence for this graph in the discussion. However, Mr. Kelly did not dismiss his idea out of hand. Instead, he authentically addressed the student's inaccurate data both times the student brought it up. Mr. Kelly's efforts in both instances showed improvisation as he validated the student's unanticipated data and interpretation and worked with him to depict his idea on the shared graph and to consider the causal significance of his idea. When the student ultimately affirmed his idea in each instance, Mr. Kelly then flexibly redirected the discussion of this idea (i.e. graphic depiction and causal structure) to the classroom community. Together, these moves displayed improvisation because Mr. Kelly did not close off the student's inaccurate idea. Instead, he positioned this student and then the whole group to explain and critique his idea for the graph.

3.3.2. Principled facilitation of the building understandings discussion. Mr. Kelly's response in this episode was also principled in relation to the underlying epistemic and conceptual coherences designed into the curricular materials for this discussion. Epistemically, the materials asked for students to share and explain claims about the relationship between distance and magnetic force using evidence from the graph. Conceptually, the materials were designed for students to figure out that the magnetic field between magnets gets stronger when the magnets are closer to one another. In developing this graph, Mr. Kelly shifted between two major epistemic facets in the substance of students' talk about the trends in the graph. First, he attended to clarity in the students' ideas about the line graph by trying to physically draw their ideas onto the graph and then asking if his graphic depiction accurately expressed their ideas. He often re-directed this question of accuracy to the whole group to find consensus on the potential extension to the line. Mr. Kelly's principled attention to clarity resulted in co-construction of the consensus graph using students' evidence from the investigation and from their ideas about representation. Second, he attended to causality in students' talk of the trends in the shared graph. In grappling with Student 10's unanticipated idea, Mr. Kelly attended to causality by pushing the students to discuss the effects of extrapolations to the line on either side of the graph. Mr. Kelly's principled focus on causality in this portion of the episode positioned the classroom community to deeply grapple with and explain the results from their investigation. These explanations ultimately aligned with the conceptual coherences in the materials, but represented a localized arc of inquiry to reach these coherences.

3.3.3. Students' epistemic agency in the consensus discussion. This EPI positioned the classroom community to share ideas and come to agreement on the representation of the repulsive forces line graph. The co-construction was driven by students' ideas for the shape of the line and the classroom community's yes-or-no responses to each of Mr. Kelly's additions to the graph to represent their ideas. This process included attention to both anticipated and unanticipated ideas for the line graph. Further, the arc of this co-construction effort was driven by the students rather than the coherences in the curricular materials, as indicated by the unique and sometimes contradictory pattern of additions and deletions to the line graph (figure 2.10). Mr. Kelly's facilitation positioned students with epistemic agency to direct the construction of the consensus graph based on their data. Mr. Kelly's later efforts in the EPI pushed his students to explain the trends in the consensus graphs. These efforts allowed students to grapple authentically with the causal implications of the trends in their graph. Further, students were positioned not only to use their data and scientific understanding, but also to use the consensus graph itself to make sense of the relationship between distance and magnetic force at different extremes on the graph.

Figure 2.10: Additions and deletions to the repulsive forces graph across the discussion



Discussion

This study depicts one teacher's efforts to engage in Principled Improvisation in the moment-to-moment enactment of curriculum materials. Mr. Kelly addressed divergent student coherence-seeking in each EPI in a manner that authentically solicited and grappled with this divergence. He then responded in a principled manner that aligned to his instructional goals and the premeditated coherences in the curriculum. In what follows, I will first detail the implications and opportunities in conceptualizing students' epistemic agency as convergent and divergent coherence-seeking. After, I will describe how coherence-seeking can also be mobilized to understand the teacher-tool relationship and to support this relationship through curricular and instructional design.

Epistemic agency and coherence-seeking

Several scholars in science education have recently argued that teachers need the capacity to 'open up' curricular materials to support students to act with epistemic agency (e.g. Reiser et. al, 2021, Ko & Krist, 2019; Miller et. al, 2018). I believe the construct of student coherence-seeking is a useful, but underdeveloped idea for understanding and supporting teachers' efforts to 'open up' curriculum (see, Sikorski & Hammer, 2017 for initial theorizing). First, this construct entails that students seek coherence within and between ideas in the broader context of the curriculum (i.e. curricular coherences). However, this does not mean that students' coherence-seeking is constrained to these curricular coherences. Rather, this notion suggests that students' coherence-seeking can productively be understood *in relation* to the coherences of the curriculum. Therefore, students' coherence-seeking can be understood as being convergent on, or divergent from, the premeditated coherences in the curriculum. These two forms of coherence-seeking, convergent and divergent from the curricular materials, offer one useful way to support students to act with epistemic agency in the context of curricular enactment.

Shared epistemic agency in coherence-seeking. First, the ideas of convergent and divergent coherence-seeking point to an understanding of epistemic agency as shared amongst the students and teacher in the context of the curriculum (Reiser et. al, 2021;

Damşa, et. al, 2010). The students and teacher are in constant negotiation as the students seek both divergent and convergent coherence from the materials. For example, in each EPI, the students' coherence-seeking diverged from the planned interactive, epistemic, and conceptual coherences of the storyline. The teacher then worked with the students to accommodate this divergence and facilitate their convergence back toward the storyline. This idea of shared epistemic agency in coherence-seeking differs from Sikorski & Hammer's (2017) conception of coherence-seeking in a nuanced but important way. While these scholars believe that coherence-seeking ultimately "lives in learners' sense-making" (p. 937), the perspective put forward here suggests that this coherence-seeking lives in the interaction between teacher and student in the context of curricular enactment (Cohen & Ball, 1999). From this perspective, students' divergent coherence-seeking is solicited and authentically utilized, but some sense of authority always remains with the teacher to scaffold and manage students' coherence-seeking efforts through negotiation (Ford, 2008). This perspective on coherence-seeking has implications for how designers frame their goals for teachers' enactment of curriculum in the materials and curriculum-based PD. These materials and PD experiences need to communicate to teachers that strict fidelity to either curricular procedures or students' coherence-seeking is an unproductive way to think about curriculum use. Instead, these resources need to frame curricular enactment as instructional design work in the 'overlap' between students' ideas and interests and the premeditated learning targets in the storyline (Reiser et. al, 2021).

Challenges in supporting convergent and divergent coherence-seeking. The concepts of convergent and divergent coherence-seeking provide a unique window to understand the challenges teachers face as they design instruction for students' epistemic agency. In some sense, it is easier for teachers to support students' convergent coherence-seeking then their divergent coherence-seeking because the materials are by definition organized for students to engage with in a convergent manner. However, facilitating this convergence is never a simple process in which teachers offload (Brown, 2009) a large degree of agency to the materials for guiding instructional activity. Coherence-seeking lives in the negotiation between the students and teacher in the context of the curriculum and therefore is a dynamic feature of the classroom community's enactment (Reiser et. al, 2021). As such, students' convergent coherence-seeking is always a local instantiation of the planned curricular coherence and the teacher's support of this convergence is always a process in which the teacher invokes and applies these coherences in an adaptive and improvisational fashion (Sawyer, 2004). Further, a teacher may falsely identify student curricular engagement as convergent when students are not authentically engaged in coherence-seeking. Instead, the students may be engaged in a form of 'narrative seduction' (Hammer & Sikorski, 2015, p. 428) where students find the premeditated coherences of the curriculum so compelling that they do not actually check these materials for plausibility and consistency (i.e. follow rather seek coherence). Narrative seduction "happens quietly and can be hard to detect" (Sikorski & Hammer, 2017, p. 935) and therefore can easily be mistaken for authentic convergent coherence-seeking from students. Future research should explore how teachers can discern narrative seduction from convergent coherence-seeking, and how they address this problem of practice in subsequent enactment, planning, and reflection.

For supporting students' divergent coherence-seeking, the challenge is clearer. Divergent coherence-seeking is hard to plan for and facilitate in moment-to-moment curricular enactment because the materials and teacher cannot possibly plan for all the sources of student divergence. This study showed three different sources of divergence that concerned unanticipated participant behavior, science ideas, and interpretations of experimental data. While it may be appropriate for curriculum developers to suggest regular divergences in the materials for key instructional activities, it is simply not possible or useful to design materials to try to address all instances of divergence in all instructional activities across the curriculum. As such, divergent coherence-seeking always requires teachers to make adaptations to the materials to accommodate students' epistemic agency. Principled improvisation is one useful construct to explain how teachers can address and negotiate with students' divergent coherence-seeking and support students to act with epistemic agency in the context of the curriculum. However, each instance of divergence can not practically be foregrounded and advanced. Choices to use principled improvisation are shared by the classroom community, but are ultimately directed by the teacher, their instructional goals, and by the coherences of the materials (Reiser et. al, 2021). Therefore, in addition to engaging in PI, teachers also make choices about when, and to what extent, to use PI in addressing student divergences. Future research should investigate how educative curriculum and curriculum-based PD can support teachers' capacity to engage in PI during enactment.

Teacher-tool relationship and coherence-seeking

The idea of coherence-seeking also has implications for the conception of the teacher-tool relationship (Brown, 2009). Broadly, the teacher-tool relationship involves the interaction between curricular materials and teachers' practice in planning for and enacting curriculum (Brown & Edelson, 2003; Remillard, 2005). The teacher-tool relationship is rooted in the notion that all teaching involves a process of design in which teachers use curriculum materials to craft instructional episodes (Brown, 2009). Further, in moment-to-moment curriculum enactment, teachers make 'design-based decisions' (Edelson, 2002) to use curricular materials in a manner they think will help them accomplish their instructional goals and align to the structures of the materials. From this perspective, curriculum materials serve as a catalyst for teachers' decision-making and local customizations of the materials (see, Jackson, 1986; Pea, 1994).

Instructional design for coherence-seeking. In the context of principled improvisation, teachers make design-based decisions that are informed by both the students' coherence-seeking and the premeditated coherences of the curriculum. Specifically, these decisions concern which premeditated coherences and instructional goals the teacher chooses to foreground and/or background in their efforts to address their students' divergent coherence-seeking. In the initial ideas discussion in lesson 1, Mr. Kelly foregrounded the premeditated epistemic coherences (i.e. find consistency between questions) in the materials as he responded to his students' unanticipated embodied behavior. Mr. Kelly also backgrounded the designed interactive coherences from the materials to support students' desired participant structures. Together, the teacher's foregrounding and backgrounding efforts supported improvisational accommodation of the students' divergent coherence-seeking and the teacher's principled design of instruction to allow them to search for consistency between the ideas in their questions.

As a result, the instructional design of curriculum can productively be conceptualized as the teacher's improvisational and principled use of premeditated coherences to accommodate and develop students' coherence-seeking. This conceptualization has implications for how developers design curriculum and how teachers interpret and enact this curriculum. For developers, I contend that curricular materials need to better amplify the epistemic, conceptual, and interactive coherences embedded in the materials (see, Cherbow & McNeill, in review). These coherences need to be readily apparent to the teachers so they can make design-based decisions, both in planning and moment-to-moment enactment, that will leverage these coherences with their students. Through these efforts, the materials will "speak to" teachers about the rationale for premeditated coherences in activity, rather than trying to speak "through them" with scripting and intensive direction around these coherences (Davis & Krajcik, 2005). Future research should focus on the design and use of educative features to address students' convergent and divergent coherence-seeking. For example, these educative features could: 1) describe the premeditated coherences in the activity, 2) highlight common sources of divergent coherence-seeking, and/or 3) provide images of a teacher's improvisational and principled use of these coherences.

Teacher stance for coherence-seeking. In addition to this design work, it is also vital for teachers to occupy a constant stance where they attend to, make sense of, and respond to, student agency in the curriculum as forms of convergent or divergent coherence-seeking. This process requires teachers to develop the capacity to engage in principled improvisation during curriculum enactment. In turn, teachers need to develop a deep understanding of the underlying storyline, both over the broader arc of the storyline, and in the narrower arc of particular lessons and activities. Streamlined design of curricular materials will benefit the process, but teachers must also develop the capacity to mobilize these coherences in principled and improvisational ways to accommodate their students (Brown, 2009, see pedagogical design capacity). Further, effective enactment requires teachers to possess a repertoire of talk moves to flexibly leverage premeditated coherences and create opportunities for students' coherence-seeking (Richards et al., 2015; Rosebery, Warren, & Tucker- Raymond, 2016). Future research should continue to examine how teachers can use talk moves (O'Connor & Michaels, 2012) and the Epistemically Responsive Teaching (ERT) Framework (Russ, Berland, & West, 2020) in the context of PI efforts. Additionally, future research should continue to document how teachers make sense of and use curricular materials to mobilize these coherences (e.g. Cherbow & McNeill, in review). Together, these research efforts will allow the field to identify durable instructional moves and designs to support PI in various curriculum contexts.

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Section IV

Enacting curriculum that are coherent from the student perspective: Exploring the teacher-storyline relationship

Introduction

Curriculum materials are powerful tools for educational reform because these materials can organize teaching and learning to align to the goals of the reform (Remillard, 2005; Brown, 2009). Current reforms (NRC, 2012; NGSS, 2013) to science education aim to shift K-12 science classrooms from ‘learning about’ science ideas to ‘figuring out’ science ideas through participation in science and engineering practices (Schwarz, Passmore, & Reiser, 2017). Realizing this vision will require substantive changes to current science curricula to support this reform shift in K-12 science education (NRC, 2015; National Academies, 2015). One important change to science curriculum involves the focus on ‘coherence from the student perspective’ in the curricular design and enactment (Reiser, Novak, & McGill, 2017). This form of coherence arises when the classroom community sees their science work as addressing their questions and problems, rather than following the teacher’s directions for engaging with the curriculum (Reiser, Novak, McGill, & Penuel, 2021). Storyline units offer one curricular approach to support coherence from the students’ perspective (Reiser, Novak, & Fumagalli, 2015). In general, a storyline is “a classroom unit designed with a trajectory from questions to investigations to ideas in which students are partners in developing and managing the knowledge building” (p.9, Reiser et al., 2021). There are a variety of different storylines and other reform-oriented science curricula that try to support this form of coherence for students (e.g. OpenSciEd, 2020; SOLID Start, 2021, Learning in Places, 2021)

However, the design of curriculum materials alone do not ensure that enactments will be coherent from the student perspective. Teachers need the capacity to design instruction from curriculum materials to support their students' purposeful sensemaking (Sikorski & Hammer, 2017). While significant attention has rightfully been placed on developing the curricular approach and units, insufficient attention has been given to understanding and developing teachers' use of curriculum materials to design coherent instruction. This article attempts to address this gap by providing an initial image of what we call the Teacher-Storyline (T-S) relationship. We use the storyline approach and materials in this article to illustrate this relationship, but believe this work applies to teachers' use of other reform-oriented science curriculum as well. In what follows, we will first provide theoretical grounding for our articulation of the T-S relationship. This relationship is grounded in cognitive theories about artifact mediation, educational research on curriculum-use, and science reform efforts to support coherence for students in curriculum and instruction. We will then outline the teacher-storyline relationship. We describe each component of the model, and explain how these components interact with one another in the T-S relationship. Finally, we will highlight some implications from the T-S relationship for the design of curriculum materials and for teachers' learning concerning curriculum-use.

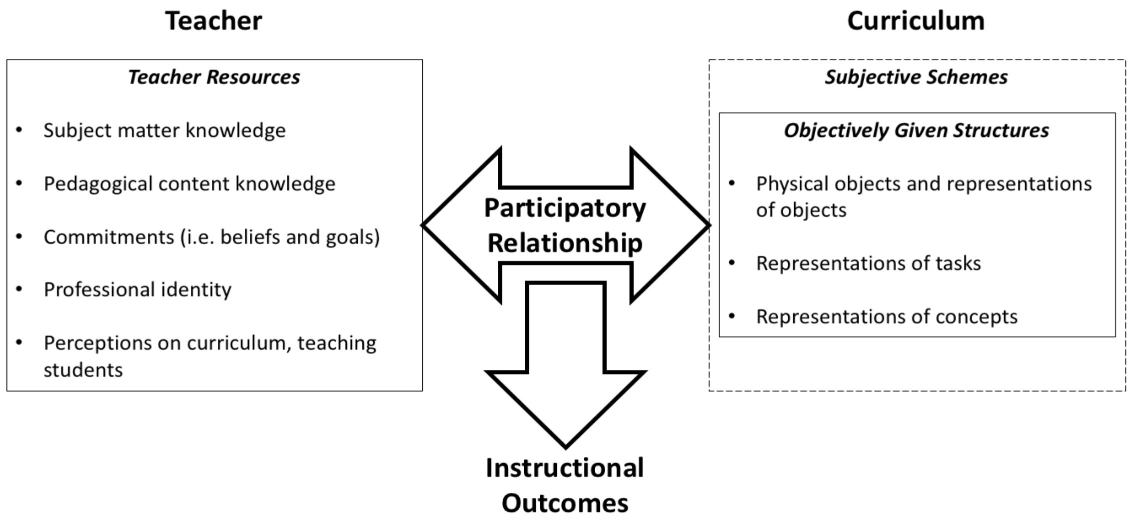
Theoretical Framework

Curriculum use as design

In this article, we will operationalize a design-oriented perspective to explain the activity in which teachers use or interact with curricular resources. Several scholars in the past (e.g. Brown, 2009; Remillard, 2005; Sherin & Drake, 2006) have put forth an interpretation of curriculum-use as a form of design activity. This notion of design is grounded in cognitive theories of tool-use and mediated action (Vygotsky, 1978). These theories focus on the relationship between the individuals or groups and the tools they used to extend their capacities and achieve their goals (Cole, 1996; Wertsch, 1991; Wertsch, 1998). The tools or artifacts mediate the agent's actions based on the affordances and constraints they place on the individual's or group's actions (Vygotsky, 1980). As a result, the agent-tool relationship can be understood as the participatory and dynamic interactions between the agent and the tool (Wertsch, 1998). Together, these theories point to an understanding of curriculum-use as involving the relationship between the teacher (agent) and the curricular materials (tool or artifact) during planning and instruction (Brown, 2009). In this relationship, the curricular artifacts afford and constrain teachers' actions through the content of their text and materials, and teachers interpret and use these artifacts in different ways based on their knowledge, beliefs, commitments, and other personal characteristics (Remillard, 2005; Ball & Cohen, 1999). Therefore, teachers' processes of reading, interpreting, and adapting curriculum resources for instruction are practices of design (Brown & Edelson, 2003). To describe this design work, several scholars have put forth different participatory models of curriculum-use (e.g. Sherin & Drake, 2006; Remillard, 2005; Brown, 2009). These models generally include: 1) teachers' own resources; 2) particular curriculum artifacts, and 3) how they interact with one another (Brown, 2002). Each part of the model plays an integral role in teachers' use of curriculum and subsequent instructional outcomes with students.

First, teachers bring particular resources to the participatory relationship with the curriculum. Brown (2009) highlights three types of resources that teachers use to interact with the curriculum: (a) subject matter knowledge (Ball, 1991; Stodolsky & Grossman, 1995) (b) pedagogical content knowledge (Shulman, 1986), and (c) goals and beliefs (Ball & Cohen, 1999). Other researchers have put forth characteristics like teachers' stance toward curricular materials (Remillard & Bryan, 2004), their professional identity (Spillane, 2000), and their perceptions of their students' needs and capacities (Sherin & Drake, 2006). Taken together, these teacher resources influence the ways teachers perceive and appropriate different aspects of curriculum designs. Second, curricular artifacts afford and constrain teachers' use of the curriculum. The text in curricular materials can be understood through both its 'objectively given structures' and 'subjective schemes' (Otte,1986). The objectively given structures are the physical form the text and materials take in the curriculum. Brown (2009) categorized these objective structures in the curriculum as: (a) the physical objects and representations of objects, (b) the representations of tasks, and (c) the representations of concepts. The physical objects represent the 'material nature' of the curriculum, including supplies and blueprints for assembling and arranging physical objects. Representations of tasks include 'instructions, procedures, and scripts' involved in the enactment of the curriculum by the teachers and students. Finally, representations of concepts refer to the organization and depiction of domain concepts through means such as ‘diagrams, models, explanations, descriptions, and analogies’. The subjective schemes in curriculum represent the manner in which the curriculum is to be understood or perceived by the teacher and students. These schemes serve as the backdrop for teachers to interpret the objectively given structures (Otte, 1986) in the curriculum. These schemes have social and cultural meaning concerning particular stances toward knowledge and learning, pedagogical representations of content, and audiences to which the materials speak (Remillard, 2005). Finally, the participatory relationship between teachers and the curriculum is a significant construct for understanding teachers’ curriculum use. This relationship is different from the teacher and curriculum components on their own, as it focuses on “the activity of using or participating with the curriculum resource and on the dynamic relationship between the teacher and curriculum” (Remillard, 2005, p. 221). For example, Brown (2009) identified ways of using curriculum as offloading, adapting, and improvising from these materials. Other scholars (Remillard, 1999; Sherin & Drake, 2006) also depict the ways that teachers draw on their own resources and capacities to interpret and use the objective structures and subjective schemes in the curriculum. Taken together, these features of the teacher-curriculum relationship illuminate how teachers engage in curricular design work (see figure 3.1 for overview).

Figure 3.1: Teacher-Curriculum Relationship



Coherence from the student perspective

The goals for K-12 science education outlined in the NRC Framework (2012) and NGSS (2013) require important shifts to current materials and teaching practices. Reiser et al. (2021) argued that commitment to these reform shifts requires that science curriculum and instruction support 'coherence from the student perspective'. Storyline units offer one promising approach to support coherence from the student perspective (Reiser, Novak, & Fumagalli, 2015; Reiser, Novak, et al., 2017). Notably, various researchers and curriculum developers use the term 'storyline' to mean different things. Further, other reform-oriented science curricula which do not go by the name 'storyline' often still contain storyline structures at the core of their design (e.g. IQWST, Shwartz, et. al, 2008). In general, all these types of curricula are concerned with students' coherence-seeking or their efforts to build meaningful, mutually consistent relationships within and across ideas (Sikorski, 2015). The difference between them comes down to whether the materials and instructional approach are organized to be coherent from the disciplinary perspective or coherent from the student perspective (Reiser et al., 2021). In disciplinary or content storylines, the organization of topics and investigations reflect the logic of the discipline (Shwartz, et al., 2008). Over time, these disciplinary storylines have improved to better chart students' progress toward canonical science ideas while taking into consideration their experiences, resources, and previous learning (Sikorski & Hammer, 2017). However, the logic to the order of these topics and activities may not be apparent or compelling to students because their engagement is motivated by the disciplinary coherences in the curriculum and not their own coherence-seeking (Phillips, Watkins, & Hammer, 2016; Jaber & Hammer, 2016).

The other type of storyline treats coherence-seeking as a feature of the classroom community's collective sensemaking. In storylines designed for coherence from the student perspective, the organization of topics and investigations reflects the work the students do to address and make progress on their questions and ideas (Reiser, Novak, & McGill, 2017; Zivic et al., 2018). Different storylines of this type will diverge in specific curricular structures and instructional goals, but in general, all involve the trajectory from questions to investigations to ideas and all position students as partners in knowledge-building. The key assertion for student-centered storylines is that students act as *authentic partners* in the development and trajectory of the community's science work (Reiser et al., 2021). The students are partners with the teacher and curricular materials in three key ways. First, the students' science work should be anchored in their questions about natural phenomena or real world engineering problems (Schwarz et al., 2009; Gouvea & Passmore, 2017). Second, students should be partners in negotiating and managing the community's progress on their questions (Damşa et al., 2010; Stroupe, 2014; Ko & Krist, 2019). Third, students should be partners in the knowledge-building efforts that generate models, explanations, and design solutions to address their questions (Manz, 2015; Ford, 2015; Osborne, 2014).

Student-centered storylines are designed to cultivate students' coherence-seeking in the context of the unit (Jaber & Hammer, 2016). However, storyline materials alone cannot ensure that the enactment of these materials will be coherent from the student perspective. That is because the coherence-seeking is ultimately a dynamic feature of the interaction between teacher, students, storyline materials, and context (Reiser et al., 2021, Ball & Cohen 1999, see instructional triangle for initial theorizing). As such, the achievement of coherent teaching and learning experiences lives in the enactment of the storyline (Sikorski & Hammer, 2017). As a result, the teacher must always read, interpret, and design storyline materials with students' coherence-seeking specifically in mind. Further, in enactment, the teacher needs to mobilize instructional design strategies and improvisational moves to effectively attend to and work with students' coherence-seeking efforts (Berland, Russ, & West, 2020; Colley & Windschitl, 2016). This moment-to-moment design work functions at the "overlap" between students' interests, ideas, and the disciplinary and curricular learning targets (Reiser et al., 2021). This work in the overlap involves difficult decisions as to which forms of student coherence-seeking to foreground and background given the teacher's existing resources and context (Robertson, Richards, & Elby, 2015; Edelson, 2002). For example, teachers often face tension between their efforts in reform science teaching and their efforts to address accountability pressures concerning state standards and testing (Cherbow, McKinley, McNeill, & Lowenhaupt, 2020). In this tension, teachers can create a situation of “pseudoagency” (Miller, Manz, Russ, Stroupe, & Berland, 2018), where students are treated as agentive only in relation to targeted canonical ideas. As a result, teachers need to use storyline materials to craft instruction that negotiates in, and expands upon, this overlap in enactment with students.

Exploring the Teacher-Storyline Relationship

We have discussed the model of curriculum-use as design (Remillard, 2005; Brown, 2009) and the goal of coherence from the student perspective in the storyline materials (Reiser, Novak, & McGill, 2017). Taken together, we can now develop an initial articulation of the Teacher-Storyline (T-S) relationship. Broadly, this relationship entails the activity in which the teacher interacts with and uses storyline materials to design instruction that is coherent from the student perspective. This relationship concerns the teacher, the storyline materials, the participatory interactions between the two, and the subsequent planned and enacted storyline that is an outgrowth of this relationship. Our model (see figure 3.2) is adapted from previous models of the participatory relationship from Remillard (1999, 2005) and Brown (2009). In what follows, we will describe each part of the Teacher-Storyline relationship model and will explain how these components interact to support coherence from the student perspective.

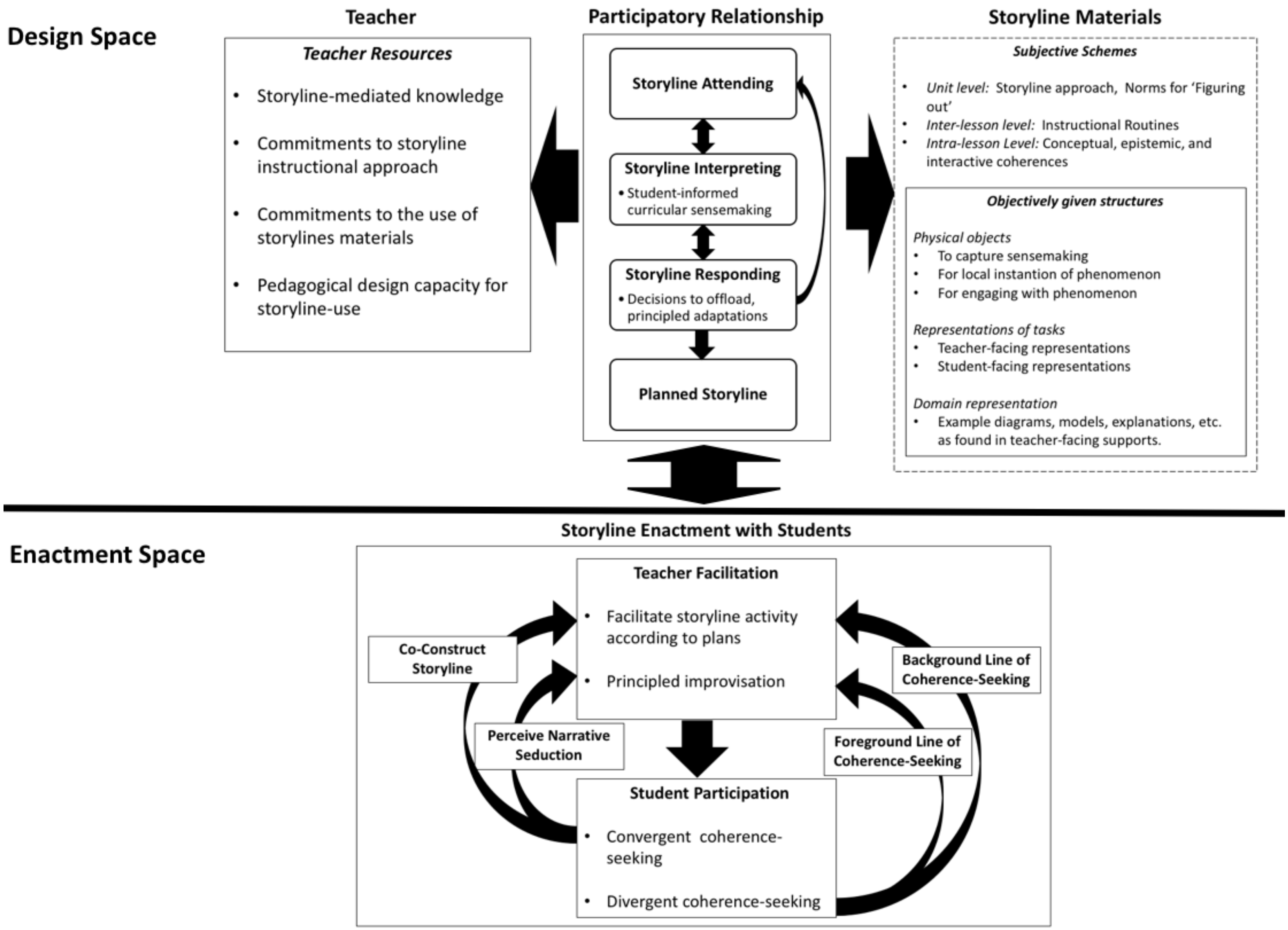
Teacher

While the storyline materials afford and constrain the teacher's storyline design work, it is the teacher who ultimately decides to read, interpret, and use these storyline materials to craft instruction (Brown, 2009). As such, it is important to understand how individual teachers interpret and use storyline materials given their knowledge, skills, and commitments (Remillard, 2005; Ball, 1993). In describing the teacher's resources, we draw on a practice-based conception of teaching and teacher knowledge (Ball & Bass, 2000; Cohen, Raudenbush, & Ball, 2003). As a result, we are interested in the resources that the teacher utilizes in their practices in the participatory relationship. In what follows, we will describe three types of resources that the teacher uses in the T-S relationship: 1) storyline-mediated knowledge, 2) storyline commitments (Ball & Cohen, 1999) and 3) pedagogical design capacity (Brown, 2009) for storyline-use. This list is far from exhaustive, but rather provides an initial idea of some of the types of resources the teacher utilizes in the T-S relationship and how the teacher uses them.

First, the teacher brings storyline-mediated knowledge to the T-S relationship. Drawing on Remillard & Kim's (2017) notion of curriculum-embedded knowledge, we use the term 'storyline-mediated' to explain that this knowledge is situated in the teacher's use of the storyline materials. However, we use the term 'mediated' instead of 'embedded' to reflect that the teacher's knowledge is not limited to the ideas and instructional designs in the storyline. Instead, the storyline materials mediate the knowledge the teacher uses as they weigh the strengths and limitations of the materials and can develop alternatives ideas, designs, and strategies to better support their students. This storyline-mediated knowledge includes: 1) knowledge of science ideas in the storyline; 2) knowledge of science teaching in the storyline; and 3) knowledge of students and context in the storyline. Knowledge of science ideas in the storyline refers to content knowledge about the targeted science ideas in the storyline. However, it is not enough for the teacher to just know these ideas as a scientist does. The teacher must know how these science ideas are 'unpacked' (Ball, Thames, & Phelps, 2008) and how these ideas are subsequently developed into complex understandings across the trajectory of the storyline. We refer to this trajectory in terms of the conceptual and epistemic coherences of the materials. These coherences represent the premeditated curricular designs (Sikorski & Hammer, 2017) for how students are expected to engage in knowledge-building work (epistemic coherence), disciplinary understandings (conceptual coherence), and interaction with another (interactive coherence) across activities, lessons, and the storyline. The teacher uses this form of knowledge to interpret and understand these coherences in the storyline and to comprehend the trajectory of these coherences across the storyline. Knowledge of science teaching and storylines refers to knowledge about the storyline instructional approach, as well as the targeted instructional designs and supports described in the storyline materials. The teacher uses this form of knowledge to interpret and understand the activity structures, instructional strategies, educative features and other supports embedded in the storyline materials, as well as the rationale for utilizing these designs and supports with students (Davis & Krajcik, 2005). Knowledge of students and context in storyline refers to knowledge of how the teacher's students might engage with particular storyline activities and embedded science ideas. This includes knowledge of students' experiences, interests, and ideas and how they would interact with the conceptual, epistemic, and interactive coherences in storyline materials. It also includes the teacher's knowledge of how their community and school context will afford and constrain their design and enactment in their classroom. The teacher uses these forms of knowledge to plan and enact from storyline materials with an eye toward engaging students' resources (Bang, et al., 2017) and for developing a working infrastructure around their design work (Penuel, 2019).

Second, the teacher's commitments (Ball & Cohen, 1999) refer to the goals and beliefs the teacher brings to the T-S relationship. These commitments go beyond the teacher's ability to teach with storylines and involve their motivations for using these storyline materials with their students (Brown, 2009). The teacher needs to be committed to the underlying instructional approach of the curriculum in order to enact these materials with fidelity to their goals (McNeill et al., 2017). In storylines, the teacher needs to be committed to a variety of instructional goals for enacting these materials with their students. For example, the teacher needs to be committed to phenomena-based teaching, the incremental building and revision of ideas based on evidence, and the collaborative and equitable 'figuring out' of science ideas with students (OpenSciEd, 2020). For all of these goals, the teacher also needs a broader commitment to enacting the materials in a manner that is coherent from the student perspective (Reiser, Novak, & McGill, 2017). This commitment to student coherence motivates the need for the teacher to engage their students in authentic partnership where they value and try to cultivate their lines of coherence-seeking in the community's co-construction of the storyline (Sikorski & Hammer, 2017). While these commitments refer to the desired instructional outcomes in using the storyline materials, there are also commitments the teacher should hold to the actual use of the storyline materials themselves. Broadly, the teacher should

Figure 3.2: Teacher-Storyline Relationship Model



have the goal to design from the storyline materials to support coherent instructional outcomes with their students. However, this view of curriculum-use runs contrary to the goals of some curricular designers and reformers, who envision a sort of 'remote control' over the course of teaching and learning through their curricular designs (Cohen, 2000). In this context, the motivation for the teacher's use of the curriculum is to enact these materials with fidelity to the procedures of the curriculum (O'Donnell, 2008). Given the dynamic nature of students' coherence-seeking, fidelity to procedures is not a feasible motivation for the teacher in using reform-oriented science curriculum like storylines (McNeill, Marco-Bujosa, González-Howard, & Loper, 2018). Instead, the teacher's use of storyline materials requires a commitment toward using these materials as an artifact or tool for local customizations that support students' coherence-seeking (Sikorski & Hammer, 2017). This commitment needs to be an explicit goal for teachers in using storyline materials.

Finally, the teacher brings pedagogical design capacity (PDC) (Brown, 2009) to the T-S relationship. PDC for storyline-use represents a teacher's ability to perceive and mobilize storyline materials in order to craft coherent storyline instruction. It involves the teacher's efforts to deconstruct curriculum materials, recognize designed coherences in the materials, and mobilize and adapt these coherences to address and work with the students' coherence-seeking. This capacity differs from the other teacher resources mentioned previously because this capacity is developed directly as a consequence of participating in the T-S relationship. As the teacher participates in this relationship, the teacher learns more about the affordances and constraints in the storyline materials to support coherence of the student perspective (Brown & Edelson, 2003). The teacher also learns more about how the students interact with these materials and how to support their coherence-seeking with their facilitation. These learning experiences emerge from both the teacher's successes and failures in using the storyline materials with students. However, the teacher is only able to tap into these learning experiences and develop their PDC for storyline-use if the teacher occupies a broader stance of practical inquiry and reflection in their use of the storyline materials with students (Forzani, 2014; Cochran-Smith & Lytle, 1993).

Storyline materials

Storyline materials afford and constrain the teacher's use of these materials in the T-S relationship. The text in storyline materials can be understood both in terms of its 'subjective schemes' and 'objectively given structures' (Otte,1986). The subjective schemes represent the manner and spirit in which the objective structures are to be perceived and understood by the teacher, as intended by the developers. Storyline materials contain material and representational resources laden with subjective meanings that mediate teachers' interactions with them (Remillard, 2005). At the unit level, the storyline approach itself is a subjective scheme to be understood. This approach provides the common trajectory to all storylines from questions to investigations to ideas in which students are partners in knowledge-building (Reiser, Novak, & Fumagalli, 2015). Each storyline unit is anchored in a phenomenon or design problem that raises questions and issues for students. Students have to see each step of their science work as progressing on their questions and problems. The subsequent steps in the storyline are motivated by gaps in their current models, explanations, or solutions. At the inter-lesson-level, there are typically particular instructional routines for developing and managing lesson investigations and sensemaking across storylines (DeBarger, Penuel, Harris, & Schank, 2010). These routines are the pedagogical patterns that the teacher facilitates with students to engage in the intellectual and social work across storyline lessons (Reiser et al., 2021). Finally at the intra-lesson level, there are subjective schemes related to the trajectory in which students engage in knowledge-building practice (i.e. investigations, sensemaking), disciplinary understandings (i.e. targeted explanations, models, solutions), and talk with one another (i.e. dialogic/interactive structure, degree of interanimation) within and across storyline activities. These epistemic, conceptual, interactive coherences are reflected in a variety of activity structures as described in the objectively given structures.

The objectively given structures are the physical forms the storyline materials take. Following Brown (2009), we identify three forms of objective given structures in storyline materials.. The first component is the physical objects. Each storyline unit contains an assemblage of physical objects to: 1) capture individual and communal sensemaking (e.g. notebooks, chart paper), 2) generate local instantiations of the phenomenon and design problems (e.g. anchoring or lesson-level phenomena) and 3) engage with these phenomenon (e.g. apparatus to investigate and measure phenomena). This component also includes blueprints or representations for assembling equipment and capturing local phenomena. The second component of Brown's model, representations of tasks, includes 'instructions, procedures, and scripts' involved in the enactment of the curriculum by the teacher and students (Brown, 2009). In different storyline types, these representations of tasks can be embodied in a variety of ways. For the teacher, there is typically a storyline guide or set of lesson plans that describe the lesson procedures and instructional strategies, including the key ideas for the teacher to emphasize and cultivate with students in each lesson. Further, the storyline materials may include other lesson resources such as lab instructions, keys and rubrics, and lesson slides that the teacher can project and use during each lesson. There can also be representations of tasks for students. These can include handouts such as readings, references, and investigation procedures. The degree of detail in these teacher- and student-facing materials will differ based on the level of guidance that developers intend for the classroom community's coherence-seeking. Finally, the third component, representations of concepts, refers to the organization and depiction of disciplinary concepts in the materials (Brown, 2009). In storylines, students are partners in developing explanations, models, and solutions in response to their questions about phenomena. Storyline materials will often contain example representations (e.g. consensus models) that the classroom community might develop at different points across the storyline. The point of the teacher viewing these representations is not for them to try to replicate them with their students. Rather, these representations are designed to focus the teacher's attention on the underlying causal account depicted in the representation. The teacher then works to articulate a local representation of this account in negotiation with their students' coherence-seeking efforts. In enactment, the community may streamline or expound upon this mechanism or visually represent it in a variety ways.

Participatory relationship and the planned storyline

The participatory relationship between the teacher and the storyline consists of the interactions between the teacher and the storyline materials. This conceptualization shifts the role of curriculum from being a fixed object to being a dialogic partner in a curricular process (Brown, 2009; Remillard, 2005). Dietiker et al., (2017) have grouped this participatory relationship into three phases of interaction: curricular-attending, curricular-interpreting, and curricular-responding. We mobilize this Curricular Noticing Framework (Dietiker et al., 2017) to understand the specific participatory relationship between the teacher and storyline materials. First, the teacher engages in the skill of storyline-attending in this relationship. This process includes the skills involved in visually taking in the storyline materials. Prior to the teacher interpreting the coherences in the materials, the teacher must first search, locate, and register these coherences in the objectively given structures of the storyline. The teacher's storyline attending-habits are constrained by the designs (e.g. graphical layout) of the objectively given structures in the materials (Remillard, 2000). In addition, the teacher's knowledge of the design, content, and approach of the storyline materials (e.g. subjective schemes) influence the teacher's expectations regarding what the teacher will find and attend to in the materials (Drake & Sherin, 2009). The teacher's resources and the storyline's affordances and constraints impact the teacher's storyline-attending habits. As a result, these habits can be developed to better 'see' (Goodwin, 1994) the coherences in the materials by both improving the design of the storyline materials or by working with the teacher (e.g. in using the materials, in professional development) to improve their storyline vision.

Second, the teacher engages in storyline-interpretation, whereby the teacher makes sense of the objective storyline structures to which the teacher has attended (Dietiker et al., 2017). This includes connecting science ideas and instructional designs described in the curriculum materials with the teacher's personal knowledge base of these ideas and designs (Ball, Thames, & Phelps, 2008). It also involves understanding the conceptual, epistemic, and interactive coherences embedded within particular descriptions of the activity, as well as how these coherences connect to what came before and what will come after (i.e. across activities, lessons, the arc of the storyline). In the context of storylines, we describe these forms of curricular sensemaking as student-informed curricular sensemaking (Cherbow & McNeill, in review). This sensemaking is student-informed because the current state and prospective forecast for students' coherence-seeking in the storyline directly informs how the teacher interprets and subsequently uses the storyline materials. Therefore, we define student-informed curricular sensemaking as a teacher's efforts to interpret storyline materials to support students' coherence-seeking in subsequent enactment of storyline activity. A teacher's student-informed curricular sensemaking is dependent on the teacher's knowledge, commitments, and experiences (Drake & Sherin, 2009), as well as the teacher's views on how curriculum should be used (Marco-Bujosa, McNeill, Gonzalez-Howard, & Loper, 2016). It also depends on how clearly these materials communicate these coherences and broader stances toward science teaching and learning in the objectively given curricular structures (Remillard, 2005).

Finally, the teacher engages in storyline-responding both in decisions of how to respond to the teacher's own interpretation and how these responses are realized in the classroom (i.e. instructional plans) (Dietiker et al., 2017). Outside of storyline enactment, the teacher makes plans about how to appropriate the storyline materials into instruction. These plans may involve the decision to offload a large degree of agency to the storyline materials to guide instructional activity or it could also mean that the teacher adapts these materials substantially to cater to students' coherence-seeking (Brown, 2009). In both cases, these decisions result in a plan for storyline enactment with students (i.e. the planned curriculum, Remillard, 2005). When the teacher makes changes to the storyline materials with the explicit goal of supporting students' coherence-seeking, we call these changes *principled adaptations* (Debarger et al., 2017). These adaptations involve additions, modifications, and omissions (Tarr et al., 2008) to the objective structures in the storyline materials. The teacher makes these structural alterations to effectively change how the students are expected to engage in knowledge-building practice (epistemic coherences), disciplinary understandings (conceptual coherences), and/or discussion with one another (interactive coherences). The teacher's adaptation functions to bring these designed coherences more in line with, and supportive of the community's current line of coherence-seeking. This form of adaptation is principled because the teacher mobilizes these coherences in their plans with the goal of supporting their students' coherence-seeking. Some principled adaptations involve changes to multiple lessons or the entire arc of the storyline (e.g. using different anchoring phenomenon). Most adaptations, however, are likely to occur within or across activities (e.g. modify investigation procedures), or from the transition from one lesson to another (e.g. add navigational discussion). This is because the teacher typically plans for storyline enactment one lesson or even one class period at a time to best respond to students' emergent coherence-seeking. However, the impact of these day-to-day principled adaptations can reach beyond the plans themselves to support students' subsequent coherence-seeking in other parts of the lesson and storyline (Ko & Krist, 2019).

Finally, our framing of these participatory interactions presupposes them unfolding in a linear fashion, but that is not the case in reality. For example, the teacher's storyline-interpreting work may raise questions or concerns that lead the teacher to attend to the materials anew and supplement the teacher's interpretation. Additionally, after the teacher makes decisions about how to respond, the teacher may return to the materials or the teacher's interpretations to flesh out this response (e.g. locate new resource, re-interpret alignment between response and materials affordances, etc.). Further, the teacher's planning work in general does not just involve choosing between offloading or adaptation. Rather, this planning work involves weaving together these forms of storyline-use in to create deliberate and productive plans for coherent enactment. This planning work is both an outgrowth of the T-S relationship and an influence on the teacher's subsequent participation in this relationship (Remillard, 2005). For example, both successful and unsuccessful storyline plans can influence whether or not the teacher pursues related types of adaptations or choices to offload in the future. Finally, these plans are important to storyline enactment because they 'prime' (Windschitl, Thompson, Braaten, & Stroupe, 2012) the teacher to consider how students will interact with the designed coherences in the materials they are going to enact. This priming effect is important for the teacher to identify and respond to students' divergent coherence-seeking in a productive manner.

Enacted storyline with students

The enacted storyline represents the co-construction of the storyline by the teacher and students in their context (Remillard, 2005). This is a critical component in the T-S relationship because the classroom community's coherence-seeking is ultimately a dynamic feature of the interactions between the teacher, the students, and the storyline materials (Reiser et al., 2021, Sikorski & Hammer, 2017, Ball & Cohen, 1999). In storyline enactment, the students and teacher are in constant negotiation as the students seek both divergent and convergent coherence from the storyline materials. Students' convergent coherence-seeking parallels the coherences in the storyline materials and students' divergent coherence-seeking departs from these coherences. The teacher makes design-based decisions (Edelson, 2002) about what lines of divergent coherence-seeking to foreground and background with the teacher's patterns of attention and responsiveness (Robertson, Richards, & Elby, 2015).

When the teacher decides to foreground divergent coherence-seeking, the teacher improvises from their plans to address the divergence between the students' coherence-seeking and the materials. The teacher works with the students to unpack and make sense of this line of coherence-seeking and to make decisions about where to go next. For example, students' coherence-seeking in an investigation might lead them to an alternate explanation for a disciplinary idea than suggested by the conceptual coherences in the materials. To unpack this conception, the teacher could background the planned conceptual coherence for the activity, and foreground the designed epistemic coherences related to supporting ideas with evidence and developing coherent causal accounts (Berland, Russ, West, 2020). The teacher can ask the students to evaluate the evidence they have for their explanation or ask them to unpack or critique the components and interactions in their causal account (Ford, 2012). The teacher might then alter their subsequent plans to help the students investigate their divergent line of coherence-seeking further. Or, the classroom community might decide that their current causal account is not supported, and choose to pursue alternative explanations that re-converge on the conceptual coherence in the materials. However, no matter the time frame, the teacher ultimately works with the students to motivate the need to investigate or build knowledge in a manner that parallels or re-converges on the coherences in the storyline materials.

The teacher could also choose to improvise from the materials even when it appears that students are engaging in convergent forms of coherence-seeking. In these examples, the teacher might perceive the students as being taken by the 'narrative seduction' (Hammer & Sikorski, 2015, p. 428) of the storyline. In this case, the students find the designed coherences of the storyline so compelling that they do not actually check these materials for plausibility and consistency (i.e. follow rather seek coherence). In both cases, we call these episodes of divergence and re-convergence, *principled improvisations* (Sawyer, 2004).These episodes are considered principled when the teacher's talk and instructional moves address divergences with an eye toward foregrounding particular designed coherences to support students' coherence-seeking. They are considered improvisational when the teacher backgrounds other designed coherences in order to better address and work with students' divergent lines of coherence-seeking. Principled improvisation can occur within and across activities or even across entire lessons to authentically address and work with the students' coherence-seeking. These episodes influence the teacher's subsequent participatory interactions and enactments, as these episodes take up instructional time, and have effects on the teacher's subsequent pacing, coverage, and time spent on the unit (Ko & Krist, 2019).

Discussion

At this point, we turn to the implications of the T-S relationship for science curriculum and teachers. We use the information in the T-S model to provide potential strategies to support the design of curricular materials and curriculum-based professional learning.

Designing curriculum materials for student coherence

Several science education researchers have recently argued that storylines and other reform science curricula need to be 'opened up' to better support students' coherence-seeking (e.g. Sikorski & Hammer, 2017, Ko & Krist, 2019; Miller et. al, 2018). We argue that the affordances and constraints of student-centered storylines offer one way that storylines have been opened up in recent years. However, there is currently a large gap between this reform approach and current forms of science teaching and learning in K-12 schools (National Academies, 2015, Banilower et. al, 2018). As a result, reform materials like storylines must communicate a considerable amount about the objective structures that describe storyline enactment as well as the subjective schemes that speak to the reform shift embodied in these materials. There is also a broader concern about the degree of premeditated coherence in the curriculum materials (Sikorski & Hammer, 2017). Somewhat paradoxically, the design of student-centered storylines often requires more designed coherence than disciplinary storylines and other reform-oriented curricula because these materials have to be designed to cultivate and mediate student coherence-seeking in the context of a storyline. Further, these materials then have to describe how to facilitate this work to teachers in the representation of tasks. As a result, the teacher-facing representations can be highly detailed and potentially unwieldy for teachers to use to design storyline instruction.

To improve these materials, we suggest developers explore ways to make the conceptual, epistemic, and interactive coherences more concrete and accessible to teachers as they attend to, interpret, and respond to the storyline materials in the T-S relationship. To make these coherences more salient, developers need to address the objective structures in the teacher-facing materials that describe these coherences in activity. One option is to address the graphical designs and layouts of these objective structures. What a teacher sees in a set of curricular materials can be haphazard or indiscriminate and is deeply influenced by the design and layout of text and images in the materials (Gueudet & Trouche, 2009). Storyline developers could reduce the amount of text in the teacher-facing materials to amplify these coherences. For example, developers could reduce the degree of scripting in the teacher-facing representations (e.g. in lesson plans). Some teachers have expressed difficulty in interpreting and enacting highly scripted storyline activities in a manner that felt non-scripted and coherent for their students (Cherbow & McNeill, in review). Further, developers could focus more on the representation of concepts rather than the scripting of key activities. Teacher-facing representations often include examples of the consensus models, explanations, and solutions that the classroom community might develop in enactment. They also often include lesson procedures concerning how the class will go about constructing this representation. Developers could bolster these supports by providing additional representations that depict different degrees of conceptual or representational sophistication, but still possess the same underlying causal mechanism. The developers could highlight the basic pieces of the causal account in each representation. This support would focus the teacher's attention to the conceptual coherences in constructing the representation as a classroom community. Instead of scripting this key activity, the teacher is afforded the latitude to consider how to plan for and enact a local representation of this mechanism in negotiation with their students' coherence-seeking efforts. Ultimately, if the goal is for teachers to design from these materials, then the over-reliance on scripting may hamstring their efforts to depart and re-emerge from the designed coherences of the storyline and may hinder their confidence and desire to do so in the first place.

Another option to open up storyline materials is to explicitly describe the threads of coherence within and across each lesson in the teacher-facing representations. This process would involve making the subjective schemes for epistemic, conceptual, and interactive coherence explicit in the objective storyline structures. In the front matter for each lesson guide, the materials could provide a brief snapshot of the coherences across the lesson so teachers could gain a quick sense of how students will engage in knowledge-building, disciplinary understandings, and interactive activity within and across each activity in the lesson. For key activities, developers could then provide descriptions of these coherences in more detail in the procedures. These descriptions would improve the teachers' interpretations of the goals of these key activities and could support them to respond to these interpretations with principled adaptations and improvisations. Finally, information about the coherences in key activities could also be included in educative features (Davis & Krajcik, 2005) in the teacher-facing representations of tasks. Specifically, these features could: 1) give rationale for the inclusion of these premeditated coherences, 2) describe how students might interact with these coherences, or 3) provide images of how teachers might principally adapt to or improvise from these coherences to support students' coherence-seeking. Taken together, these suggested supports could more effectively communicate to teachers about the goals and designed coherences in the materials (Remillard, 2000) and could support them to utilize them in principled instructional design.

Teacher professional learning

The gap between the reform approaches and current forms of science K-12 teaching also needs to be addressed with professional learning (PL) for teachers (National Academies, 2015). We believe that designers should give explicit attention to the teacher-curriculum participatory relationship when designing PL for teachers. Teachers would benefit from sustained curriculum-based PL at two levels to address their participation in the teacher-curriculum relationship. On one level, teachers should engage in curriculum-based PL with other science teachers to learn about the reform approach and its underlying goals and practices. Teachers should participate in this learning through engagement with reform-based curriculum (Penuel & Reiser, 2018; Davis & Varma, 2008). This type of PL addresses teachers' knowledge and commitments to the reform approach because these experiences and associated materials provide motivation and concrete tools to help teachers to achieve reform shifts in their science classrooms. This PL should also address teachers' commitments toward the use of the reform curricular materials themselves. Specifically, teachers need to commit to using these reform materials as a tool for local customizations that support students' coherence-seeking (Sikorski & Hammer, 2017). In the past, teachers have viewed curriculum materials as authoritative and inflexible (Remillard, 1991; Romberg, 1997). Teachers need support to shift their commitments concerning curriculum-use.

PL designers should make the practices of the participatory relationship (i.e. attending, interpreting, responding) explicit to teachers and an explicit goal for their professional learning experiences. This participatory view of curriculum-use is different from how teachers have traditionally viewed curriculum in the past (Cohen, 2000). Teachers often use curriculum as a source to procure classroom activities, rather than as a tool to support their own learning and design of instruction (Marco-Bujosa et al., 2017). Therefore, I argue that teachers need explicit professional support in this participatory relationship. To support this relationship, teachers can analyze images of curriculum-use from other classrooms (e.g. classroom video, artifacts, vignettes) or can engage in these participatory practices themselves while working collectively with other teachers. In analyzing images, teachers should see how different teachers and classroom contexts engage in different forms of participatory work, but still address similar underlying goals with their students. This goal could be coherence from the student perspective, but it also could be other goals for reform curriculum-use (e.g. equitable participation). Further, these images of curriculum-use would benefit from supporting resources (e.g. teacher interviews) that detail the teacher's rationale for attending, interpreting, and responding to these materials with these particular goals in mind. Another way to support teachers with this relationship is by engaging in the practices themselves. The teacher should participate in the teacher-curriculum relationship to plan and rehearse a key activity or series of activities (Lampert, et al., 2013). The goal of this participatory work is not for teachers to design final plans they intend to use in enactment. Rather, the goal is for teachers to learn about the reform approach to curriculum-use through engagement in the participatory relationship.

At the second level, teachers should engage in curriculum-based PL with other teachers in their school or district. This form of PL involves teachers working together to design instruction from curriculum that address their collective goals and context. We suggest that teachers participate in professional learning communities (PLCs) (Hord, 1997) with the explicit goal of engaging in the teacher-curriculum relationship together. This PLC would make the participatory interactions (attending, interpreting, responding) the focus of the teachers' on-going professional learning. The teachers would work together to read and interpret materials, and to collectively discuss their interpretations and prospective plans for enactment. They would then deliberate and make final decisions on their plans for enactment to support their goals. These plans could include choices to offload, customize, and/or make principled adaptations to the materials. In practice, these groups could collaborate on key lessons that they all intend to enact, or they could collaborate on different lessons that only a portion of the PLC will teach. After enactment, the PLC would then reflect on the successes and challenges in their plans and would discuss the direction of subsequent participation in the teacher-curriculum relationship. The enactment of planned curriculum could also be video-recorded and then collectively analyzed during the reflection sessions. For example, the video-recorded teacher could select particular clips that highlight successes and challenges in enactment, or that depict episodes of principled improvisation.

The PLCs could also use tools to support their collective engagement in the participatory relationship. For example, the teachers could decide to use particular conversational routines (e.g. stimulated recall) or material artifacts (e.g. planning tools) (Horn & Little, 2010) to mediate their attention and interpretations of the materials for which they are planning. They could also use tools to scaffold their efforts to customize their offloads or make principled adaptations from the materials. Finally, this PL should be sustained across curricular units and school years, and connected to the school, district, and state context (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Taken together, this form of PL would enhance the teachers' storyline-mediated knowledge for the storylines from which they design. It would also likely reaffirm their commitment to using curriculum as the teachers would constantly be working together to improve their curricular designs and enactments. It would be most effective at addressing teachers' pedagogical design capacity for storyline-use because the teachers would gain more understanding of the affordances and constraints in storyline materials and would also gain experience using the materials with the specific goal of developing their interactions in the teacher-curriculum relationship. Each PLC member would enhance their own pedagogical design capacity as the group collectively developed an assemblage of reliable instructional designs and strategies for enacting reform curricular materials.

Ultimately, I argue that teachers would benefit from PL that focuses on the teacher-curriculum participatory relationship. This work at both levels could help teachers to learn about this relationship and engage in principled instructional design to support coherence for their students.

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Section V

Conclusion

The three papers in my dissertation addressed the Teacher-Storyline (T-S) relationship in different ways. Broadly, the T-S relationship involves the teacher's use of storyline materials to design and enact instruction with the goal to be coherent for their students. The first two papers were empirical and provided evidence of the teacher's participation in this relationship. In the first paper, the teacher interpreted and planned from the storyline materials to support his students' epistemic agency during enactment. In the second paper, he designed moment-to-moment instruction to share epistemic agency with students engaged in divergent coherence-seeking from the storyline materials. Together, these papers highlighted that the teacher's curricular design work involved both planning and enactment. Further, the teacher's design work in these studies reflected a broader and more complicated set of practices that teachers frequently engage in as they use storyline materials. Finally, the findings in these studies provided an image of the ongoing relationship between the teacher and the storyline materials concerning students' epistemic agency in their coherence-seeking. The teacher designed instruction from the storyline materials and engaged in practical inquiry with the instructional goal to share epistemic agency with his students. The teacher's curricular design work around this goal positioned the students to better see their science work as making progress on their questions and problems, rather than merely following the teacher's directions (Reiser et al., 2021).

However, this relationship to curriculum and students marks a shift in the way teachers typically use curriculum with students. In other reform curricula like disciplinary storylines, the teacher designs for students to make progress on canonical science ideas (Sikorski & Hammer, 2017). The teacher takes the students into consideration, but this work involves connecting the students' resources to the logic of the premeditated disciplinary storyline. In student-centered storylines, this design-work is directly in consideration of students' coherence-seeking (Jaber & Hammer, 2016). Therefore, teachers need to use these storyline materials with the explicit goal to support students' coherence-seeking. This is by no means the only goal that teachers have for their use of storyline materials. However, this goal is integral to other storyline instructional goals, such as phenomena-based activity, incremental building and revision of ideas, and equitable 'figuring out' with students. This is because these other goals are contingent on students seeing their science work in the storyline as their own. As a result, teachers need to be committed to the goal of coherence from the student perspective in their interactions with storyline materials.

My third paper conceptualized these teacher-curriculum interactions and the teacher's resultant plans and enactments for students' coherence-seeking. This relationship concerns the teacher, the curricular materials, the participatory interactions between the two, and the planned and enacted storyline that is an outgrowth of this relationship. Broadly, this relationship is participatory because the teacher brings a variety of resources to their use of curriculum and the curriculum affords and constrains the teacher's interactions with their design (Remillard, 2005; Brown, 2009). More specifically, the teacher attends to, interprets, and responds to the storyline materials to produce plans for enactment. This participatory work with the materials is carried out by the teacher with the goal to support students' coherence-seeking. That means that the teacher must interpret or make sense of the materials for students' coherence-seeking, as seen in the first paper. It also means the teacher needs to enact these materials based on their plans and on students' emergent coherence-seeking, as evidenced in the second paper. Together, these three papers contribute to an initial image of the T-S relationship. This image has implications for the design of curriculum and professional learning to support, as discussed in the third paper. This image also prompts other questions about this relationship. In what follows, I will address two lingering questions concerning this relationship.

How can students truly act with epistemic agency in the teacher's facilitation of a planned curriculum?

At its core, this question concerns the 'irreducible tension' between agents and the tools they use (Hutchins, 1996; Norman, 1991; Pea, 1993; Wertsch, 1998). Curriculum materials are inert objects that represent concepts and activities (Brown, 2009). It does not matter whether these materials are designed to be coherent from the disciplinary or student perspective. In the end, all materials consist of static depictions of particular lines of coherence-seeking for figuring out natural phenomena or solving design problems. This premeditated coherence in the materials is in 'irreducible tension' with students' coherence-seeking because these efforts are a dynamic feature of the community's science work in enactment (Reiser et al., 2021). While this coherence-seeking is undoubtedly shaped by the affordances and constraints of the curriculum, it is never fully isomorphic to these premeditated coherences during enactment (Sikorski & Hammer, 2017). As a result, there is always tension between the students' bottom-up coherence-seeking and the teacher's facilitation of top-down premeditated curricular designs.

However, teachers cannot avoid this tension when they use curriculum with their students. It is only through the teacher's negotiations between the materials and the community's coherence-seeking, that students may act as epistemic agents in their science work (Reiser et al., 2021). As a result, students' epistemic agency is always contingent on the teacher's curricular design work (Ko & Krist, 2019). My model of the T-S relationship brings some clarity to what this work entails (see Figure 3.2). It describes how the teacher's participatory interactions result in plans and enactments from materials to share epistemic agency. It also points to a more practical conception of epistemic agency than that put forth by other researchers (e.g. Sikorski & Hammer, 2017; Miller et. al, 2018). For example, these researchers call for materials to be 'opened up', but pay comparably less attention to the fact that the teacher has to subsequently 'close in' on the materials again if they want to continue to use them with their students. My model depicts the teacher practices involved in both diverging and re-converging on the planned coherences in the materials.

In practice, these re-convergences can be motivated by the classroom community's own science work as described in my model. However, the re-convergence could also be driven by students' engagement in 'pseudoagency' (Miller et al., 2018). This is the case for all curricular enactments, not just instances of re-convergence. For example, the teacher might perceive the students as being taken by the 'narrative seduction' (Hammer & Sikorski, 2015, p. 428) of the materials. In this case, the students find the designed coherences of the storyline so compelling that they do not actually check these materials for plausibility and consistency. In this case, it appears the class is co-constructing the storyline, but students do not perceive they are doing so. Instead, they are just following rather than seeking coherence from the materials. The line between agency and pseudoagency is always fuzzy and is contingent on the teacher's curricular design work (Ko & Krist, 2019) and the students' own perceptions of their epistemic agency (Arnold & Clarke, 2014). As a result, I think the goal for teacher's use of curriculum should not be to eliminate episodes of pseudoagency, but rather to address and design from it in order to minimize these episodes in the moment (i.e. principled improvisations) and in future plans (i.e. principled adaptations).

Therefore, teachers can improve their capacity to share epistemic agency by engaging in practical inquiry and reflection around their participation in the T-S relationship. In their participation, the teacher would not shy away from the threat of pseudoagency or from following students' divergent lines of coherence-seeking. Instead, the teacher would address and design from these instances as they emerge in enactment. This curricular design work would operate in the "overlap" between students' interests, ideas, and the coherences in the materials (Reiser et al., 2021). Over time, the teacher would develop greater capacity to craft instruction that negotiates in, and expands upon this overlap in order to support students' epistemic agency. Teachers can also help students' own efforts to act with epistemic agency by directly addressing their role in curricular knowledge-building. Students should perceive they are in partnership with the teacher in the development and trajectory of knowledge-building in the curriculum (Miller et al., 2018; Reiser et al., 2021). As a result, I argue that the teacher should not pretend the curriculum completely lacks premeditated plans. Instead, the class should develop explicit norms around their partnership with one another and with the materials. The teacher should also make it clear that the class, not the materials, will drive coherence-seeking. This means students should perceive they have the agency to diverge from or build upon these materials as they see fit.

Ultimately, the 'irreducible tension' between top-down coherences and bottom-up coherence-seeking should not be avoided by the teacher in their design work and in their discussion of their role and their students' role in curricular knowledge-building. Rather, I would argue that it should motivate the teacher's design efforts and be the place from which students share epistemic agency and power in their science learning. However, the irreducible tension described in this section remains an open question in education research and an essential area for subsequent investigation and theorizing.

How does the socio-political context interact with the T-S relationship?

The socio-political context is mostly absent from my model of the T-S relationship. This was both a conscious decision and a limitation of the model. On the one hand, it was a practical choice to focus on the teacher, curriculum and his students to explore these relationships in depth and not on the socio-political context in which this work occurs. On the other hand, it does not change the fact that issues of power and identity manifest in all of the teacher's interactions with curriculum and students

(Gutiérrez, 2013). As a result, I wanted to consider some of the questions and potential implications of the sociopolitical context in which the teacher's participation in the T-S relationship occurs.

First, I want to focus on the curricular materials themselves. There are a variety of different storylines and other reform-oriented science curricula that try to support coherence for students (e.g. OpenSciEd, 2020; SOLID Start, 2021, Learning in Places, 2021). These curricula have different designs and instructional approaches, as well as varying goals and assumptions about knowledge and how it is learned. My dissertation work involved one teacher's use of an OpenSciEd storyline unit. This unit was designed to be aligned to the current science reforms and to particular NGSS performance expectations. A common socio-political critique of such reform-oriented materials is that these efforts only provide "greater access to settled forms of disciplinary knowledge" (p. 3, Warren et al., 2020). Critical scholars have argued that students should disrupt settled disciplinary ideas and practices (Tuck, 2009) and imagine and work toward alternative possibilities for their learning and relations to disciplinary ideas and practices (Espinoza, 2009).

The storyline unit in my dissertation was designed to be coherent for students, but the students ultimately seek coherence in 'settled' disciplinary knowledge. I raise this point not to cast judgment on these units. They were explicitly designed to be aligned with NGSS standards (OpenSciEd, 2020), and with the goal to support students in 'figuring out' disciplinary knowledge (Reiser et al., 2021; Schwarz, Passmore, & Reiser, 2017). However, there are other storyline units with the explicit goal to desettle disciplinary knowledge in their designs. One such example is the *Learning in Places (2021) Seasonal Field-Based Science Storyline.* This unit was organized for students to ask questions and engage in field-based investigations related to the seasonal impacts on plant and animal life cycles. The key difference between this storyline and OpenSciEd storylines is that it is specifically designed for students to grapple with the nature-culture divide during enactment (Bang, Warren, Rosebery, & Medin, 2012). Instead of operating within the bounds of settled disciplinary knowledge, this *Learning in Places* storyline unit positions students, families, and educators to engage in ethical deliberation and decision-making about seasonal phenomena that are both social and ecological.

This work parallels Bruno Latour's (1993) argument that the modernist distinction between nature and culture is a human construction. He conceived of a "Parliament of Things" wherein natural phenomena, social phenomena and the discourse about them are not seen as separate objects, but rather as hybrids made and scrutinized by the interaction of people, things, and concepts (Latour, 1993). I think this is a valuable avenue to pursue in designing storyline materials because it positions students to engage and make sense of these hybrid phenomena using a mix of scientific, social, moral, and other forms of practice (Warren et al., 2020, see horizontality). Further, students can analyze the current lines drawn between nature and culture in modern society and can reflect on how power and historicity influenced how these lines have been drawn (Bang, et al., 2012). As a result, I suggest that curricular designers should continue to expand their use of the storyline approach and materials to investigate more de-settled phenomena and design problems.

Second, I want to consider the teacher's planning and enactment of the storyline materials. I discussed previously that the teacher's curricular design work in the T-S relationship operates in the "overlap" between students' interests, ideas, and the coherences in the materials (Reiser et al., 2021). My discussion could imply that this 'overlap' is a natural occurrence in which the teacher simply chooses to work. In reality, this overlap is actually a socio-political construction facilitated by the teacher's attention and responsiveness. The teacher's effort to 'see' students' contributions is not a transparent, internal psychological process. Instead, this 'seeing' is learned, used, and maintained in social activity using a range of historically constituted discursive practices (Goodwin, 1994). As a result, issues of power and identity are reflected in the way the teacher attends to the overlap between students' interests, ideas, and the coherences in the materials. Teachers typically attend to the substance in students' talk that linguistically aligns with targeted canonical knowledge (Brown, 2019; Miller et al., 2018). This attentional approach often ignores the bulk of diverse students' 'funds of knowledge' (Moll, Amanti, Neff, & Gonzalez, 1992) about phenomena.

Bryan A. Brown (2019) describes these funds in terms of conceptual continuities that exist between students' everyday language and scientific language. These continuities are always present in students' talk because students are constantly engaged in deep sensemaking about the phenomena that occur around them (Barton & Tan, 2018; Bang, et al., 2012). Therefore, it is up to teachers to broaden their conceptions of science and students' everyday forms of language in order to better attend and respond to students' diverse resources (Brown, 2019). Further, in enactment, teachers need the capacity to expand upon and diverge from the overlap in order to support students' epistemic agency. Finally, the teacher should also extend this lens to their participatory work with the curriculum. Teachers should 'see' their students and their resources in the materials as they attend to, interpret, and respond to them in the T-S relationship.

However, the teacher's work to expand this overlap does not actually disrupt the position of the disciplines themselves as settled and exempt from reproach or historicity (Warren et al., 2020). This instructional work is aimed at providing students with greater access to settled disciplinary ideas and practices. The question then becomes how teachers can design instruction that engages students in 'acts of epistemic disobedience' where they critique and reimagine settled disciplinary knowledge (Tuck, 2009; Warren et al., 2020). Curricular materials, like the *Learning in Places* storyline, offer support to students' acts of epistemic disobedience. Fostering epistemic disobedience also requires that teachers think and act "as careful, expansive readers of their students and their ideas" (p. 3, Warren et al., 2020) in designing and enacting instruction. This instructional design work involves more than just teachers' knowledge of their students and discipline they teach. It also requires they possess sociopolitical knowledge to reinvent or subvert the working infrastructure in their school in order to be advocates for students' epistemic disobedience (Gutiérrez, 2013).

This sociopolitical knowledge emerges from the teacher's broader commitments to teach in a way that interrogates the universality, objectivity, and neutrality of disciplinary knowledge and that critically engages students in the political and intellectual histories that have shaped this knowledge (Warren et al., 2020). Some K-12 science teachers may view these commitments as overreaching. This may be especially true for teachers who place scientific knowledge and science as an endeavor in high esteem. These teachers may hold commitments about knowledge and knowing that align more with current science reforms or with more naive forms of scientific realism. Ultimately, teachers may benefit from a more socio-political stance to curriculum use, whether their goal for students' learning is to increase access to this disciplinary knowledge or to disrupt it. In each case, it supports students to form more expansive relationships to scientific knowledge and practices in their learning. Consequently, future research should investigate how the socio-political context interacts with the T-S relationship, including its influence on the teacher's participatory interactions with the curriculum and their enactment with students.

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