Redistributing Epistemic Agency: How Teachers Open Up Space for Meaningful Participation in Science

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Abstract: Taking the practice turn (Ford & Forman, 2006) necessarily involves students in making judgements about the state of their knowledge and in making decisions about how their investigations should proceed. In this study, we investigate how teachers *open up* aspects of their curricular activities and invite students to partner in the epistemic decisions that drive classroom activity. We draw on work in 3 classrooms as instrumental cases to illustrate what teachers did to 'open up' the curriculum and how these moves re-distributed epistemic agency. In each of the three cases, what teachers opened up had different implications in terms of their *reach*: the resulting "ripple effect" of the impact of the decisions that students were involved making. These cases illustrate the "disciplined improvisational" work (Sawyer, 2004) required to open up space within the constraints and boundaries of the curriculum to create opportunities for re-distributing epistemic agency.

Role of epistemic agency in scientific practice

One of the key challenges of the "practice turn" in science education (Ford & Forman, 2006), captured in part by the Next Generation Science Standards (NGSS Lead States, 2013), is supporting learners' participation in building explanatory model-based accounts of natural phenomena (Lehrer & Schauble, 2006; Passmore & Svoboda, 2012). As embodied by this "practice turn," students should be involved in both making judgements about the state of their knowledge so far and in making decisions about how their investigations should proceed accordingly (Ford, 2015; Stroupe, 2014). Involving students in this way is often cited as a distinguishing factor between "rote" versions of doing science and more meaningful forms of participation in science practices (Barton & Tan, 2010; Berland et al., 2016).

We describe this aspect of this vision for meaningful science learning as supporting students' epistemic agency. We view epistemic agency as a dynamic and multidimensional construct negotiated through interaction, rather than as a binary property that one either has or does not. More specifically, we view student agency in classrooms as "the way in which [a student] acts, or refrains from acting, and the way in which her or his action contributes to the joint action of the group in which he or she is participating" (Gresalfi, Martin, Hand, & Greeno, 2008, p. 53). We add the modifier of epistemic because we are focused on the actions (or refrains from action) that are *consequential to the collaborative construction of a shared knowledge object* (Damsa et al., 2010). In our case, this shared knowledge object is an explanatory account of a natural phenomenon. To make the "practice turn," there needs to be significant redistributions of agency in the classroom, in ways that invite students to partner in the epistemic decisions that drive classroom activity. What this looks like, and how teachers do this in the context of a set curriculum, is the focus of this study.

What makes epistemic agency *epistemic*?

Actions that we consider consequential to the construction of a shared knowledge object are those that are connected to, or have an impact on, the intellectual nature of the task itself. For example, imagine an engineering challenge designing a fast CO_2-powered car. In this challenge, students are charged with designing the car and explaining how and why some cars in this context are faster than others. Students might take actions such as deciding on the type of material used for the body of the car. We would say their doing so indicates agency. But whether this action reflects *epistemic* agency depends on the rationale behind this decision. For example, a rationale for choosing balsa wood instead of oak because it has less mass and therefore requires less force to speed it up has implications for the explanatory account. We would argue that this action + rationale reflects epistemic agency. However, the same decision with a different rationale could be non-epistemic in nature: if balsa wood is prettier or easier to paint, for example, then the action of choosing balsa wood is not (in that moment) a reflection of epistemic agency.

In the engineering task described above, there are different "levels" of activity that can be opened up for students' decision-making (Figure 1). For example, when students decide between balsa wood and oak when considering speed, this decision is directly tied to the claims they can make based on that data (Claims, Figure 1).

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Students could also be involved in deciding *how* they should go about investigating that one car is faster than another, such as choosing whether to measure instantaneous speed at a single point, or the average speed across a set or total distance. These decisions influence the methods for investigation (Methods, Figure 1), and the data generated from the trials have a direct impact on the claims that can be generated, supported, or refuted using those data. At yet another "level," one could imagine students making choices about what the engineering goal is in the first place (Goal, Figure 1), such as deciding whether they are investigating how to make cars fast, or whether they want to make cars that are both fast and use sustainable energy sources. This decision would have implications for the entire duration of the explanatory arc: all the subsequent twists and turns in the models they generate, the methods they use, and the claims they support or refute. Decisions at each of these "levels" invite students into doing substantive intellectual aspects of the work. But they have a different resulting "reach" in terms of the impact on students' subsequent learning.

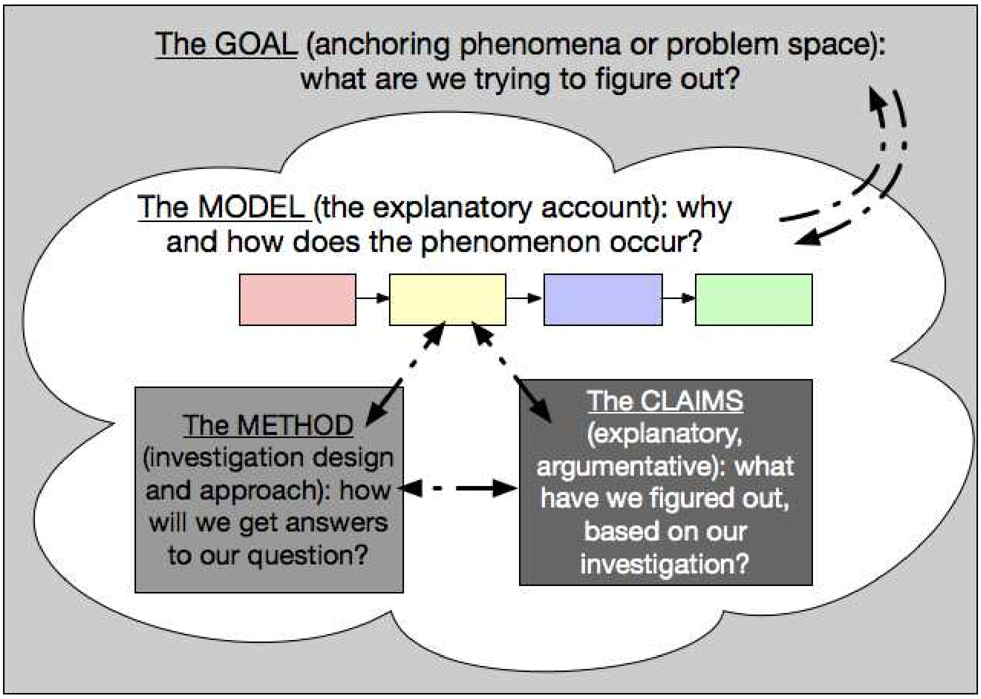

Figure 1. "Levels" at which teachers can open up space for epistemic agency within scientific activity.

Teacher decision-making that opens up space for epistemic agency

For students to be able to make any of these decisions, teachers need to do work to renegotiate the positional framing (Shim & Kim, 2018) of students in their classrooms, as these kinds of epistemic decisions are typically considered to be the teacher's responsibility. Following Hand's (2012) conceptualization of students "taking up space" in mathematics classrooms, we call this teacher work "opening up space": creating room for students to be able to make disciplinarily substantive decisions about their science inquiry. In considering when and how to open up space, teachers are fully aware that they themselves have significant responsibilities and constraints that prevent them from giving "full reign" over to students: limited time with students, accountability to content standards, responsibility for student safety and well-being, etc. Therefore, teachers must make strategic decisions about when and how to open up space for students to take on greater epistemic responsibility.

We focus in this paper on the different "levels" at which teachers might strategically decide to open up space for student decision-making, and how opened spaces at those different levels impact students' subsequent participation in science practices. As such, we focus on curriculum materials as a guiding resource for teachers' noticing and decision-making about opening up space. We pay particular attention to the consequences of opening up space at each gradient level in terms of both teacher facilitation and students' subsequent activity.

Curriculum as resource in teacher decision making

Curriculum has historically been designed and used as a resource for shaping science learning in K-12 classrooms. The design principles and features of curriculum materials influence what teachers teach because they specify the set of activities or phenomena that cohere to a set of learning objectives or student performances. But how lessons are enacted is subject to a great deal of variation. Curriculum enactment is a function of the social interaction between teachers and students, embedded in specific questions or phenomena, and influenced by how schools and districts support and assess teachers and students. Thus, teachers are constantly engaged in the work of adaptation and improvisation (Brown & Edelson, 2003; Sawyer, 2004); how they frame, launch, and enact tasks can directly influence the epistemic goals and knowledge building processes that students engage in (Kang et. al, 2016).

In the context of engaging students in scientific practices, taking the practice turn requires that teachers create room for uncertainty and contention (Ford, 2015; Manz, 2015). It also requires that teachers scaffold students into norms for sensemaking and evaluation. Teachers need to notice and respond to students' ideas, but also provide opportunities for students play a key role in doing the substantive work of proposing claims and questions and evaluating candidate ideas in the face of emerging evidence (Maskiewicz & Winters, 2012). Although teachers' responsiveness to students' ideas and their adaptive use of curriculum materials is necessary, it also creates varying degrees of uncertainty in how science learning unfolds in the classroom. This uncertainty pushes back on the very purpose of clear and tractable learning objectives and outcomes that teachers are accustomed to designing their instruction around. That is, by shifting epistemic agency, teachers subject their classrooms and instructional plans to uncertainty.

In this study, we explore variation how teachers shift epistemic agency by opening up aspects of their classroom activities. The research questions guiding this study are: *when and how do teachers create space for students' epistemic agency? How does that impact students' participation?*

Methods

The primary data source for this paper is a corpus of transcripts derived from video recordings of middle school science classrooms collected as part two NSF-funded projects. The goal of both projects was to understand how students learned to participate meaningfully in science knowledge-building practices and how teachers supported that participation over time in the context of the same curriculum, *Investigation and Questioning our World Through Technology*, or IQWST (Krajcik, Reiser, Sutherland, & Fortus, 2011). As a part of that work, both authors conducted classroom observations and generated field notes, analytic memos, and preliminary analyses that focused on how aspects of the enactment differed from other observed classes and from the written curriculum. Multiple lessons (and sometimes, the same lessons) were observed over 3 years.

Guided by our working definition of epistemic agency, we worked to identify candidate moments from our preliminary analyses as instrumental cases (Stake, 1995) in which teachers did significant work to open up aspects of the IQWST curriculum to students' decision-making. That is, we were looking for moments in which the "opening up" was notable and even surprising to us as observers. We took this approach because our goal is to carefully examine and develop a rich, contextualized description of epistemic agency and the teaching work and tensions involved in supporting it rather than to make claims about, for example, how often or regularly teachers opened up spaces for students' epistemic agency. We then verified that each of the selected moments were instances in which epistemic agency was re-distributed, from the teacher to the student. To be considered an instrumental case each selected moment had to fit the following criteria:

1. when something that was written as taken-for-granted in the curriculum materials was presented in class as problematic, uncertain, or open to negotiation, OR
2. when teachers added a discussion that was not in the written curriculum materials at all; AND
3. when students responded to the teachers' invitations in 1 and/or 2 by generating multiple possibilities for claims and provided rationales for those possibilities.

For each of the cases, we then characterized the level at which space was being opened to a redistribution of agency: that is, what was it that there was now room for discussion and deliberation about (see Figure 1)? For each of the 3 identified cases, space was being made around: 1) Phenomena or problem space that are being explored; 2) Methods for exploration, including both whether and how to conduct investigations; OR 3) Claims about the underlying causes of a phenomenon, including both claims drawn from previously constructed models and new observations or conjectures. Taken together, these cases represent variations in what the teacher opened up, and in turn, differences in the levels of epistemic agency for students to take up. For each case, we describe the context of the lesson, what aspects of classroom activity were being opened up to uncertainty, what the teacher did to shift epistemic agency, and how these decisions shifted student participation.

Findings

Case 1: Opening up space for developing methods for investigation

This Chemistry lesson took place in the Spring semester of the 6th grade IQWST unit centered on the driving question, "How can I smell things from a distance?" The unit spanned multiple weeks and explored the molecular nature of matter. Rather than starting the unit by introducing students to the particle nature of matter, students explore a variety of phenomena to develop a model of how people smell odors. This model is then used to explain the behaviors of solids, liquids, and gases. The model that is generated and revised throughout this unit reflects the understanding that matter is made of particles that are in constant motion.

The focal lesson, as specified in the curriculum materials, asks the teacher to begin with a demonstration that involves two unlabeled flasks of clear liquids. Students are asked to generate observations that can potentially differentiate between the two liquids, and that they "should recognize that further investigation is needed". The teacher is then asked to demonstrate how an indicator paper, like other detectors explored in lessons prior, detects the presence of different materials by changing colors. The teacher would then carry out a demonstration that shows that the two liquids are different by placing the indicator paper into the two flasks. Because one flask contains ammonia and the other, acetic acid, the indicator paper turns blue and red, respectively. Thus, the indicator provides observable evidence that the flasks contain different liquids.

Instead of following instructions outlined above, Ms. K began the lesson by showing students the two unlabeled containers of clear liquids, and then asked her students, "*...how* can we tell the difference between these two sources of odor? Who can tell me? What's different? Let's put a list on the board here of what's different between these sources of odor." After the students identified their similarities (e.g. both liquids were clear) and differences (e.g. one seemed "foamier" than the other), Larry conjectured that the two flasks might contain different liquids. Ms. K then asked how they might test Larry's claim, saying, "They *might be* different types of liquids. How can we figure that out? How could we tell?" Rather than jumping in and using the indicator paper to show *that* the liquids were different, Ms. K's invitation re-distributes agency by opening up the method of investigating *whether* the two were different, rather than taking this as a stated fact.

Students took up Ms. K's invitation by proposing a variety of ideas for investigation, such as smelling, shaking, freezing, weighing, and tasting the liquids (to which Ms. K responded that this was not allowed in the science lab) to determine whether they were the same or different. Another student proposed combining each liquid with another chemical to see how they react, or weighing the two flasks to detect differences in density. Finally, Steven suggested a method of investigation that mirrored how the indicator paper would be used:

> Steven: So you could get a turkey baster or a syringe or something, and then put [it] in there, take some of the liquid, and put it on a paper and do the same thing with the other one. And then if something different happens, then you'll know the difference between what it is."

It is important to note that Steven not only suggested *what* materials that could be used (turkey baster, syringe, paper), *how* they might be used, but also what the results would imply about the liquids. Inviting students into this work has important epistemological implications because students are invited into the work of making decisions about how they might go about investigating the difference between the two liquids, which impacts the type of data that might be used as evidence to support alternative claims.

Case 2: Opening up space for generating alternative claims and motivating model revision

This focal lesson comes early in an IQWST unit centered on the driving question "How do my eyes allow me to see?" The unit began with an optical illusion that seeded uncertainty in whether students could really believe their eyes. The beginning lessons explore the behavior and properties of white light as "interacts" with various objects, and progresses to an exploration of how light moves, how light is detected by the eye, and how light is perceived. Over the course of the unit, students co-construct and refine a model of light's behavior, based on the data from their data collection activities. Notably, this unit is used in the Fall semester, and students' very first introduction the practices that are emphasized in the curriculum. Thus, there are a number of lessons dedicated to discussing what counts as scientific model, an exploration of how to depict ideas and relationships in model form, as well as the various types of models that count as a scientific model.

In line with the written curriculum, Ms. B began the lesson with a demonstration. She turned off all the lights in her classroom and closed the blinds and aimed a flashlight at a piece of white paper that has been taped to the whiteboard, and asked students to explain why they were able to see the paper. She then directed the beam of light at a handheld mirror, rotating the mirror so that it reflected the light around the room, and, to the students' dismay, directly at their eyes! In the written curriculum, this initial demonstration was intended to "generate evidence about the difference between the ways light bounces off a mirror and off a [paper]". The curriculum specifies that after this demonstration, the class should move directly to gathering empirical data using a light meter, a piece of paper, and a mirror, so that they can use these patterns to describe how light bounces differently off these objects (e.g. scattering, reflecting).

Instead of moving directly to the activity involving light meters, Ms. B engaged her students in a whole-class discussion that spanned half of the class period. During that discussion, she explicitly used the differences in how light behaves with a mirror and a piece of paper to problematize their current model. For instance, when Ms. K directed the beam of light toward the students, who reacted by laughing, grimacing, and talking over one another when the beam of light was aimed directly at them. Ms. B called out this discrepancy in light's behavior, saying, "When I [aimed the light at the] paper you weren't yelling." She then asks the students to explain *why*: "So *what makes it different* when light bounces…*why* do you think it's different from when the light hits your paper and when it hits the mirror?"

Students responded to Ms. B's invitation by proposing candidate explanations. Adam first proposed that these differences might be happening because light is carrying different information when it bounces off a mirror versus a piece of paper. Later, Illiana weighed in and conjectured that the light is *shining* off of the paper, but *bouncing* off the mirror. Although the class agreed that the light was behaving differently, Ms. B pointed out their existing model was insufficient for explaining why:

> Illana: when you use paper, it's just shining (inaudible) but when it hits the mirror it's bouncing…
>
> Ms. B: So why does it do it for a mirror and not for a paper?
>
> (Many hands raised in the front of the room)
>
> Illana: 'Cuz the mirror is like if we look you can see your reflection...(inaudible)
>
> Ms. B: Why (asking Illana, who seems stumped)…Anne?
>
> Anne: Because that's the mirror and...(inaudible) its cuz the light...(inaudible) light anymore because some light (inaudible)
>
> Ms. B: So is the light hitting different objects differently?
>
> Students in unison: Yes
>
> ….
>
> Ms. B: But how does light know that? How does light know…to act differently when it hits this (pointing the flashlight at the paper) and react differently when it hits this (pointing the flashlight at the mirror)?

Ms. B's continued press for *why* encouraged students to propose alternative claims about what might be causing the observed differences in how light behaves with a mirror and paper. These questions emphasized that their current model was unable to account for these different behaviors. Notably, the curriculum materials specify that this demonstration should be used to help students see *that* light behaves differently, but it does not articulate how these observations problematize the existing model. Opening up their model to uncertainty encouraged students to consider reasons for the different behaviors.

At the conclusion of this opening discussion, Ms. B positioned the data from their upcoming investigation as an opportunity to gather evidence for or against those claims, saying, "Should we get some data, collect some more information about this? Try to figure this out?" Thus, the data generated through their subsequent investigation were positioned as evidence for refining their current consensus model.

Case 3: Opening up space for expanding the explanatory goals

This case took place during the first few days of an 8th grade biology unit organized around the driving question, "Why do organisms look the way they do?" Over the course of the unit, students worked to build a Mendelian model of genetic inheritance. As written, the first lesson in the curriculum had students a) look at a photo of fish and birds and speculate about the functions of their different traits; b) record the frequencies of various human traits amongst their classmates, such as hitchhiker's thumb and attached vs. detached earlobes; and c) discuss whether these traits were inherited or acquired.

Instead of beginning the unit as written, Mr. M skipped the pictures of birds and fish and had students make observations about the traits of people around them. This motivated a conversation about whether these traits were inherited or acquired, which (unexpectedly) lasted for two class periods. Mr. M had planned for this discussion to then lead into an investigation in which students collected data on a specific trait by observing a specific group of people (e.g., their families; people who came into Burger King over the course of an hour; the first 20 people whose photos came up on a Google Image search for “celebrities”; etc.).

During the discussion about human traits, a debate began about whether height was inherited or acquired when a student made a claim that height was inherited: if your parents are tall, you are likely to be tall, and if they are short, you are likely to be short as well. Several students immediately responded to this claim with counterexamples from their own families: a sibling who was very tall even though their parents were short, or a mother who was short but an aunt who was tall like them. In addition, a few students brought up ideas about nutrition, such as that they should not drink coffee because it would stunt their growth, or that they should drink milk because it would make them grow tall and strong, leading them to argue that it was at least partially acquired. Still other students argued that it was totally random: height was unpredictable based on either your parents or grandparents, or from your nutritional choices.

Mr. M allowed this discussion to continue for nearly the entire 40-minute class period, much longer than in any of his other sections. Towards the end of class, he made a move to transition them into the planned data collection activity (Activity 1.2), still leaving open the possibility of continuing the discussion:

> Mr. M: I’m not going to resolve this but I’m feeling like, if this is becoming a compelling question, [...] if we’re going to figure out if something is random, I feel like we should collect some data. So uh. Let’s take a couple more comments and if we’re kind of moving towards that ‘what’s the pattern’ question, then I want to move to [Activity] 1.2. If not, if we’ve just got, if we’re generating some questions, cool, let’s do it now. So um. [points to Carmen] Did you have--?

In response, Carmen brought up how her hair is very similar to her aunt’s but not to either of her parents’ and asked if inheritance could work that way rather than only through parents and grandparents:

> Carmen: I actually wanted to make a counterarg—like you said not aunts and uncles, but like I have really wavy and like sometimes curly hair, but like my mom and my sister and my dad all have like the straightest hair, but like my aunt has really curly hair like me, so like, can’t like that be a thing too?

It is important to note here that Carmen’s input was a direct interruption to Mr. M’s bid to “move on” to the next planned activity, and to Mr. M’s insistence earlier in the conversation that students stick to “direct” lines of inheritance (parents and grandparents). It also demonstrates that students were bought into this additional dimension of complexity. In response, Mr. M pointed out it sounded like there was a pattern that a lot of people were noticing: they had traits that didn’t come directly from parents or grandparents. Mr. M then explicitly acknowledged the push-back they had been giving him and allowed space for the four students who still had their hands up to share their ideas:

> Mr. M: Let’s here, so, I’ve been trying to pull us in a certain direction, I like where you guys are pulling us though, I like that you’re wanting to stick with examples from our own families. In our last four I want us to make sure that you’re turning to our speakers [...], so I want us to face this way and let’s go to Elena.

The bell rang after Elena shared. Before they left, Mr. M gave each student an index card and asked them to record the patterns from their families that they thought were important "clues" to helping them understand inheritance. When students returned the next day with their index cards with family patterns, they made a second driving question board with those “family cases.” As they were constructing this driving question board, the discussion about whether each trait mentioned was inherited or acquired continued, including conversations about traits such as athleticism, spoken language, and race. After another entire class period of this discussion, Mr. M asked students to pick one of these traits to observe and to pick a population in which to observe it over the course of the weekend (Activity 1.2 as planned).

Mr. M’s decision to allow the classroom conversational space to be opened to students’ persistent interest in the patterns in their own families, and his in-the-moment response to create a second driving question board, broadened and made more complex the set of phenomena that students were trying to explain. In addition, his doing so allowed students to jointly decide, through conversation, what kind of explanation they were going to be working to build over the course of the unit. This was no longer a unit about different traits in different species, or quirky differences between humans like hitchhikers’ thumbs. Instead, it was a unit about complex patterns of inheritance within their own families—the thing that was both interesting and bothersome to them. It set the expectation that whatever models they were developing should be able to at least partially explain these complex patterns, and that whatever their models could not explain should drive their future investigations. And that was the case: students continued to draw on family-based examples throughout the unit, even while discussing the genetics of plants and moths.

Discussion

In each of the three cases, what teachers opened up had different implications in terms of their *reach*: the resulting "ripple effect" of the impact of the decisions that students were involved making (Table 1). Ms. K opened up the methods for investigation in Case 1, creating the opportunity for students to shape how they conducted the investigation and the claims they could draw from it. In Case 2, Ms. B problematized their existing model of light, which opened up space for students to make alternative claims. These decisions framed their subsequent investigations for the next few days, leading to revisions to an aspect of their light model. Finally, in Case 3, Mr. M opened up the opportunity to expand the phenomenon that anchored the entire unit. The "reach" of this decision was long-ranging: even though his students completed most of the activities in the unit as written, they were framed by, and constantly connected to, a need to explain the puzzling patterns of inheritance that students observed in their families.

Table 1: Overview of cases

	What aspect is the teacher opening up?	How do students participate?	Reach
Case 1 (Ms. K)	The methods for investigation	Students brainstorm candidate methods & tools that will generate evidence to help distinguish two unknown liquids	Within the investigation in a single lesson
Case 2 (Ms. B)	Their current explanatory model for light	Students propose alternative claims for the observed phenomenon. This leads to a new phase of evidence collection and subsequent model revision in later lessons	Investigations and model revision within days of a single unit
Case 3 (Mr. M)	Anchoring phenomenon that motivates explanatory goal	Students continued to bring up puzzling patterns of trait inheritance in their own families, which eventually become part of the anchoring phenomenon.	Influences explanatory goals (and models, investigations, and claims) for the entire unit

Importantly, none of these cases were instances where students did the "opening up" spontaneously or intentionally (cf. Calabrese Barton et al., 2013; Engle & Conant, 2002). This was purposeful on our part. When teachers open up space for students to make choices about acting or not, and how that action contributes to the joint action of a group (Gresalfi et al., 2008), they also subject their own instructional practice to uncertainty—about what students will bring to the table, whether it fits in with their instructional goals, etc. These cases describe the "disciplined improvisational" work of teaching (Sawyer, 2004). They illustrate how teachers can open up space while still maintaining some of the constraints and boundaries of the curriculum (and therefore limiting the degree of uncertainty they are introducing to their teaching) to create opportunities for re-distributing epistemic agency. Seeing aspects of their curriculum—the methods, models, and anchoring phenomena—as entry points for re-distributing epistemic agency may help teachers make inroads to shifting their classroom instruction towards more responsive instruction: not all teachers may feel capable of shifting their instructional practice to look like Mr. M's at the start, as it requires substantive changes to in one's instructional sequence. But they may be able to take a step towards it on the level of a single lesson, like Ms. K. The language of "opening up space" and considering the resulting "ripple effect" may scaffold productive ways of talking about these goals with teachers as we work to increase opportunities to re-distribute epistemic agency in science classrooms.

Highlighting this as an area for supporting teacher learning suggests that it may be productive to think about how we might develop educative curriculum materials that support these teacher learning goals. In addition to getting teachers to attend to places in their curriculum that they can invite students' participation in ways that helps students to develop accurate content knowledge, we should also be considering whether and how to design materials that focus teachers' attention on ways to increase students' ownership and agentive participation in knowledge-building work. For example, as in the case of Ms. B, this could be positioning data collection activities as opportunities for students to apply their knowledge to design procedures and predict their outcomes, rather than an exercise in obtaining a target outcomes. Repeated attempts at creating space for epistemic agency may scaffold teachers toward accepting uncertainty as productive tension for teaching.

The cases presented here are exemplary cases of how teachers hold the need to meet specific learning objectives in tension with the desire to provide students with opportunities to make meaningful and consequential decisions, and how they navigate both goals well. The decision-making involved in navigating this tension is important to address and support in professional development and teacher preparation. Generating language around these improvisations can be fruitful beginnings for thinking about how we might support teachers to increase opportunities to re-distribute epistemic agency.

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