Designing for and Analyzing Productive Uncertainty in Science Investigations

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Abstract: This paper explores methods to design and analyze learning environments in which uncertainty is incorporated into students' activity to support the development of science practices and content understandings. I describe how a second grade landforms investigation was designed to incorporate *productive uncertainty* about the relationships between phenomenon, empirical investigation, evidence, and explanation. I then describe, apply, and reflect on an analytic method to trace uncertainty through (1) instantiation in the learning environment (2) recognition and introduction into conversation, and (3) conversations in which uncertainty supports participation in science practices.

A major question in current research in science education is how to engage young students in the epistemic practices of science in ways that are meaningful to them and powerful for the development of science understandings. Making progress on this challenge will involve (1) understanding what forms of practice are most appropriate targets for young students, (2) developing principles for designing learning environments that support meaningful engagement in practices, and (3) understanding the forms of support that allow teachers to orchestrate these learning environments.

Recently, scholars have stressed the importance of *establishing a need for science practices* in learning environments. Researchers have argued that unless students participate in science practices in the context of "figuring something out," those practices are likely to have little scientific meaning (Berland and Hammer, 2012). They have stressed that learning environments should highlight disciplinary forms of uncertainty and allow students to grapple with them (Engle, 2011; Reiser, 2004). From this perspective, science practices are *emergent* from the learning environment, in the sense that students engage in and develop science practices for their own science activity (Cobb & Yackel, 2006). These approaches focus on the purposes of science practices, ask when those purposes are meaningful to young students, and use methods to analyze the local development of practices in classroom communities. This paper seeks to make a contribution to emergent approaches to science practices: first by exploring how forms of uncertainty that are under-represented in learning environments can be productively built into young students' science investigations, and second, by developing a method for tracing the relationship between uncertainty and the emergence of science practices.

Incorporating uncertainty into elementary science investigations

The work reported here draws from socio-cultural and emergent approaches (Cobb & Yackel, 1996; Saxe, 2002) that treat practices as constituted and adapted in communities to solve shared problems. Scientific activity is driven by the need to manage uncertainty; uncertainty not only about how to explain the world, but how to represent the world in the form of an experiment, what to measure, and how to convince peers to see what the scientist wants them to see. These uncertainties manifest for scientists as decisions about what to do (e.g., what the best experimental design is), as push-back from empirical work (for example, in the form of surprising experimental results), and as critique from an audience (e.g., the disagreement of a peer about whether a measure is appropriate) (Knorr-Cetina, 1999; Pickering, 1995). For scientists, uncertainties constitute sites for argumentation, explanation, and the development of new understandings. From this point of view, students need to experience some of this uncertainty if they are to engaging meaningfully in scientific practices and develop an understanding of what those practices are for (Ford & Forman, 2006; Manz, 2015).

Productive uncertainty in classroom learning environments

When I refer to *scientific uncertainty*, I mean an aspect of scientists' work that is non-obvious and contingent, which must be figured out by the scientist and negotiated in response to feedback from peers and the material world (Pickering, 1995; Rouse, 1999). I use the term *productive uncertainty* as a pedagogical construct to describe an approach where students might profitably engage with scientific uncertainty, in the sense that by grappling with some of the decisions scientists must make, students would make progress on scientific practices and consent understandings. Constructs that I draw on include research on productive disciplinary engagement that stresses the need to "problematize" content (Engle, 2011; Reiser, 2004), the use of "cognitively demanding tasks" (Henningsen & Stein, 1997), and "productive failure" (Kapur, 2008). I draw from these literatures to identify three sets of principles for incorporating productive uncertainty in learning environments.

Understanding what to make uncertain

Students should engage in tasks designed to open up decisions or problems that are important from a disciplinary point of view, without so much ambiguity that the learner cannot engage with key uncertainties.

Helping students experience, and make public, moments of uncertainty

Students must recognize and engage with disciplinary uncertainties: there must be a moment where students feel puzzled, see a conflict, or disagree with a member of the classroom community. These moments establish a need to engage with disciplinary practices and content.

Helping students resolve or learn from uncertainty

There needs to be support to resolve or learn from the uncertain experience, in the form of tools that scaffold students' engagement and teachers guiding discussions where strategies and solutions are compared, and, when necessary, introducing and unpacking next steps or canonical procedures and ideas.

Empirical uncertainty as an under-leveraged resource in elementary classrooms

Drawing from the Science Studies Literature (e.g., Gooding, 1990; Pickering, 1995), I conceptualize important forms of uncertainty as emerging for scientists as they manage the transitions between the complex and material *phenomena* they seek to understand, the *empirical investigations* that they use to "get a grip on" the world, the *observations and evidence* that the investigations generate, and the *explanations and explanatory models* of phenomena that are the targets of scientists' work (Manz, 2015). The default assumption, represented in many curricula and research-based interventions, is that the easiest entrée to scientific practice is to ask students to engage in highly simplified investigations so that they can learn to support claims with evidence, then later problematize what counts as evidence. The result is that forms of uncertainty that are central to scientific work are often obliterated or made invisible in elementary science investigations. For example, elementary students rarely are asked to consider how to design an experiment to represent a phenomenon, determine what to count as evidence, or consider misfits between the experiment and phenomenon as they apply their results to understand the world. Several studies have demonstrated that young students *can* recognize these forms of uncertainty and productively grapple with them, but we know little about how to systematically design, and support teachers to orchestrate, environments that use empirical uncertainty to support scientific practices and understandings.

Central conjecture

Drawing from the three principles for productive uncertainty described above, I conjecture that forms of empirical uncertainty that are typically removed from elementary students' experience with experiments *can be* productive for students' development of scientific practices and content understandings. However, I also conjecture that for uncertainty to be productive, it must be strategically designed into the learning environment and carefully managed by teachers.

In particular, the conjecture that drives this study is that engaging students in a rich phenomenon and choice in how to investigate it can generate variability in students' methods, claims, and evidence; this variability can in turn be recognized and made public by students as they present and compare findings, in turn eliciting sense-making discussions in which teachers support students to engage in science practices and consider important content understandings. In previous work (Manz, 2015), I have explored this conjecture in one instantiation of students using a plant growth experiment to understand plant needs and growth patterns in a wild backyard area. In this study, I sought to apply this conjecture to working with a small group of teachers, in order to better understand the design elements in the learning environment and teacher discussion moves needed to support the implementation of productive uncertainty in empirical investigations. Below, I describe the context in which I enacted the study and the analytic methods developed to further test and refine the conjecture.

Study Context

This work was conducted in a suburban district in the Northeastern United States that had recently adopted new materials to better align to the state's new standards, which are modeled on the Next Generation Science Standards (Achieve, 2013). The district elementary science leader approached the researchers to help her adapt the curriculum materials to support deeper sense-making opportunities for young students. She recruited five second-grade teachers to work with the research team on adapting one of their investigations. The teachers varied in their years of teaching experience from 2 to more than 15 years of experience, in their science content understandings, and in their comfort teaching science, as is typical of elementary teachers in the United States.

The research team first supported the teachers to conduct an investigation that involved scientific uncertainty (in the sense that teachers had to make decisions about how to represent the phenomenon, what to use as evidence, and how to interpret their findings) and debrief how the need to make decisions and the different decisions made supported sense-making, explanation, and argumentation. We then worked with teachers to adapt an investigation from the science kit used in their district to incorporate scientific uncertainty as an opportunity for student sense-making. The focal investigation comprised two lessons from a landforms unit. In the investigation, students sprayed soil, sand, and gravel with water and blew on the materials through a straw to understand how wind and water can shape land. The kit did *not* provide direction for teachers to support students to think about how to represent wind and water, how to design an informative comparison, what data to collect, or how their findings allowed them to understand how wind and water might shape land.

We worked with teachers over five meetings to create a shared set of lesson plans that spanned approximately six 45 minute lessons. In the re-designed lessons, students examined photographs and discussed how wind and water might shape land by moving earth materials; examined earth materials and made predictions; designed investigations in groups using a straw and spray bottle to test their ideas; developed and supported claims in small groups; presented and critiqued claims and evidence; and discussed the phenomenon again based on their investigations. Table 1 shows how the sets of design principles for incorporating productive uncertainty in learning environments were instantiated in this design.

Table 1: Productive uncertainty design principles as instantiated in the landforms investigation

Design principle	As instantiated in this design
What to make uncertain	- Focus on allowing students to experience uncertainty about how to represent a phenomenon in an experiment, how to construct evidence, how to interpret evidence, and how to use their investigation to explain the phenomenon. - Bound uncertainty so that students make a limited number of choices (e.g., give students materials to use but allow them to decide how to use them) - Students design experiments in small groups
Helping students experience and make public moments of uncertainty	- Allow student groups to come to different conclusions about whether and how wind and water move the earth materials - Student presentations and student questions after experiments are completed - Examining original and new phenomena after experiment completed: share examples of movement (e.g., boulder in a field) that cannot be explained by investigation findings.
Helping students resolve and learn from uncertainty	- Teacher facilitation of discussion of differences in findings - Beginning and ending set of lessons with the same phenomenon

Methods

A team of two researchers collected data over the course of the investigations, from the initial introduction of the phenomenon to the discussion of the phenomenon after students' experiments were concluded. Four teachers consented to videotaping. In these classrooms, one video camera was used to film whole group discussion and student groups during small group work. All classroom artifacts and student work were collected. In the fifth classroom, researchers attended all lessons, took close field notes, and photographed artifacts.

We next developed a method to test and refine the conjecture, which we represented as:

> Rich phenomenon + Choice in how to represent and investigate it → Variability in students' initial ideas, methods, claims, and evidence → Recognition and discussion of variability → Development of practice and conceptual understandings.

This paper focuses on our initial development and application of methods to analyze the instruction in two of the classrooms. We chose to begin with these two classrooms because we had complete records for them and because the teachers were the most likely to allow students to make decisions and then to discuss those decisions. Therefore, these data sets provided the richest opportunity for developing and refining analytic methods. Because of the short time frame of the investigation, the data was used to support inferences about *opportunities* to participate in practices and consider content, rather than to detail development. Data analysis occurred in four phases.

Phase 1: Activity map

In the first phase, we used field notes and classroom artifacts to create an activity map for each classroom that summarized the major shifts in activity and the video, artifacts, and student work associated with each activity. For example, activities for both classrooms during the first two days were discussing pictures of the phenomenon, examining earth materials and making predictions about whether wind and water can move them, whole group predictions, introducing the investigation, and small groups planning investigations. We organized the activities into three major stages: (1) Examining the phenomenon and making predictions, (2) Planning, conducting, and making claims in small groups, and (3) Sharing findings and discussing implications.

Phase 2: Cataloguing and summarizing activity

In this phase of analysis, we moved systematically and sequentially through all video and classroom artifacts for each classroom investigation. We developed focal categories for each stage of the investigation, independently coded and refined categories based on a sample of the data, then exhaustively sampled and coded the data for all episodes or artifacts related to the focal categories.

Phenomenon and predictions: How did students make sense of the phenomenon?

For this stage, our focus was describing the aspects of the situation that students thought were relevant as they examined the phenomenon and the earth materials. These included: the size of the particles, the strength of the wind or water, explanations for how and why materials move (e.g., water makes soil heavier and harder to move, water loosens dirt and then allows rocks to move). In addition, the predictions, and variability in predictions, made by the class were summarized (e.g. all students agreed that wind could move sand, students disagreed about water moving sand because some thought that sand might clump and not move).

Conducting investigations: What forms of uncertainty were realized in the learning environment?

For this stage, we focused on what forms of scientific uncertainty were realized in the learning environment. Following the study conjecture, we defined focal forms of uncertainty as decisions that students made about how to represent a phenomenon in an experiment, how to construct evidence, how to interpret evidence, and how to use investigation to explain phenomenon. As indicators of students making decisions, we documented teacher and student questions, variability in how groups made decisions, and evidence of disagreement and discussion during small group planning. For example, in each classroom, we documented the following forms of uncertainty: the angle and distance that the straw was held in relation to the materials, what to use as evidence of movement, and what claim to make.

Discussion: What forms of uncertainty were brought up and how were they addressed?

In this investigation stage, students and teachers presented and discussed findings, agreed on a conclusion about the investigation, and discussed the implications for understanding phenomena in the "real-world." We documented how the forms of uncertainty in Stage 2 were introduced by teachers and students in these discussions and analyzed when and how the introduction of the uncertainty supported moments where students engaged in science practices and explored new or deeper science content.

Phase 3: Tracing uncertainty through each investigation

In this third phase of analysis, we developed a summary table for each classroom in which we followed each form of uncertainty that students and teachers grappled with through the course of the investigation, with an eye toward understanding: (1) how the uncertainty was realized in the learning environment, (2) how it was introduced into whole group conversation, and (3) whether and how it supported opportunities for whole-group sense-making. Table 2 shows one row from this table for one teacher, following decisions generated around the strength of the spray of the water bottle (as operationalized in distance the water bottle was held from the materials, nozzle setting, and amount of water sprayed). Each sub-row refers to one instance of strength of spray that was brought up in whole group conversation.

Table 2: Example row for forms of uncertainty summary table: strength and amount of water in Ms. A's class

Form of uncertainty	Evidence that we see the uncertainty realized	How it was brought up in whole class discussion	What happened
Strength of water sprayed by the spray bottle (How to operationalize the phenomenon in an informative comparison)	Different groups choose different numbers of squirts in their investigations. There is talk about strength of spray in groups (though nozzle setting is set in Ms. A's class). Students seem to be using different distances in video of groups performing investigations.	170526_V3 [00:07:53.27] During a group's presentation, student asks if the presenters planned the number of sprays they used.	When group answers five, Tr. directs students to identify that this controlled the amount of water across conditions.
		170526_V3 [00:09:17.27] Researcher points out that class disagrees about claims.	Student notes that they might have different ideas because some groups sprayed harder.
		170526_V3 [00:12:12.23] When students are asked to generate a whole-class experiment, a student points out amount and strength of sprays as something to control.	Tr asks why that's important and evaluates the idea as important to experimental design.
		170526_V4 [00:02:13.08] Researcher asks why it matters that sand and soil get the same number of sprays.	Student answers with control of variables response – experiment doesn't work the same if you change the sprays, obviously the sand would move farther. Tr. briefly asks other students if they agree.
		170526_V4 [00:06:57.20] Tr. draws students' attention to the spray bottle spraying less hard as it runs out of water.	No student response invited.
		170526_V4 [00:07:53.15] When Tr. sprays, the bigger rocks move. Tr. asks why they moved for her and not in group investigations.	A student says that in her experiment, they did rocks last and maybe the bottle didn't spray as much.

Phase 4: Developing themes

In this phase, the two researchers separately reviewed the summary forms for each of the two teachers and developed memos to summarize the forms of uncertainty that emerged in each classroom, the ways that these were introduced into whole group conversation, and the kinds of conversations that emerged. We were particularly interested in understanding whether students or teachers were bringing up uncertainty, how teachers responded to different forms of uncertainty, which forms of uncertainty appeared to be productive for science practices and content understandings, and challenges that teachers and students faced. We then worked together to compare, discuss, and refine themes.

Findings

Table 3 shows the forms of uncertainty that were realized in the learning environment, and the ways that these were introduced into classroom conversation. I first describe these columns more fully. I then share findings about how the introduction of these forms of uncertainty supported conversations that allowed students to engage in science practices and explore or deepen content understandings, and document challenges that emerged as teachers guided these conversations.

We documented similar investigation choices in each classroom; however, the choices that students grappled with differed somewhat across the two classrooms. These differences appeared to be related to teacher choices about how to introduce and guide the investigation. In each classroom, students made different choices in how they positioned the straw and water bottle, how they arranged the earth materials (e.g., leaving them in the petri dish, placing them in a mound out of the dish), and what they used as evidence of movement (e.g., a qualitative comparison of distance, measuring distance, separation in the petri dish, materials floating).

However, we also saw differences in the choices that were realized in students' investigations across classrooms. For example, in both classrooms, our videotape records provided evidence that at least one group considered using the water bottle to make a pool of water. However, in Ms. B's classroom this strategy was not taken up; in fact, a classroom assistant working with the group redirected them to use the bottle to spray. In Ms. A's class, a researcher intervened to make space for and amplify a student's proposal to use the spray bottle to fill the petri dish, then put the materials into the dish and see how they moved when the water was moved. In contrast, in Ms. B's class, methods for marking and measuring distance were highlighted and encouraged, and a greater variability in measurement strategies was generated.

Table 3: Forms of uncertainty realized in the learning environment and introduced into whole class discussion

Uncertainty	Class	Ways introduced into whole class discussion
How wind and water shape land	Ms. A, Ms. B	Students make different predictions about earth materials and draw on different experiences; teachers highlight disagreement.
What to use to represent wind & water	Ms. A, Ms. B	Teacher asks students to consider, then introduces and provides rationale for decision to use spray bottle and straw.
How to use straw: strength	MS. A, Ms. B	Teacher highlights as something to consider, students bring up spontaneously when asked how they are planning as something to consider and control, students bring up as something to question each other about, students bring up as accounting for different results, student brings up as something that the experiment doesn't represent well about the real world.
How to use straw: angle/direction	Ms. A, Ms. B	Teachers highlight as something to consider.
How to use spray bottle: form of water (rain vs. pool)	Ms. A, not fully in Ms. B.	Presenting students use different methods, students question each other about method, teacher introduces alternative (pool) as a method for whole class, students disagree about how alternative can generate evidence.
How to use spray bottle: strength	Ms. A, Ms. B	Teacher points out as something to consider, students question each other, students generate as explanation of different results, students bring up as something to consider when planning, teacher draws attention to differences in joint experiment.
How to use spray bottle: angle/direction	Ms. A, Ms. B	Students ask questions, students bring up to explain different results, student disagreement about angle to use in joint test.
Earth materials in vs. out of dish	Ms. A, Ms. B	Teacher brings up as something to consider and ask about; Students bring up as not representing world.
How materials are arranged	Ms. A, Ms. B	Students bring up as something to ask each other about; students use to explain different results (clumping materials, big vs. small rocks).
Order wind and water are tested	--	
Form of evidence generated for wind	Ms. A, Ms. B	Students introduce different evidence into conversation, students ask each other about evidence, students ask to define what counts as evidence (e.g., what counts as moving), teacher introduces and ratifies particular forms of evidence (measuring distance), students disagree about evidence in joint investigation.
Claims about wind	Ms. A, Ms. B	Students introduce different claims into whole group discussion, students point out disagreement in claims and generate explanations for disagreement.
Form of evidence generated for water	Ms. A, Ms. B	Teachers ask about evidence in recaps, teachers ask student presenters about evidence, students introduce different forms of evidence into conversation, students ask each other about evidence and clarify evidence, students spontaneously compare evidence.
Claims about water	Ms. A, Ms. B	Students introduce different claims into whole group discussion, students note that their claims were different from other groups and seek to explain.

In the two classrooms, investigation choices were introduced in whole group conversation in ways that positioned students as making and justifying decisions; that is, as grappling with scientific uncertainty. First, teachers highlighted differences in what students were doing, probed student methods, and in one classroom asked students to make and justify decisions to develop a joint experiment. Students were positioned in these conversations as navigating uncertainty about the angle and distance of the spray bottle and straw, how they arranged materials, what they paid attention to in order to determine whether the earth materials moved, and what claims to make. In addition, these forms of uncertainty were introduced into conversation *by students* when asked to talk about investigation decisions, suggesting that students were taking them up as legitimate decisions that required sense-making. Importantly, we also noted that students brought up these decisions to account for different results, to question their classmates about, or to disagree with methods proposed by others. For example, students in Ms. A's class quickly suggested that they likely used the straw differently after they participated in a gallery walk that made visible that they had come to different conclusions. In addition, when groups presented their claims and evidence, students asked each other about the angle and strength of blowing and spraying, clarified how far different materials had moved, and (most rarely) explicitly disagreed that a method could be used to support a claim, as when a student disagreed that moving the materials in the petri dish showed that they moved with water, because the tester was moving the dish, and therefore moving the materials.

Analysis of the discussions demonstrated several teacher responses to the introduction of uncertainty. One response when teachers heard variability in decisions that might affect results was to ask questions to probe what students had done and make differences visible to other students. Another was to highlight an idea that a student brought up (for example, asking to compare the nozzle setting used by another group) as important, perhaps noting it on the board as something to consider or ask others about, then moving on. A third response was to open up a question or disagreement to talk by multiple students. A fourth was to effectively dismiss or argue against the concern: this was rarer, but informative, as it was most likely to occur in one classroom and at times where the teacher was focusing on bringing the class to a joint conclusion, for example about how to conduct their joint investigation or to develop a conclusion that wind and water *can move* rocks, sand, and soil.

Finally, we closely analyzed conversations to understand what opportunities they provided for students to participate in science practices and develop content understandings. Analysis suggested that when teachers made space for student questions and for multiple turns of student talk, students had opportunities to engage in practices related to investigations, in that they made decisions about and brought up the importance of controlling variables, of considering the level of variables used in their experiments (e.g. the strength of the force of the wind or water), and of considering how an investigation did and did not represent the phenomenon. They engaged in practices of argumentation they considered why their claims were different and probed each other's evidence. In addition, the investigation provided opportunities for students to engage in explanation as they explored the reasons for their results, tried to understand differences in results (for example, there was a lengthy conversation in Ms. B's room about why a downward spray might exert force that moved rocks more than sand), and explored why the investigation could not fully help them explain phenomena of wind and water changing land, often proposing new mechanisms for movement or making new connections to phenomena.

We also noticed several challenges across both classrooms. First, during presentations, teachers often interjected so often that students were actually able to ask each other relatively few questions. Second, we noted that in discussions teachers only very rarely helped students relate the forms of uncertainty that they were recognizing to the goal of trying to agree on a shared conclusion about the experiment or understand the phenomenon. That is, they were more likely to name something to consider ("We have to control that," "you're thinking about the real-world") than to ask "Why would that matter?" or "Could that explain why…" Finally, we noted that students' consideration of ways that the experiment might *not* represent the phenomenon of wind and water shaping land appeared both to be particularly rich for the development of explanation and content understandings, in that students were beginning to make visible the mechanisms by which wind and water shape land, as well as particularly difficult for teachers to take up and guide, especially in the cases that these considerations were at odds with either controlling variables or using evidence to support a shared conclusion.

Discussion

The conjecture that drove this work was that incorporating forms of empirical uncertainty that are typically left out of elementary students' empirical investigations can generate variability in ideas and methods that, when recognized and introduced into classroom conversation, can support productive episodes of sense-making in which students engage in scientific practices and make progress on content understandings. In this paper, I described and applied an analytic method for cataloguing and following uncertainty to explore this conjecture.

The analytic method is one that our research team is finding productive. In particular, we are finding it useful to separately consider and relate the three related aspects of (1) uncertainty as realized in the learning environment through variability in student choices and thinking, (2) uncertainty as recognized by students and introduced into conversation as a decision that requires sense-making and that might account for differences in results, and (3) uncertainty as grappled with in conversation, potentially supporting science practices and sense-making about content. Here, engaging in these three forms of analysis allowed us to document rich variability in student decisions, show that students could recognize the importance of investigation decisions and initiate conversation about them, and explore opportunities and challenges in the ensuing conversations. I expect that all three forms of analysis will be essential to generating learning environments where uncertainty is productive.

We plan to more closely analyze the investigation as taught in all five classrooms to understand which forms of uncertainty appeared most productive and which appeared at odds with each other (e.g. a focus on controlling variables and representing the phenomenon of wind and water shaping land) to inform the next iteration of designing the investigation. We will then refine *what is made uncertain* (productive uncertainty design principle 1 above) to focus attention on those decisions that appeared to most productively support sense-making and to help teachers attend to and draw out those uncertainties as a resource for science practices and understandings. I suspect that such a step; that is, generating more opportunities for uncertainty in the first instantiation in a design in order to understand which offer the greatest potential for student learning, is a fruitful move to make in designing for science practices and understandings.

In addition, the similarities in the decisions that students grappled with suggest that certain forms of uncertainty might be predictably generated and recognized by students in this investigation; this finding will be further tested with the remaining three teachers, and if stable, could support the development of an investigation that is legitimately uncertain for *students* but somewhat predictable for *teachers.* If this is the case, we could better draw from practices used in mathematically cognitively demanding tasks, where teachers anticipate, select, and juxtapose different solution strategies (Stein, Engle, Smith, and Hughes, 2008) to support productive discussion. Differences across instantiations (e.g., that in one classroom, where the teacher used gallery walks and highlighted disagreement, student were more likely to bring up variability in methods to account for findings) can support the refinement of design principles for productive aspects of the learning environment and teacher moves that elicit and support uncertainty. Similarly, the consistent challenges that we noted, e.g., teachers not discussing the implications of surfaced forms of uncertainty, can be used to refine conjectures and methods of working with teachers, for example, by developing teacher moves. This work can support the important goal of moving past cookbook elementary school investigations while developing the supports that teachers and students need to manage this more complex instantiation of scientific work.

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