'Mangling' Science Instruction: Creating Resistances to Support the Development of Practices and Content Knowledge

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Abstract: This paper explores Pickering's "mangle of practice" as a tool for designing classroom environments that integrate content knowledge and scientific practices. I describe the design of science instruction for an elementary school class, characterizing how it built from "The Mangle." I then identify two forms of activity that emerged, *defining attributes* and *mapping between the experiment and target system.* I show how each became a useful practice as material resistances in the system were made public and describe how each served as a site in which concepts and practices were evaluated in relation to each other. Finally, I comment on implications for the design of learning environments that make knowledge-building practices both accessible and relevant to students.

Introduction

There is a consensus that science learning environments should integrate content knowledge and scientific practices so that students learn to generate, use, and support scientific ideas (National Research Council, 2012). In this paper, I explore a concept from the Science and Technology Studies literature, Pickering's (1995) notion of "the mangle of practice," as a tool for designing activity that both establishes a need for scientific practices and provides a context for developing content knowledge. I share how Pickering's ideas guided the design and analysis of a plant growth experiment conducted in a third grade classroom.

The Mangle of Practice

Pickering's exploration of "The Mangle" elaborates how, in professional activity, scientific practices and ideas become needed, are made problematic, and are revised in light of each other. Pickering conceptualizes science as a dance of human and material agency comprising iterations of resistance and accommodation. Scientists enact their agency by developing hypotheses, procedures, machines, and measures, which they apply to material phenomena. The world responds by doing something, generally something unexpected and somewhat mysterious; it *resists* its capture by human agency. Scientists then must engage in *accommodation,* developing new goals, practices, and understandings. On this view, practices and understandings are tuned and stabilized in relation to each other. When experiments do not perform as expected, scientists reconsider both their material procedures (e.g. experiments or measures) and their conceptual accounts, that is, their understanding of the phenomenon and how the experiment represents it. Producing a scientific finding involves making procedures, conceptual accounts, and results hang together. Therefore, material puzzles are essential to the development of both practices and concepts: they destabilize them, establishing a need to reconsider each in light of the other. These processes are evident in historical analyses of scientific activity (Gooding, 1990) and ethnographic accounts of laboratories (Nersessian, 2012).

Why the Mangle Might Be Useful in Classroom Settings

Scientific practices do not transfer unproblematically from expert settings into classrooms; understandably, their purposes and forms tend to be unfamiliar to students (Hogan & Corey, 2001). Two prominent instructional strategies for introducing scientific practices have been making their structures explicit and simplifying the demands of applying them. However, it is becoming clear that students can adopt taught forms without understanding their purposes or finding them meaningful for their activity (Berland & Reiser, 2011; Kuhn & Pease, 2008). In response, researchers increasingly seek to design contexts that establish a need for practices and to study their development over time. These approaches are consistent with sociocultural accounts, which emphasize that practices are constituted in community activity as members seek to align behavior and accomplish goals (e.g., Wenger, 1998). They involve a shift in how we frame "scientific practices" in classrooms. Rather than viewing them as forms of activity in which scientists engage and that we seek to introduce to students, we might define something as a "scientific practice for students" if it is constituted by a classroom community for a function that is important in their scientific activity.

The Mangle provides a framework for considering both when students might experience a need for scientific practices and what it might mean to adapt those practices in extended activity. In Pickering's account, practices emerge and are refined in order to cope with resistances; that is, they are made necessary by the material and uncertain nature of scientific activity. There is some evidence that purposefully designing materiality and uncertainty into learning environments can situate the development of sophisticated scientific processes (Lehrer, Schauble, & Lucas, 2008; Roth & Roychoudhury, 1993). However, to date, there have been few accounts of how materiality and uncertainty are made visible in instruction, how they situate new forms of activity, and how those forms of activity are constituted in classrooms as practices with identifiable functions.

In addition, the Mangle explicitly integrates conceptual work into descriptions of scientific practices, providing a lens for considering the development and use of content knowledge. Pickering's description is consistent with recent accounts that frame ideas as resources for navigating activity, rather than as units of declarative knowledge (Hall & Greeno, 2008). These resources might include ways of attending to significant aspects of situations, organizing information, and making inferences. Applying the Mangle to classroom learning environments supports an important shift from equating content knowledge with the explanation that is the *target* of an investigation toward fine-grained consideration of the ideas that students draw on to navigate their work *throughout* the investigation.

In the remainder of the paper, I apply the Mangle to explore the following questions: (1) How can we create resistances in learning environments that destabilize practices and ideas, creating a need for students to consider and tune the two in relation to each other? (2) What does it look like for students to engage in this process? I describe the design of an investigation conducted with an elementary school class, characterizing how it built from Pickering's ideas. I then identify two forms of activity that emerged in the classroom, *defining attributes* and *mapping between the experiment and target system.* I show how each practice became useful as resistances in the experiment were made public and how each involved tuning concepts and practices in relation to each other. Finally, I comment on implications for the design of learning environments that make knowledge-building practices both accessible and relevant to students.

Design

The context of this work was a multi-year design study conducted with third-grade students (ages 8 & 9) in an urban school (approximately 70% free and reduced lunch). The students' teacher had 30 years teaching experience and had participated in four years of professional development around modeling-based science instruction. We engaged students in developing explanations of "the wild backyard," a trapezoidal-shaped area behind their school (1). The school wall cast a changing pattern of shade on the backyard, resulting in differential sunlight and moisture and related patterns of plant distribution. The target explanation was one of *differential success:* different plants are successful in different amounts of sunlight. This explanation is initially very challenging for students to construct, as they find it difficult to privilege and relate light and plant presence among the myriad potential variables in the backyard (Manz, 2012).

I report here on one phase of the second year of the design study, conducted with a class of eighteen students (13 male, 5 female). The "plant growth experiment" was conducted between the end of February and the beginning of May. By the start of this phase, students had begun to identify "sunny" and "shady" areas of the wild backyard as well as areas that they thought received "some sun and some shade." However, they were confused about the effects of light, partly due to the fact that many of the plants they had been studying in the fall had died in the areas where they had been located (this was due to seasonal change and life cycle processes, but it was a puzzling result for students). We introduced the Wisconsin Fast Plant™, which completes its life cycle in seven weeks, as a context for exploring both the effects of light and plant life cycle processes.

We designed the plant growth experiment to engage students in the mangle of practice as they developed explanations of differential success (Figure 1).

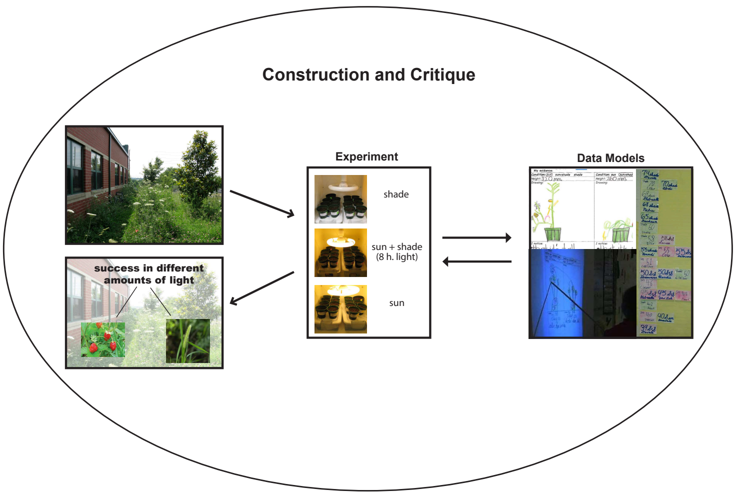

Figure 1. Design

We introduced a material model of the backyard in the form of an experiment in which students placed Fast Plants in different conditions to mimic those that they had identified in the backyard setting ("sun," "shade," and "sun & shade," referring to areas that were sometimes in shadow). As indicated by the arrows in Figure 1, the processes of designing the experiment and applying its results to develop explanations of the backyard involved significant uncertainty, and therefore constituted sites for experiencing the Mangle. Students had to grapple with how the experiment represented the conditions in the backyard and how its results informed their understanding of plant needs in the backyard (How should they represent light? Did the Fast Plants represent all the backyard plants?). In addition, rather than telling students what about the plants might be important to observe and how to observe and record it (e.g. directing them to graph plant height), we conceptualized the development of data models as another site for mangles to emerge. Numerous plant attributes might be important to observe and compare; these attributes changed over time and often contradicted each other. Through the design choices above and their implementation in the classroom, we sought to position students as constructing and critiquing the system portrayed in Figure 1 (Ford, 2008; Gresalfi, Martin, Hand, & Greeno, 2009). Forms of activity in which we engaged students included small and whole group discussions about how to set up and interpret the experiment, individual writing in science journals, and class "research meetings" in which different students presented ideas about which plants were more successful and took questions from their classmates.

Methods

Consistent with methods for design-based research, conjectures about students' practice and productive means to support development were iteratively developed and refined over the course of the study (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). As the lead researcher, I worked with the teacher and larger research team to design all activity, reviewed evidence of student learning to support ongoing re-design, and was as an active participant, sometimes a co-teacher, during lessons. Data sources included video-recordings, field notes, student work, classroom artifacts, and interviews. During each lesson (n=16, 1-1.5 hours each), a video was made of whole group discussion. During individual and small group work periods, one camera followed the teacher, while one to two additional cameras were used to capture the work of groups.

Retrospective analysis of the data focused on describing normative, or "taken-as-shared," practices (Cobb, Stephan, McClain, & Gravemeijer, 2001) and understanding the purposes they served for students. That is, I sought to develop a description of what counted as practices *in this classroom community,* rather than first specifying and describing a desired practice, then looking for evidence that students were developing aspects of it. However, I was also guided by disciplinary considerations, in that I focused on interactions around the experiment, data models, and explanations of the backyard, as illustrated in Figure 1.

I began by using grounded analysis (Glaser & Strauss, 1967) to describe students' participation in construction and critique. I was interested in which aspects of the system described in Figure 1 were framed as the target of claim-making, justification, and disagreement, rather than as subject to recall or review. For example, students developed and argued about which plants were more successful and how to measure the plants, while the number of days that the plants had been growing was routinely treated as unproblematic and subject to recall or reference. I then sought to understand which forms of construction and critique became practices for students*,* in that they were repeated, involve broad participation across the class, were initiated by students as well as teachers, and appeared to serve fairly stable (though not always identical) purposes.

After developing a set of categories to describe practices, I divided the data set into activity phases (e.g., a discussion of how to measure the plants). For each activity phase, I asked what practices students were engaged in and described how ideas about plants were used. I also looked for and described evidence of *accommodation,* in that students positioned practices or ideas as problematic or needing elaboration. Finally, I made conjectures about why students were using a practice or idea, with an eye toward noting any resistances they were grappling with.

In this paper, I focus on two forms of activity that developed into repeated classroom practices, *defining attributes* and *mapping between the experiment and target system.* These practices were chosen because there were multiple instances of each and each showed evidence of accommodation in reaction to system resistances, but they emerged at different times in the investigation and appeared to serve different purposes, providing an interesting contrast. I then conducted a more detailed analysis of these two practices. I identified each instance of the practice and bounded it within an episode in which it was initiated and used, resulting in 48 episodes (32 for defining attributes and 16 for mapping). For each episode, I described who initiated it; asked whether there was evidence of student construction, critique, and accommodation; and analyzed how ideas about plants were brought to bear on activity. Examining patterns across episodes allowed me to develop a description of how each practice emerged and was appropriated, what role resistances played, and how ideas about plants were brought to bear on use and accommodation of the practice.

Findings

In this section, I share my analysis of the two focal practices, *defining attributes* and *mapping between the experiment and target system.* For each practice, I present a brief description, then address two questions: (a) How did the practice emerge? (b) How did it help students consider and develop ideas?

Defining Attributes to Cope with Changing Plants

As students looked at plants and discussed which condition the plants were most successful in, they generated and observed many plant attributes to support their claims, including "big," "height," "growing," "light green," or "dead." They engaged in *defining attributes* when they described attributes in more specific terms that allowed others to see and compare them across plants and when they requested that an individual or the class construct a more specific description. For example, early in the investigation, Ellen noted that one of her plants had what she called "a bump." Azhad initiated an episode of definition by asking "Is that bump, is it part of the leaf or part of the stem?" prompting a series of conjectural definitions that named the bump as a precursor to another feature, such as a leaf. There were 32 episodes in which students requested and/or proposed definitions.

Emergence of the Practice

Teachers (2) modeled and asked for definitions across the duration of the investigation. Most of the teacher-initiated definitional episodes began when a student used a term such as "growing" or "big" to compare plants and a teacher asked for elaboration of the chosen attribute. For example, when Charles noted, "the sun and shade is smaller than the shade," Mrs. W. asked him what he meant by "smaller," then continuing to press him until he had defined *size*, which could encompass a variety of attributes, as *height*. Across the data corpus, Mrs. W. and I initiated sixteen episodes of defining attributes. Eleven of these had a similar structure to the episode above, in that we followed a students' use of an attribute by asking "What do you mean," "How do you know," or "What tells you" and students responded by elaborating with more specific descriptors.

Students initiated half (n=16) of all definitional episodes. Many were attempts to identify attributes in the face of plant change, which constituted a resistance for students. For example, when Dante claimed that the plants in the sun & shade condition were doing best because the plants in the sun condition were dying, Azhad disagreed, beginning an episode in which definitions were proposed and challenged. (3)

1. Azhad: No, because I don't see no one dying.
2. Dante: You don't see those leaves that are getting dried up? I know that some [plants]
3. Brady: [How] do you know it's dead though?
4. Britney: (*undecipherable*) drying up
5. Dante: [I know it's]
6. Alex: [Those are] OLD leaves.
7. Jasmine: [Those are] the seed leaves, [that's why they're dying.]
8. Chad: [No they're not.] (*walks over to the lightbox)*
9. Azhad: Those are the [leaves that grew first.]
10. Alex: [Those are the seed leaves.]
11. Madison: [Those are the old leaves.] They're trying to grow new ones.

This excerpt exemplifies how definition emerged as students struggled to see the same thing in the face of a changing system that resisted description. Both Azhad and Brady problematized the notion that death could unproblematically be "seen;" Azhad when he argued that he did not see any dying plants (Line 1) and Brady by positioning death as an inference that needed to be justified (Line 3, "How do you know it's dead though?"). In response, Dante defined dying by bringing in a new, more specific attribute, "leaves that are getting dried up." In turn, students contested this definition. They argued that the leaves drying up were the "old leaves," or seed leaves that they had learned come first and provide the initial food to the plant, and that their drying up might not have anything to do with death. After Mrs. W. reviewed students' characterization of the leaves as seed leaves, Dante went back to the plant boxes and said, "No, I see some spiky leaves that are brown," referring to the true leaves that come later in a plant's life. Across the episode, Dante engaged in accommodation, progressively refining his definition so that others could see the plants in the sun condition as dying and, he hoped, agree that they were not getting what they needed. He needed to do so to contrast the attribute he sought to apply to the plants, death, to the normal processes of maturation claimed by other students.

Across the data corpus, twelve out of the sixteen episodes of definition initiated by students involved struggling with how the plants were changing over time. The students used similar constructions as teachers, in that they asked "How do you know" and "What do you mean," but they applied these constructions to a different subject (change over time) and were more likely to use them when engaged in disagreement, as in the episode above. Therefore, it appeared that definition was a practice that they found useful for their own purposes, which involved developing shared ways of seeing plant features in the face of life cycle changes.

Definition as a Site for Conceptual Work

Definitional episodes were rich sites for the recruitment and refinement of the forms of ecological thinking that we sought to develop. Across these episodes, ideas about plants were *differentiated*, *related*, and called on as *mechanisms or predictable processes* to support claims. Consider the disagreement about Dante's claim. As Dante was challenged by his classmates to show that the plants were dying, and conversation shifted to definition, he brought in new aspects of the system (the plants' leaves, Line 2), *relating* them to death. When his classmates, in turn, contested the notion that brown leaves indicated death (Lines 6-11), they did so by proposing an alternative *mechanism,* in this case a *predictable process* of maturation, to account for leaf change, arguing that the old leaves that were trying to dry up so they could grow new ones. As students contested the definition of death, leaves were *differentiated* into seed leaves (or "old leaves") and true leaves ("spiky leaves"). Here, definition was a highly conceptual process that pitted plant maturation against death.

Over the course of their work, students appeared to develop stable accommodations, in that they increasingly defined attributes in relation to life cycle processes. For example, on April 21, Brady indicated that his plant was successful because it had "buds where flowers will grow." Here, the attribute of the "bud" was identified and defined in terms of a future feature. In fact, as we asked students to conclude which plants were more successful, this predilection caused difficulty for the classroom teacher, who was ready to end the investigation and decide that the plants in the sun condition were more successful because they had produced seedpods. While students privileged seedpods as a sign of reproduction and therefore success, they disagreed that the sun plants were more successful and supported their counterclaims with prolonged argumentation about what counted as a seedpod. Several students argued that the pistils on the sun & shade plants, where flowers had fallen off but no seeds were growing, were "newborn" seedpods where seeds would grow. Steven interrupted a count of seedpods, saying "There's this question I wanted to ask people, what if their seedpods are dead, does that count as a seedpod?" In these episodes, students framed the seedpod as a maturing, dying entity, complicating its definition, which they considered necessary for a shared understanding of which plants were more successful.

These definitional episodes showed evidence that a resistance (i.e., the changing nature of the plants) destabilized, and supported the development of, both practices (identifying and defining plant attributes) and conceptual accounts (maturation, death, and reproduction; major life cycle concepts). In order to contest and develop definitions, students needed to call on ideas about plant growth. Therefore, definition was a context within which these ideas were useful and became the subject of argumentation. In this way, definitional practices and understanding of plant life cycles were tuned in relation to each other, as Pickering describes.

Mapping between the Experiment and Target System to Explore Differing Results

One way in which this experiment differed from many investigations conducted with elementary school students is that it was explicitly designed to model another phenomenon that students experienced: the backyard system. At several points, students *mapped between the experiment and target system*: they thought about the ways that the experiment was and was not like the backyard and the consequences differences might have. Similarly to *defining attributes,* students engaged in this form of activity when requested to do so by the teacher, but also initiated episodes, in this case by proposing important similarities or differences to consider and challenging the mappings that others made between the systems. Sixteen episodes were located in the data set.

Emergence of the Practice

Throughout the investigation, the teacher asked students to make explicit mappings between the backyard and the experiment. For example, as students were setting up the experiment, she asked them whether it was OK that the shade condition (the lightbox with the light off) let some light in, as it was translucent. Students decided to block the back of the lightbox with cardboard to be like the school wall that blocked light, but argued that it was fine that the sides let some light in, because light could get into the shady areas of the backyard from the sides too. On seven occasions, the teacher explicitly asked students to make mappings, either by focusing on making connections between the conditions of the experiment and the backyard or by asking students to use the experiment to make predictions about where Fast Plants would be successful in the backyard.

During several of the conversations seeded by the teacher, students initiated the discussion of aspects that did not map and, on a few occasions, spontaneously discussed the implications of these misfits. Consider, for example, the conversation below.

1. Mrs. W: How does what we did in here relate to the conditions in the backyard?
2. Aden: It relates because there umm ... the conditions, well it-it doesn't relate because

the conditions in here... say-let's say it may grow that tall right now in that thing (*looking at light boxes in the room*) right in that box thing but out in the backyard it, it will be way taller.

3. Mrs W: You think it will grow more in the backyard than with the Wisconsin Fast Plant™.
4. Aden: Cause that box doesn't give that much light but the sun, it gives a lot of light.

In this episode, Mrs. W. asked students to remind her about the mappings between the backyard and experimental conditions. Analysis suggested that she treated these mappings as unproblematic and was seeking to review connections (e.g., both had sunny conditions). However, Aden brought up a difference between the two systems, stating that the light was stronger in the backyard than in the experiment, and indicated a result of the difference, that the same plant grown in the backyard would be taller than the specimens in the classroom experiment. These kinds of conversations were scattered throughout students' work with the experiment, suggesting that students noted the slippages between the experiment and backyard and thought they had consequences for comparing results in the two systems.

Near the end of the investigation, the use of mappings exploded (ten of the 16 episodes occurred on two consecutive days of instruction; eight of these involved student initiation of relations or implications). Mrs. W. introduced a claim about the backyard based on the results of the experiment. She argued that the class had shown that the best amount of light for plants was sun, and that therefore

> "I think the just right amount of light for all plants in the backyard is sun. So when we go outside, I think we will find no plants in the shade, some plants in the sun and shade, and lots and lots of plants in the areas that always get sun."

As she presented her argument, several students began to disagree with her. Initially, students noted that her argument was not correct based on what they had seen in the backyard, calling out "No, mine's not really in a place in the sun" and "Because when you go in the Wild Backyard there are some- there are some plants…in the wild backyard, but in HERE they're not growing" Students then began to generate reasons for the differences in plant growth in the two locations. For example, Steven argued, "the lightbox doesn't have as much sun as the sun, we're just pretending it does" while Madison suggested that the shade outdoors was "not always in the shade because sometimes it is in the sun (e.g., when the sun moves throughout the day)." Here, students explicitly recognized and responded to resistances, in that they argued that the results of the experiment did not mirror what they saw or would expect to see in the backyard setting it was meant to represent.

As they continued conversations in small groups the next day, several students noted that the experiment had used Wisconsin Fast Plants™, while there were many kinds of plants outdoors, as when Azhad argued "We have two different plants…some are MADE to live in the shade," prompting Mrs. W. to revoice his contribution, "OK, so you're saying these plants aren't like all plants," initiating the following conversation.

1. Ellen: No they're not because they might [come from different countries. Different cities. Different kinds of *undecipherable*]
2. Azhad: [OK. Do you have any] plants next to your bush?
3. Mrs. W: Next to what bush?
4. Azhad: Your bush.
5. Mrs. W: At home?
6. Azhad: Yes.
7. Mrs. W: Yeah, I do.
8. Azhad: And I have plants growing under MY bush. But- cause they're different plants. I have roses, I've got daisies.
9. Mrs. W: But what makes the difference?
10. Azhad: (*Points to lightbox.*) Cause these are different plants. These are Wisconsin Fast Plants. [Mine is daisies]
11. Mrs. W: [So you mean] different plants need different amounts of light?
12. Ellen: Yes [cause] they don't [really] need the same thing
13. Azhad: [Yes]
14. Jasmine: [Like] wild strawberries they hardly need any light because they're growing right there in the shade.

In this excerpt, all three students talking with Mrs. W. suggested that the Wisconsin Fast Plants used in the experiment could not stand in for all plants. Both Azhad and Jasmine introduced examples of plants growing in the shade (Line 8 and Line 14). In doing so, they grappled with resistance that they experienced: plants in other settings growing in conditions that their experimental plants could not. In response to these resistances, they developed accommodations by using mappings to support nascent model-fit practices, suggesting that differences in plant kind could account for differences in growth.

Seeing the results in both systems (experimental and backyard) appeared to establish a context in which considered how the experiment was and was not a useful model of the backyard setting. When students' attention was directed to the question of whether the experiment could predict growth in the backyard, they engaged more fully and heatedly in discussing mappings between the two systems, initiating new relations (e.g., plant kind, moisture) and participating in longer episodes with more widespread participation. Therefore, here again, resistance supported students to develop a practice that was useful and meaningful to them.

Mapping as a Site for Conceptual Work

Engagement in mapping between the two systems demonstrated similar forms of conceptual opportunities, in that students *differentiated ideas* and *called on ideas as mechanisms.* For example, to argue against Mrs. W., students differentiated plants into "kinds of plants" as they argued that Wisconsin Fast Plants were not like all plants and introduced "daisies" (Line 10) and "strawberries" (Line 14). They differentiated growth conditions as they began to focus on how much light the plants received and whether moisture differences might also matter for the distribution of plants outside. They also evoked mechanisms to justify the relevance of the differences they noted. As students suggested that it was important that the Fast Plants were a different kind of plant than those in the backyard, they began to talk about plants' needs, supporting their claim that plant kind mattered by using ideas of differential success, evident in Azhad's statement that "some are MADE to live in the shade" and Jasmine's explanation that "wild strawberries they hardly need any light" (Line 14). The identification of needs allowed Mrs. W. to guide students toward thinking about why different plants might have different needs, provoking talk about plant structures and strategies and introducing a book that provided new information. When Diego argued that the differences in results were caused because the backyard got more water than the Fast Plant systems, students questioned why he thought water could make up for lack of sunlight.

Here again, resistances situated the interrelated development of a practice, mapping between the two systems, and concepts, namely differentiation of conditions and explanations of differential success. Ideas such as plant kind, amount of light, or presence of moisture were not useful to students when they were discussing the experiment in the absence of considering the backyard. However, differing results across the two systems destabilized ideas that had been effectively black-boxed by the experimental conditions, causing students to develop forms of accommodation consisting of both mapping practices and new categories and explanations.

Discussion and Conclusions

In this paper, I described two activities, *defining attributes* and *mapping between the experiment and target system,* in which students engaged as they conducted the plant growth experiment. The results suggest that these activities were constituted as scientific practices in this classroom community. They appeared to be meaningful to students, in that they were often initiated by students rather than teachers and they served identifiable purposes in their work: coping with seeing the same thing when plants were changing and understanding why the results of the plant growth experiment did not represent growth patterns in the backyard. Described more generally, these functions, seeing the same thing as others and mapping between experiments and phenomena to evaluate model-fit, are central to scientific activity (Gooding, 1990; Nersessian, 2012; Pickering, 1995).

The results support the conjecture that students' scientific practices would emerge and be refined in response to resistances in the material system. For example, students engaged in definition in order to agree on plant features in the face of change, a resistance that made it difficult to agree on what attributes were and what they meant. Their use of the practice was related, but not identical, to that of teachers, who initiated episodes of defining to help students refine ideas that, from the teachers' point of view, appeared vague (e.g., "big."). An additional finding is that classroom structures and actions were important design features that made these resistances visible and problematic. Students were repeatedly asked to present claims about plant success and note attributes that supported their ideas, making variability in their interpretations visible and seeding definition. The teacher purposefully introduced a problematic claim (that there should be no plants in the shady areas outside) in order to highlight a resistance; this action supported an explosion of mapping practice.

In addition, these results suggest that purposefully designing resistances into students' work can support the integration of scientific ideas and scientific practices in instruction. First, the paper highlights the conceptual affordances of the very parts of experimental activity that are usually simplified for use with young students. For example, many studies have shown that students do not "see" what scientists see when looking at phenomena (Chinn & Malhotra, 2002; Eberbach & Crowley, 2009). As a result, young students are often presented with categorical variables or provided explanations that essentially tell them what to see. Here, however, wrestling with what to see and how to see it in the same way was both an accessible activity for students and a site for conceptually rich talk about plant life cycles, an idea students found challenging in the backyard setting. Likewise, dealing with differences in the two systems both seeded model-fit practices and provided an opportunity to further differentiate ideas about light and plant kind. The paper also contributes to the literature by describing three forms of "conceptual development" that occurred as students developed new practices to cope with resistances: differentiating categories, relating entities or attributes, and calling on mechanisms. Future research will focus on predicting the conceptual affordances of particular resistances and preparing teachers to recognize the emerging opportunities for students to differentiate, relate, and call on ideas as mechanisms. In this way, resistance can be made into an affordance, rather than a source of chaos.

Finally, and in keeping with the theme of the conference, this paper highlights a distinction between engagement in "practice" and "practices" to which the field might profitably attend. Here, practices were lent meaning by students' engagement in *scientific practice,* in that they were actively wrestling with developing shared ways of seeing and knowing in the face of resistances. One fruitful direction for future work might be to make *practice* a central target of design, with the understanding that epistemic *practices* are meaningful only in the context of epistemic struggles.

Endnotes

(1) "We" is used to refer to the author, the larger research team, and the classroom teacher.
(2) "Teachers'" refers to the classroom teacher and the author. Since both of us asked students questions and commented on their ideas, I treated both of our comments as framing and elaborating activity in ways consistent with "teaching."
(3) Transcript conventions: CAPS emphasis; [ ] overlap; - self interruption; … pause; (*italics*) gesture; other punctuation added to increase readability.

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