Problematizing as Scaffold for Engaging in Scientific Argumentation

Mon-Lin Monica Ko, Learning Sciences Research Institute, University of Illinois at Chicago, mlko@uic.edu
1240 W. Harrison Street Room 1570F Chicago, IL. 60607

Abstract: Supporting students' engagement in disciplinary practice is a major tenant of recent reforms in science policy and reform, and yet eliciting and building upon students' everyday knowledge through engagement in scientific practice remains a central challenge to this work. This paper presents evidence of how *problematizing* – a term previously used to design scaffolds embedded in technological tools and supports utilized in smaller, face-to-face settings – can work in a class-wide setting, as a support for noticing gaps in students' current explanations both while motivating the need to engage in investigations and while building consensus explanations to account for science phenomena.

Arguing to Learn: Generating Explanatory Accounts for Phenomena

A focus of reforms in standards, learning environments, teacher preparation programs and professional development is to support teachers' and students' engagement with scientific practices to generate explanations for real-world phenomena (Achieve, 2013; Windschitl, Thompson, & Braaten, 2008). Engaging in argument as a means for developing scientific explanations has been characterized as *arguing to learn* because arguments are generated to explain phenomena and build an understanding of disciplinary core ideas (McNeill, Lizotte, Krajcik, & Marx, 2006). Classrooms in the U.S. rarely engage in arguing as a means of constructing evidence-based explanations (Pasley, Weiss, Shimkus, & Smith, 2004), and thus, scaffolds may be needed to enculturate students into the practice of articulating claims, evidence, and reasoning in their explanatory accounts (Berland & McNeill, 2010). Developing evidence-based accounts for phenomena can be challenging when multiple candidate explanations can be constructed using the same evidence, when similarities or differences between alternative explanations are not obvious, or in cases where *how* the explanation accounts for the to-be-explained phenomena is unclear. Because students frequently hold conflicting ideas about science phenomena, identifying the differences between multiple candidate explanations may support students in building on or integrating explanations generated from their everyday knowledge of the world and evidence-based accounts (Linn & Eylon, 2011). These challenges point to the need for instructional contexts and scaffolds that support students in becoming increasingly adept at generating evidence-based arguments to explain phenomena.

Problematizing as Discursive Scaffold for Complex Learning

Problematizing has been discussed in the Learning Sciences literature as a key principle for fostering productive disciplinary engagement and also as a design principle for software tools to support complex learning (Engle & Conant, 2002; Reiser, 2004). In contrast to simplifying or making complex tasks more explicit, problematizing maintains complexity while recruiting students' attention, resources to generate dissonance and curiosity for resolving the task at hand to support students in engaging with difficult problems (Reiser, 2004). This paper makes the case that problematizing scaffolds can support students' engagement in disciplinary discourse practices and build criteria for generating evidence-based explanations for phenomena.

Why might problematizing be a scaffold for engaging students in arguing to learn? For one, problematizing may help students articulate their reasoning and thinking processes, a key aspect of engaging in scientific argumentation (Osborne & Patterson, 2011). Second, when multiple explanations are plausible, argumentation can be used to identify differences between alternative explanations and make clear how evidence and reasoning supports or refutes these candidates. Problematizing may thus support this decision-making process by helping students categorize or distinguish between alternative accounts. Lastly, problematizing students' existing ideas can bring gaps and disagreements to light. Uncovering differences between alternative explanations or gaps in one's reasoning is crucial to the construction of well-grounded arguments supported by sound evidence and reasoning and also takes into account and rebuts alternatives. Though features of this type of scaffold appear to be well suited to supporting the established challenges of engaging in argumentative discourse, how this can be accomplished has not been well articulated.

Moreover, promoting conceptual change involves the disciplinary practice of scrutinizing and revising one's conceptual understandings in light of new evidence, (Duschl, 2000). Problematizing scaffolds can help make explicit the differences between candidate explanations generated from everyday knowledge or from first-hand evidence and established scientific principles. Engaging students in sense-making discussions in which they are accountable to their peers, standards of reasoning, and disciplinary norms for knowledge building can support students' constructing, evaluating and critiquing scientific explanations (Michaels, O'Connor, & Resnick, 2008). Understanding how teachers and students establish and instantiate a disciplinary standard of reasoning and arguing to develop explanations for phenomena is critical. Sense-making talk holds great potential for problematizing students' everyday accounts as insufficient explanations, and generates a need to utilize evidence and science principles to generate a coherent explanatory account.

In this paper, I draw on 2 cases from one 6th grade classroom to illustrate discursive practices that mirror the core principles of problematizing as a scaffold for productive engagement in science practice. I first describe the larger longitudinal study that documented variations in how four 6th grade classrooms took up the science practices. Then, I specify how one teacher's classroom was identified as a particular case of *problematizing,* and finally, elaborate on two cases from this class to illustrate how problematizing scaffolded the process of distinguishing and integrating everyday and evidence-based explanations to motivate the need to engage in investigations, and also to support students to coming to a consensus explanation.

Methods

Curriculum Context

This study took place in the development and national field trial testing of reform-based science curriculum, *Investigating and Questioning our World Through Science and Technology* (IQWST). The 6th – 8th grade curriculum engages students in scientific practices to investigate core ideas in science (Krajcik, McNeill, & Reiser, 2008). IQWST lessons are comprised of investigations that involve students in asking and observing science phenomena, conducting data investigations, reading relevant texts, and discussions to support students' sense making of core disciplinary ideas and practices. Drawing on the work of pilot studies, which uncovered that teachers' curricular adaptations varied in their intent to support students' sense making of the disciplinary core ideas (Ko & Reiser, 2010), 3 multi-day lessons, spanning the Physics and Chemistry units, were selected to better understand how teachers and students engaged in constructing investigation questions, data collection, and the development of a consensus explanation for various phenomena. The 3 multi-day lessons were observed throughout the school year in four 6th grade classrooms, spanning from October to February during 2010-2011 to provide insight into teachers' disciplinary practices for students who have not yet had any experience with the IQWST curriculum. The two cases presented in this study come from the first 6th grade IQWST unit on light. In both Physics lesson 6 and lesson 11, students are engaged in the work of developing and refining their models of how light interacts with matter: exploring why light behaves differently when interacting with a mirror or a piece of paper, and what happens to white light when it interacts with colored filters.

Analytic Processes

The larger longitudinal study investigated variations in how classrooms engaged in scientific practices. To first describe how classrooms engaged in asking questions, conducting investigations and building explanations, all lessons observed across the four classrooms were videotaped and transcribed. Ongoing field notes of the classroom activity and pre and post interviews with the participating teachers supplemented the videotaped classroom observations as resources for developing and refining candidate conjectures. Field notes were taken for each day a lesson was enacted. A finalized version of the field notes, documenting significant events and their time stamps in classroom observations were recorded and finalized within 1-2 days of the observation. Ongoing memos and jottings, comprised of reviews, reflections, and ongoing questions that emerged from the classroom observations and interviews, were used to further refine ongoing hypotheses about the variations in how classrooms engaged in scientific practices, as well as the factors that contributed to the differences across the four classrooms.

As a result of this ongoing analysis, I found that although classrooms engaged in the same set of data collection investigations, *how* these investigations were motivated and subsequently *made sense of* differed across the four classrooms. This observation led to an increasing focus on the sense-making discussions that preceded and followed data collection activities across the four classrooms.

Discourse Analysis

To capture variations in how classrooms motivated and made sense of investigations to generate explanations, classroom talk was divided into episodes, based on the scientific practices in which students were engaged. Using a grounded approach of moving back and forth between the findings from prior work, existing literature on classroom discourse and scientific practices, and looking for confirming and disconfirming evidence within the available data, 22 codes were developed to describe ways in which students and teachers were engaged in scientific practices. These codes captured how classrooms went about asking questions, making sense of data, and generating explanations as well as the cognitive and material resources that were used to do this work. A second coder coded 49% of the total data corpus, with a reliability of $\kappa = .82$. Agreement was reached through discussion on all discrepant episodes.

Looking for patterns in the resources that teachers and students drew on to build explanations for phenomena revealed the epistemic criteria utilized to do knowledge-building work. Within the entire set of codes identified and refined through the analysis of the total data corpus, 3 codes captured the types of resources with which teachers and students construct, critique or defend candidate explanations for scientific phenomena: 1) *data from classroom investigations*, 2) *previously established principles and models*, and 3) *students' everyday knowledge*. 'Data' consisted of the qualitative and quantitative observations that students generated during classroom investigations for the current lesson. 'Previously established principles and models' were defined by the evidence-based claims generated through previous investigation activities and sense-making talk that addressed each unit's driving question; these principles were displayed in the class as visual representations or written statements and were co-constructed by students and teachers. Finally, 'everyday knowledge' – derived from student's daily observations of the natural world, was also used to generate candidate explanations.

Teacher and Case Selection

The coding process revealed variations in how often and in what ways the aforementioned resources were used to construct candidate explanations differed across classrooms and over the course of the 3 observed lessons. While all 4 classrooms utilized the 3 resources during discussions, two classes used *previously established principles* and *data from investigations* most often to generate questions and to build explanatory accounts for how light interacts with matter. The remaining classrooms put forth a greater proportion of explanations drawn from students' everyday knowledge, although the classrooms conducted identical investigations. These patterns suggested that investigations were treated differently across the four classrooms; in some, explicitly as opportunities for students to build on their existing knowledge with science principles and data to generate explanatory accounts for phenomena.

I reviewed the transcripts of all four teachers, and then zeroed in on Laura's class, to better understand how this was accomplished. In her class, candidate explanations generated from data, students' everyday knowledge, and previously established principles were juxtaposed to *motivate a need* to engage in investigations, but also as a means to *constructing consensus explanations* when alternative accounts were present. This is in contrast to classrooms where investigations goals for investigation were stated by the teacher, rather than driven by surfacing gaps in students' current explanations. During consensus-building discussions, Laura's class went through a laborious process of presenting alternative explanations and identifying evidence for or against candidate explanations to arrive at a single consensus explanation. Other classrooms, in contrast, simply identified and re-stated the same explanation, and often without accounting for or refuting alternatives.

After identifying these patterns, revisiting transcripts, and returning to extant literature on argumentation and explanation, I conjectured that these patterns revealed a unique case of how *problematizing* scaffolded students' engagement in scientific practice. A review of existing literature on argumentation in science classrooms further confirmed this conjecture; using frameworks specifying progressions in students' argument patterns and products (e.g. Berland & McNeill, 2010; Osborne & Patterson, 2011), the talk exhibited in Laura's classroom demonstrated sophisticated argumentation when motivating investigations and generating explanatory accounts for phenomena. I identified 2 such cases within the transcripts from Laura's class, presented in detail below, to highlight *how* problematizing is accomplished, *what* is problematized, and the key *scientific practices* (Achieve, 2013) that these discourse patterns enable students to engage with. Thus, these episodes from Laura's class were selected as *paradigmatic* cases (Flyvbjerg, 2006) of problematizing as scaffold. Analysis of students' performance on several pre post measures, when compared to other classrooms, also indicated greater gains in these students' ability to attend to disciplinary criteria when generating science explanations (Buckingham & Ko, 2013). For this reason, I selected segments of Laura's classroom as a rich case of how students are scaffolded into arguing to learn. Laura has over 20 years of experience teaching both science and math, and holds a degree in elementary education. Approximately 10 hours of video footage was observed in Laura's classroom from October to February throughout the study. At the time of the study, Laura used preliminary version of the field trial IQWST curriculum for 5 years, conducted professional development for new teachers, and worked closely with one of the lead universities creating the curriculum materials. The 3 other teachers were in their 2nd year of using the curriculum materials.

Findings

Case 1: Problematizing to Motivate Investigations

In Physics lesson 6, students investigate how light interacts with various types of objects. In previous lessons, students have already begun to describe how light interacts with matter by describing that light "bounces" off. However, the class has yet to explore how this bouncing differs when light is shone on different types of objects, such as a piece of paper or a mirror. Though this phenomenon may seem quite commonplace, everyday accounts for why light bounces differently are examined in Laura's class as worthy of further inquiry.

The lesson begins as Laura takes a flashlight and shines light onto a piece of paper that is taped to the whiteboard in the front of the class. While the students readily draw on previously established principles to explain that light bounces off the paper, students have difficulty explaining why the light bounces differently off a mirror. Laura relentlessly probes students to explain why light interacts with the two objects in such different ways (claims of how the light interacts with objects underlined below, the teacher's probing questions *italicized*, and description of non-verbal moves or behavior in (parentheses)):

Episode	Resources used	Teacher and student talk
1	Previously established principles and models	Laura: So the light's hitting the paper. Are you able to see the paper? Students: Yes Laura: Okay why are you able to see the paper? (Almost all students have hands raised) Oh look at all these hands. Why are you able to see the paper Joshua? Joshua: Because the light from the light source is bouncing off the paper and into my eye. …(Additional talk ensues)…
2	Data from investigation	Laura: So light's just hitting the paper and bouncing off and going into your eye, and now what if I use a mirror (Teacher shines light on a hand held mirror, directing light back and forth towards the students, as students begin to yell "Ah my eyes!")…*When I did the paper you weren't yellin*g (Teacher aims the light back at the paper) Matt: Because it's bouncing off differently Laura: *So what's makes it different when light bounces* (Teacher continues to use the mirror to shine light on the students)…So what happens? *Why do you think it's different* from when the light hits your paper? And when it hits the mirror? Alan?

Although the Laura's students use previously established principle that light comes from a source, bounces off the paper and into the eye, to explain how light interacts with paper (episode 1), this principle comes under scrutiny after Matt admits that the light is "bouncing differently" off of the mirror. Laura underscores this by directing the light in various directions (at times hitting the students' eyes) to further emphasize the contrasting ways that light interacts with the mirror and paper (episode 2). Building off of Matt's claim that light bounces differently, Laura asks the class, "so what makes it different…why do you think it's different?" The previously established principle "light bounces off…into my eyes" no longer provides a coherent account of how light interacts with both paper and mirrors, signaling a need to revise their previously established principles and models.

In response to Laura's probing, a series of exchanges follows in which students attempt to generate an explanation for these differences in how light bounces. As students begin offering candidate explanations drawing on their everyday knowledge, Laura utilizes previously established principles and observational data to further reinforce the insufficiency of these candidate explanations. The juxtaposition of previously established principles and models of how light interacts with matter and the observed difference in how light interacts with paper and mirrors generates a momentum and need for students to engage in further investigation:

Episode	Resource used	Teacher and student talk
3	Students' everyday knowledge	Alan: Uh I think its different 'cuz when it hits the paper it's carrying a - there's kind of photographic message like when it's hitting the mirror (Inaudible) light rays so there's no picture Laura: *Okay so what would you say? (*Looking at another student, not Alan)...do you have any ideas? Patrick: I think - (Inaudible) maybe its 'cuz (Shrugs his shoulders)
4	Previously established principles and models	Laura: I mean you said the light was bouncing off paper and going into your eyes (uses the mirror again playfully to shine into Ss eyes) we'll just assume that that happens. Okay – Irene?
5	Students' everyday knowledge	Irene: when you use paper, it's just shining (Inaudible) but when it hits the mirror its bouncing off the mirror (Inaudible) Laura: *So why does it do it for a mirror and not for a paper*? (Lots of student hands raised in response to this question) Irene: 'Cuz the mirror is like if we look you can see your reflection...(Inaudible) Teacher: *Why* (asking Irene, who appears to be stumped)? Good questions.
6	Data from investigations	Laura: So *is* the light hitting different objects differently? Students: Yes. Laura: *Why*?...How does light know how to do that?...*should we collect some more information about this*?

In the above episodes, students generate several different candidate explanations: Alan proposes that the paper projects a photographic message of light (episode 3) and Irene suggests that light *shines* on paper but *bounces* off a mirror (episode 5). In both instances, Laura probes these candidates by asking "why?" or "what would you say?" and reminds students, "You said the light was bouncing off…and going into your eyes" (episodes 4 and 5). Contrasting previously established principles and models from students' prior investigations in the unit and the observations of light shining on paper and mirrors further underscore the paucity of their existing explanations to account for the differences between how light reflects off the mirror and paper (episode 6).

As a result of these series of exchanges in which the teacher and students draw on data, students' everyday knowledge, and previously established principles, discrepancies between students' previously established principles and models and their current observations of how light interacts with mirrors and paper are highlighted. By making the gap between what students see and what they know explicit, the upcoming investigation becomes an opportunity to collect data to support a more complete explanatory account. These set of exchanges in Laura's classroom establishes a disciplinary-specific purpose to what might otherwise be viewed as a science lab activity, and creates a demand for students to revise their existing model in light of these perplexing observations of how light interacts with objects.

Case 2: Problematizing to Build Consensus Explanations

In Physics lesson 11, students work with C-spectra, colored filters, and an overhead (emitting white light) to explore components of white light and how white light interacts with filters. At this point in the Physics unit, students have begun developing and refining a model of how light interacts with matter, coming to consensus through investigations and discussions that white light interacts with objects by *reflecting* off, *transmitting* through, or getting *absorbed* by the object. During this lesson, students try to extend this existing model to explain colored light and how white light interacts with colored filters.

Laura begins this inquiry by projecting light through an overhead projector covered by a piece of paper with a rectangular slit cut in the middle, covered by C-spectra paper (which breaks white light into its component color spectrum). Without any colored filters, the white light transmits through the spectra paper and projects a rainbow of colors representing the components that makes up white light. However, when the orange filter is placed over the rectangular slit and C-spectra, the blue and purple components of white light seem to "disappear". After the class works together to investigate the colors of light "disappear" by using various colors filters, Laura challenges students to generate an explanatory account for their observations, asking, (specifically about the effect of the orange filter on white light), "Where are those colors…where is the blue and purple light going?" (Line 519-523, 11/15/2010)

In response Laura's request, students begin to put forth candidate explanations for the missing light. In the transcript below, Jonathan and Lana offer up candidate explanations, drawn from their everyday knowledge and previously established principles, to account for the missing blue and purple light. An issue arises when Lana misappropriates a previously established principle to explain the missing light; while Laura acknowledges the validity of the principle, she points out this principle does not adequately explain how the white light from the overhead (composed of visible spectrum, *including* blue and purple light) hits the colored filter and somehow disappears as it gets transmitted to the whiteboard:

Episode	Resource used	Teacher and student talk
1	Students' everyday knowledge	Jonathan: <u>It's disappeared.</u> Laura: It's disappeared, but I'm going to tell you I did not do any magic…*this is going to be a phenomenon that we can explain*…so, Lana, what do you think happened to the color?
2	Previously established principles and models	Lana: <u>You don't need the blue to make orange</u>, <u>so I don't think it shows up</u>. And because you need blue to make purple, I don't think it shows up either.
3	Data from investigation	Laura: Okay. So you're right. So we don't need it. *However, you didn't answer my question.* So here's the white. It disappeared. Where did it go? Here's the white light (pointing to the light bulb in the overhead). It's coming up. It gets to here (Teacher points to the projection lens above the overhead screen). Do you all agree it gets to here? Several students: Yeah. Laura: *So where does it go?*

After Jonathan suggested that the light has disappeared, Laura pushed students to account for the underlying mechanisms of how this has happened by saying, "this is a phenomenon we can *explain*" (episode 1). Using a prior activity in which she mixed various colors of light, Lana used principles of color composition, specifically, that *orange light is not made up of blue and purple light*, to explain that the light does not show up (episode 2). In response to Lana's candidate explanation, Laura returns to the demonstration with the overhead projector, pointing out that while Lana's right - blue light is not needed to create orange light, the white light (containing the blue and purple spectrum) travelled through the projector, and interacts with the C-spectra paper and the orange filter. By establishing consensus that blue and purple light were projected from the overhead, Laura simultaneously points out the shortcomings of Lana's explanation while requesting further explanation from her classmates, asking "so where does it go?" (Episode 3)

Following this critique of Lana's candidate explanation, Dale and Caitlyn draw on their everyday knowledge to generate additional candidate explanations for the missing light. When Laura later returns to Lana a second time for an explanation of the observed phenomena, Lana now utilizes the language from previously established principles about how light interacts with matter to suggest that the filter might be *reflecting* the missing light. Laura offers Lana's idea to the class, and then supports them in drawing on previously established principles and observational data to determine if there is sufficient empirical evidence in support of Lana's claim. Through the following exchanges, the class moves from generating candidate explanations to using principles to find disconfirming evidence to support a subset of these candidates:

Episode	Resource used	Teacher and student talk
4	Students' everyday knowledge	Dale: <u>It gets re-filtered back.</u> Laura: Okay…Caitlyn? Caitlyn: I think it's still there, but <u>the orange filter's…covering it.</u>
5	Previously established principles and models	Laura: [The] Filter's covering it. So it's covering it so we can't see it, right? And, sorry, Lana, tell me your answer again. Lana: <u>The filter reflects</u> it <u>because you don't need blue and purple to make orange</u>.
6	Data from investigation	Laura: Okay. *So what do we think about [the filter] reflecting it*? Matt: I don't know. Laura: *It's reflecting which colors, Lana*? Lana: <u>Blue</u>. Laura: *Does anybody see blue?* Students: No. Kyle: No. I see orange in the background.
7	Previously established principles and models	Laura: *If it was going to reflect blue, would you see blue*? Kyle: Yes. Mike: I don't know. Laura: So we could still go with what Colleen's saying, right? Like it gets there, but then we don't know where--it's going somewhere. Assad: <u>It's absorbed</u>. Laura: Assad? Assad: It's absorbed. Laura: Why do you think absorbed? Assad: <u>Well, because it's not being reflected and it's not being transmitted it's not being scattered.</u>

After Dale and Caitlyn offer up their ideas, Laura returns to Lana for further elaboration on a previously stated explanation. Although her stated idea (the filter reflects the missing light) differs this time, her reasoning for "because you don't need blue and purple to make orange" remains the same. Laura publicly acknowledge this claim and asked students evaluate it by asking "so what do we think about it…?" (Episode 4-5) Lana's explanation that the missing light is *reflected* is taken up and evaluated in episode 6, where Laura taps students previously established principle that when light reflects, *it bounces off objects and into our eyes*. After students realize that they do not see blue light being reflected off the orange filter, Laura further emphasizes the implications of this observation based on their principles, saying, "If it was going to reflect blue, would you see blue?" The combined effort of first gathering additional (observational) data and the use of previously established principles leads Assad to deduce that the missing light is absorbed by the filter because "it's not reflected…transmitted…scattered" (in episode 7).

Over the course of the 7 episodes presented above, Laura's class not only utilizes variety of resources to generate candidate explanations, they also critically evaluate them using previously established principles to identify the relevant disconfirming evidence. Although the teacher instigates the critique of candidate explanations, students are involved in the joint effort to identify contradictory evidence and offer alternative explanations that adhere to their previously established principles. After Assad proposes his candidate explanation, the classroom continues to work with several colored filters to gather additional supporting evidence for this candidate explanation, bolstering its validity. Later, the class deepens the idea that white light interacts with colored filters by *absorbing* a subcomponent of its total spectrum while letting others *transmit* through by using this same explanation to explain how colored sunglasses work. Through this sense-making talk, the students eliminated alternative explanations using evidentiary support and increased the generalizability of their current explanation – both critical aspects of epistemic criteria for knowledge building in science.

Discussion

The two cases presented in this paper, both from Laura's class, exemplify how sense making discussions serve to problematize students' understanding, thereby engaging students in sophisticated argumentative practices. The first case demonstrates that when discrepancies between students' current understanding and the observed phenomena are highlighted, students are motivated to engage in investigations to generate a more satisfactory explanatory account. The second case illustrates that by drawing attention to evidentiary support for candidate explanations, students attend to the fit between evidence, alternative explanations, and the disciplinary processes for moving towards consensus. In both of these cases, the problem-space is not simplified; rather, students are encouraged to offer up a multitude of candidate explanations and supported in sorting through these ideas (see Table 1 for summary of 2 cases).

Table 1: Problematizing as scaffold for motivating investigations and generating explanations

	Case 1: Problematizing to Motivate Investigations (Physics 6)	Case 2: Problematizing to Build Consensus Explanations (Physics 11)
What resources are used to problematize?	Data from investigations (observations) Students' everyday knowledge Previously established principles and models	Data from investigations (observations) Students' everyday knowledge Previously established principles and models
Are discrepancies highlighted?	Yes – between students' observations and previously established principles	Yes – between candidate explanations and available evidence
Are alternative explanations presented and tested?	Yes – class puts forth several alternatives but they are found to be insufficient based on students' observations	Yes – class draws on data and previously established principles to eliminate candidate explanations
Scientific practice students engage with	Evaluate limitation of existing model or explanation; analyze and interpret data to provide evidence for phenomena	Construct explanations with evidence; using scientific reasoning to show how evidence supports or refutes explanations
Function of teacher's discourse moves	Documenting candidate explanations publicly and marking explanations as objects of attention; requiring students to reason and justify candidate explanations; drawing attention to the fit between claims and available evidence.	

Based on existing literature, the patterns of talking in the cases presented here embody the core principles behind how problematizing scaffolds students into the practice of building causal accounts for perplexing phenomena. Whether the class is *motivating* investigations or *building consensus explanations*, through the juxtaposition of data, students' everyday knowledge, and previously established principles and models, students are pushed to coordinate this body of knowledge by critiquing and evaluating gaps in their current understanding and to use principles and data as evidentiary support. As a result, students begin to see investigations as opportunities to build stronger explanatory accounts and view the work of constructing consensus explanations as the process of coordinating claims, evidence, and reasoning for multiple accounts.

It is important to note that these two cases were not selected as examples of problematizing scaffolds at work from the outset of the study. Taking this analytical lens emerged through a thorough analysis of the discourse from all four 6th grade classes, and by returning to the existing literature to describe the type of scaffold that was utilized in Laura's class. Notably, students drew on in similar everyday knowledge, previously established principles and models, and data from investigations in all of the 4 observed classrooms. It was not simply drawing on these bodies of knowledge, but rather, identifying gaps and insufficiencies between them that moved the students forward in Laura's class. Identifying these episodes as cases of problematizing emphasizes the role of scaffolds that go beyond a prescriptive understanding of science argument as claims, evidences, and warrants. We see students building criteria for evaluating claims organically out of reflecting on the insufficiency of one's existing knowledge and understanding the role of science principles and data as resources for constructing increasingly sufficient explanations in Laura's classroom. The remaining 3 classrooms did not exhibit the consistent tensions born out of noting the explanatory power of different candidate explanations, or how these explanations differentially accounted for the observed phenomena as was observed in Laura's class.

Several follow up questions are worthy of further inquiry. Are these scaffolds taken up within students' discursive repertoire over time? That is, does Laura take on less of the responsibility, while students take increasing ownership over critiquing and evaluating one another's explanatory claims? Moreover, does this form of critical and evaluative talk become an integral and spontaneous component of the classroom practice? Identifying additional exemplars of problematizing scaffolds can contribute to the design of social, discursive, and technological tools in ways that do not remove the complexity of the knowledge building work in which students engage (Davis & Miyake, 2004). Furthermore, there is a need to identify other such pedagogical moves that constitute a problematizing repertoire for teachers.

Lastly, the examples presented from Laura's class provide insight into how to apprentice students into the scientific practices of arguing to learn, and specifically, integrating evidence-based and everyday explanations for phenomena. Rather than discounting the everyday accounts that students bring into the classroom, or relying solely on the data generated from investigations as resources for knowledge building, understanding the disjuncture and connections between these bodies of knowledge can equip teachers with the necessary probes that encourages students to add, distinguish, and sort out competing candidate explanations using evidence and science principles (Linn & Eylon, 2011).

References

Achieve. (2013). Next Generation Science Standards. Retrieved from http://www.nextgenscience.org/next-generation-science-standards

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765–793.

Buckingham, B.L.E, Ko, M. (2013). *Using Classroom Discourse to Account for Differences in the Causal Coherency of Written Explanations*. Paper presented at the National Association for Research in Science Teaching, Rio Grande, Puerto Rico, April 6 – 9.

Davis, E. A., & Miyake, N. (2004). Explorations of scaffolding in complex classroom systems. *The Journal of the Learning Sciences*, *13*(3), 265–272.

Duschl, R. (2000). Making the nature of science explicit. In *Improving science education: The contribution of research* (pp. 187–206). Open University Press.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*(4), 399–483.

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, *12*(2), 219–245.

Ko, M. & Reiser, B. J. (2010). *Connections, clarity and logistics: science teacher's enactments of reform-based science curricula.* Paper presented at the American Education Research Association, Denver, CO, April 30 – May 4.

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-Goals-Driven Design Model: Developing Curriculum Materials that Align with National Standards and Incorporate Project-Based Pedagogy. *Science Education*, *92*(1), 32.

Linn, M. C., & Eylon, B.-S. (2011). *Science Learning and Instruction: Taking Advantage of Technology to Promote Knowledge Integration* (1st ed.). Routledge.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting Students' Construction of Scientific Explanations by Fading Scaffolds in Instructional Materials. *Journal of the Learning Sciences*, *15*(2), 153–191.

Michaels, S., O'Connor, C., & Resnick, L. B. (2008). Deliberative discourse idealized and realized: Accountable talk in the classroom and in civic life. *Studies in Philosophy and Education*, *27*(4), 283–297.

Osborne, J. F., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, *95*(4), 627–638.

Pasley, J. D., Weiss, I. R., Shimkus, E. S., & Smith, P. S. (2004). Looking inside the classroom: Science teaching in the United States. *Science Educator*, *13*(1), 1–12.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *Journal of the Learning Sciences*, 273–304.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941–967.

Acknowledgments

The research reported here was supported by the National Science Foundation through Grant ESI-0227557, ESI-0439493, ESI-0101780 and DRL 1020316. The opinions expressed are those of the author and do not represent views of the National Science Foundation.