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LEARNING PROGRESSIONS AS VISION TOOLS FOR ADVANCING TEACHERS' PEDAGOGICAL PERFORMANCE

Abstract: Learning progressions were originally designed as continua of performances that students could exhibit around different dimensions of key scientific ideas. Our research group has applied these ideas to the development of a learning progression for early career educators that can be used by teachers to critique and advance their own pedagogical performance over time. Our principal claim is that the impact of learning progressions in educational settings can only be fully realized if the concept is extended from being about tools describing student performance to tools and tool systems that move teachers toward more effective and equitable instruction. This paper explores the ways in which first year teachers used a model-based inquiry learning progression as well as other tools to envision what is possible in a secondary science classroom.

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In this paper, we share the results of ongoing empirical and theoretical work on the development of a learning progression that describes increasingly sophisticated ways that *teachers* plan for, enact, and assess various components of reform-based teaching— specifically supporting students' Model-Based Inquiry (Windschitl, Thompson, & Braaten, 2008). Over the past three years we have conducted longitudinal case studies of 11 secondary science teachers, tracking their teaching performances and using this data to design a learning progression for early career educators.

Based on what we've come to understand about the ability of novice teachers to engage their students in productive forms of inquiry, we assert that the impact of learning progressions on student achievement can only be fully realized if the concept is extended from being about tools describing student performance to tools and tool systems that can be used by teachers to critique and advance their pedagogical performance over time. Or, put another way, to realize the potential of student learning progressions, they must be used by educators who themselves understand and can scaffold complex performances around authentic science.

This logic is based on the following. First, ambitious goals for science learners can only be realized by equally ambitious kinds of teaching. This teaching can be thought of as a set of complex performances that are quite different from traditional forms of instruction. Second, as most practitioners gain experience, they often use little more than informal observations of students to assess their own instructional efficacy and they depend upon a kind of untested folk wisdom to make changes in practice (Goodlad, 1990; Huberman; 1995; Little & Horn, 2007; Lortie, 1975; McGlaughlin & Talbert, 2001). This has been characterized as "bricolage" or tinkering. In this view teachers develop as independent artisans, picking up a new activity here and a new technique there, choosing these to fit within their own styles and work settings. In light of this, it is important to the field that expert performances in science teaching be systematically characterized and represented in ways that are useful to educators. Currently, "what counts" as advanced pedagogical practice is underspecified. Moreover, we do not have descriptions of potentially productive kinds of practices from beginning instantiations to most sophisticated. As a result, no resources have been developed to help teachers recognize where elements of their practice are on such a continuum and what the next level of performance might be.

Development of a Teacher Learning Progression

The design of our learning progression is informed by three areas of scholarship:

- The nature of authentic disciplinary practices in science (including areas of epistemology, science studies, socio-cultural perspectives on development of scientific knowledge)
- How students learn science (including areas of meta-cognition, conceptual change, model-based reasoning)
- Novice teacher development (including novice-experts literatures, teacher learning).

Authentic Disciplinary Practice in Science

From the literature on science studies and the epistemology of science, we assert that there are particular practices that are integral to the core work of science— this core being organized around the *development of evidence-based explanations of the way the natural world works* (Giere, 1991; Longino, 1990). Roughly speaking, this involves the creative process of developing hypotheses from theories or models and testing these against evidence derived from observation and experiment. Our conception of "core work" is not intended to represent specific activities that *all* scientists engage in, rather it is conceptualized around an epistemology of scientific knowledge held by the scientific community— a set of commitments about the nature and grounds of knowledge that help define "what counts" as a scientific way of generating and validating new ideas. Using this premise to reconceptualize school science inquiry, we advocate for coordinating the language and activities in classrooms around epistemic features of scientific knowledge (Smith, Maclin, Houghton & Hennessey, 2000; Windschitl & Thompson, 2006)— that it is: testable, revisable, explanatory, conjectural, and generative.

By *testable*, we mean that scientific knowledge, in the form of models or theories, is advanced by proposing new hypotheses that express possible relationships between events, processes or properties within these models or theories, and by using various domain-specific methods for gathering data aimed at evaluating these hypotheses. By *revisable* we mean that scientific ideas can change in response to new evidence or because a phenomenon is conceptualized in an entirely different way (e.g. kinetic vs. caloric models of heat transfer). By *explanatory* we mean that the goal of science is to provide causal accounts of events and processes, as opposed to accumulating descriptive detail about phenomena or merely seeking patterns. By *conjectural* we mean that causal accounts often involve theoretical or unobservable processes that can only be inferred from empirical observation (data) and that scientific argument aims to persuade others that explanations based on these inferences account most adequately for the observations. By *generative* we mean that scientific knowledge, in the forms of models and theories, are the prime catalysts for new predictions, insights about phenomena, and hypotheses for testing; they are not simply "end-products" of inquiry (Hempel, 1966; Knorr-Cetina, 1999; Kuhn, 1970; Latour, 1999; Longino, 1990; Ochs, Jacoby & Gonzales, 1994).

Authentic forms of inquiry for school science can be grounded in these five ideas and, in particular, in reasoning with and about models. Contemporary studies of scientific work have demonstrated that experimentation and the broader enterprise of inquiry is becoming routinely situated in model-building, testing, and revision (Darden, 1991; Duschl & Grandy, 2005; Giere, 1988; Kitcher, 1993; Longino, 1990; Nersessian, 2005). Scientists as a matter of practice express ideas in the forms of inscriptions (i.e. textual, pictorial, or graphic expressions such as notations, drawings, diagrams, charts, or maps) analogies, physical constructions, or computer simulations in order to describe and understand natural processes that range from atomic bonding to the life cycles of stars (Latour, 1990). We hold a synthesis view that models are representations constructed as conventions within a community to support disciplinary activity (Lehrer & Schauble, 2003). Regardless of how models are conceptualized, they generally emerge from some phenomenological context (event, question, problem), they involve identifying key features or attributes of the phenomenon, and they specify how they are related (Romberg, Carpenter, & Kwako, 2005). The general aim of modeling is to test an idea— represented as a system of related processes, events or structures— against observations in the real world and to assess the adequacy of the representation (i.e. model) against standards of evidence. Successful instructional frameworks for modeling typically guide students through a number of processes: engaging with a question or problem (often through material involvement with a natural phenomenon); developing a tentative model or hypothesis about causal or otherwise associative relationships in the phenomenon; making systematic observations to test these hypotheses; creating models of the phenomena that would account for the observations; evaluating this model against standards of usefulness, predictive power, or explanatory adequacy; and finally, revising the model and applying it in new situations (see Hestenes, 1992; Lehrer & Schauble, 2006; Lesh et al., 2000; Metcalf, Krajcik, & Soloway, 2000; Schwarz & White, 2005; Stewart et al., 1992, 2005).

Certain forms of model-based inquiry (MBI) encompass all five dimensions of the epistemic nature of knowledge (noted in italics below). In these inquiries, models are treated as subsets of larger, more comprehensive systems of explanation (i.e. theories) that provide crucial frames of reference to help *generate* hypotheses for *testing,* act as referents in interpreting observations, and are themselves targets of *revision*. Arguments for the support of *conjectural* models (as opposed to purely descriptive, empirical models) involve using observations (for example, a balloon affixed to the top of a flask will begin to inflate when the flask is heated) to support *explanations* involving unobservable entities or processes (in this case, that heat causes molecules of air to move more rapidly, producing a pressure inside the flask that is greater than that outside). Conjectural models are representations of scientific phenomena (inscriptions typically) that coordinate observable features of that phenomenon with hypothesized explanatory events, properties, or structures that are not directly observable because of their inaccessibility (the mantle of the earth or molecular movement) or conceptual nature (forces, metabolic rates in organisms).

In sum, although different domains in science have their own fundamental questions, methods, and standards for "what counts" as evidence, they are all engaged in the same knowledge-building pursuit— the development of coherent and comprehensive explanations through the testing of models (Hempel, 1966; Knorr-Cetina, 1999; Kuhn, 1970; Latour, 1999).

These images of scientific practice have been reflected in recent authoritative documents as necessary components of school science (summarized in National Research Council, 2005a; National Research Council, 2005b; National Research Council, 2007). The recent volume *Taking Science To School* (NRC, 2007), for example, identifies four strands of proficiency for students *and for teachers* who are responsible for guiding young science learners. Students and teachers should be able to:

- Understand, use, and interpret scientific explanations of the natural world
- Generate and evaluate scientific evidence and explanations
- Understand the nature and development of scientific knowledge, and
- Participate productively in scientific practices and discourse (p. 334).

These proficiencies are embodied most clearly in classroom activities such as content-rich model-based inquiries and non-routine problem-solving. What these proficiencies "look and sound like" in practice however, has not been well-translated into models for teacher performance (such as a Learning Progression for teachers), nor have underlying skills and understandings required for these performances been articulated.

How Students Learn Science

The learning sciences have provided insights into how students, over time, approach and process scientific content and epistemic features in science. We know, for example, that children at early ages are capable of complex reasoning, such as theory building and testing, especially when given multiple opportunities to sustain their engagement with supportive practices (Duschl, 2008). When learning to reason scientifically we know that students:

- rely on prior knowledge and experiences from interactions in their day-to-day lives outside of school,
- rely on pre-existing epistemic frameworks for understanding how science is done and how knowledge is communicated in science,
- hold onto preconceptions or partial understandings if there are no opportunities to confront and wrestle with these ideas,
- can use verbal and written scaffolds to build scientific language and knowledge,
- try-on, edit, and add ideas though conversations with peers and more knowledgeable others as well as through reflection and self-monitoring,
- build understandings from the concrete to the abstract,
- apply conceptual frameworks to support understanding in new situations (NRC, 2005b)

The learning sciences also provide some insight into the types of environments that best support this learning. We know for example that students learn best when teachers:

- promote active productive thinking and dialogue,
- encourage legitimate peripheral participation in valued disciplinary practices,
- provide guided participation in scientifically authentic social and intellectual processes,
- make thinking visible and provide feedback on scientific thinking and learning. (Duschl, 2008; NRC, 2005b)

Thus, how students develop cognitively in science communities can be cast generally as a dialogic theory of learning, but this form of learning requires a pedagogical focus on the epistemic features of scientific knowledge-building and the social practices of scientists. It is through conversations about explanatory models and the nature of scientific evidence that learners engage in making sense of scientific concepts and about the nature of science.

Novice Teacher Development

The ways in which MBI is manifest in classrooms depends in large part upon the capabilities of teachers to design and enact complex forms of instruction. We currently have limited understandings of how individuals develop the skills, knowledge, and habits of mind to become such proficient teachers. Much of what we know comes from expert-novice studies, but these have not followed individuals over a period of years, rather, these studies compare the thinking and practice of novices with separate groups of more experienced practitioners (see Berliner, 2001). Developmental pathways and a list of critical experiences that can advance the practice of novices over time have not been empirically validated. There are other kinds of research, however, that provide important clues to what might help or hinder teachers' learning throughout their careers. We outline these below.

Pre-service teachers have pre-conceptions about *science content* and *science as inquiry*. In multi-case studies of pre-service secondary science teachers' understandings of authentic inquiry practices during science methods courses (Windschitl, 2004; Windschitl & Thompson, 2006) most participants subscribed to a "folk theory" about scientific inquiry in which forms of knowledge and specialized disciplinary rhetoric that are crucial to reform-based teaching (e. g. model development, explanation, argument) had little or no role. The emphasis by these pre-service teachers was on collecting and analyzing data, but not on connecting this data to an underlying explanation. Two factors shaped participants' thinking about these inquiries. One was previous school-related research experience which influenced not only what they recognized as explanations or models but also the way they believed these could be incorporated into inquiry. The other was a widely-held simplistic view of "the scientific method" which constrained the procedures and epistemic frameworks they used for investigations.

Pre-service teachers also enter preparation programs with existing hypotheses about *how people learn*. One personal theory that many new teaching candidates hold about learning is that it amounts to a simple "transfer" of information from texts and teachers to students who acquire it from listening, reading, and memorization (Feiman-Nemser & Buchmann, 1989; Richardson, 1996). This shapes their thinking about what kind of teaching is appropriate and possible in classrooms (National Center for Research on Teacher Learning, 1991). When we consider the kinds of knowledge-building, problem-solving, metacognition, and collaboration that are part of student learning, such an oversimplified view of teaching seems a major impediment. These preconceptions, developed in teachers' "apprenticeship of observation", also condition what they then learn in training experiences (Linn, Eylon, & Davis, 2004). If this initial understanding is not engaged/confronted during teacher preparation, they may fail to grasp new concepts about teaching and learning or they may learn them for the purposes of a test, but revert to their preconceptions later (Darling-Hammond & Bransford, 2005).

We also know that even when novice teachers are exposed to powerful conceptual frameworks to help them think about organizing instruction and analyzing classroom events (Bransford & Stein, 1993; Grossman et al., 2000) they will either not know how or when to enact these ideas when they enter the classroom, or, they will simply reject these frames and rely instead on conservative teacher-centered instruction (see Abd-El-Khalick, Bell, & Lederman, 2000; Appleton & Kindt, 2002; Bransford & Stein, 1993; Brickhouse & Bodner, 1992; Goodlad, 1990; Grossman et al., 2000; Mellado, 1997; Nolen, Ward, Horn, Childers, Campbell, & Mahna, in press; Palmquist & Finley, 1997; Simmons et. al, 1999; Windschitl & Thompson, 2006). Reform-based teaching methods are often fundamentally different from how student teachers were taught and sometimes how teacher educators themselves learned as students (Borko & Mayfield, 1995).

Part of the challenge in helping novices take up reform-based practices is that, as they begin their careers, they are not merely being apprenticed into a set of teaching strategies, but often into an intuitionist epistemology of professional knowledge and problem-solving (Goodlad, 1990). Teachers use little more than informal observations of students to assess their own instructional efficacy and depend upon a kind of untested folk wisdom to deal with dilemmas of practice. Huberman (1995) has characterized this approach to practice as “bricolage” or tinkering. In this view teachers develop as independent artisans, picking up a new activity here and a new technique there, choosing these to fit within their own styles and work settings. Both Huberman and Lortie suggest that these tendencies are reinforced by the everyday intellectual isolation of the classroom (see also Goodlad, 1983; Jackson, 1968; Little, 1990; McGlaughlin & Talbert, 2001) and by the absence of a shared and explicit vision of good teaching that could support conversations about how to improve practice.

Given the over-reliance on personal intuition, the isolation, and the lack of models for effective teaching, interventions designed to foster ambitious pedagogy in novice educators must consider new ways of making public “what counts” as accountable practice. Apprenticing teachers, and in particular novice teachers, into this type of teaching however, is complicated by the “hard wired” routines of low-level questioning in classrooms (e.g., I-R-E discourses and discourses of teacher control), by the lack of clear models of more sophisticated practice, and by inexperienced educators’ limited understanding of students’ capacities to engage in challenging work (Elmore, 2005).

Our Model-Based Inquiry Learning Progression for Teachers

Our learning progression encompasses a continuum of pedagogical sophistication along 11 different dimensions of reform teaching, which, in sum, support Model-based Inquiry. This tool includes categories such as “designing lessons with attention to students’ engagement with models in an inquiry context” and “identifying full scientific explanations of phenomena and students’ approximations of these explanations.” (See appended—Full MBI Learning Progression)

The development of the progression followed specifications similar to those guiding progressions for student performances in various content domains (Smith et al., 2006). The learning progression was based not on teacher knowledge but on teachers’ performances in the broad areas of planning, enacting, assessing and reflection upon instruction. The lower anchors of pedagogical performance are based on empirical analyses of how novice secondary teachers typically engage students in inquiry (Crawford & Cullin, 2004; Windschitl & Thompson, 2006; Windschitl, Thompson, & Braaten, 2008a; Windschitl, Thompson, & Braaten, 2008b). The upper anchors (advanced levels of supporting MBI) are based on conceptual analyses of how expert teachers foster more sophisticated scientific practice and discourse in the classroom around developing models, applying evidence, and constructing explanations. The structure of this progression is similar to student learning progressions also in that it encompassed time units of approximately two to four years. Using this tool we predict that novices can locate specific elements of their inquiry practice along a continuum, envision what the "next steps" should be in advancing their practice, and share common language with other participants using the progression.

In our research we have addressed one overarching challenge associated with the development of all learning progressions— the fact that progressions are based on *theoretical* advances in performance that can occur over time, rather than actual accounts of individuals who have developed along various dimensions of the learning progression over periods of two to four years. Much of how the field of teacher learning thinks about the development of teacher reasoning and practice has been framed by novice-expert dichotomies in which groups of novices have their practice described and a separate group of experts has their practice described (Berliner, 1994; Carter, Cushing, Sabers, Stein, & Berliner, 1988; Lin, 1999). Assumptions are then made that fill in the transitional space (Dreyfus & Dreyfus, 1986).

In contrast, our research has followed the progression of pedagogical reasoning and practice of a number of novices across several early learning-to-teach contexts for a period of three years, and in some cases four years. We have taken data from methods coursework early in a teacher preparation program (where participants received extensive instruction in supporting students' Model-based Inquiry), from student teaching and from participants' first year of teaching (we have additional data on some participants' second year of teaching as well). The 11 individuals were candidates in a teacher education program at a public university in the northwest United States. All entered the program with a bachelor's degree in an area of science or engineering. Our data sources include written materials from their methods coursework, about nine classroom observations for all 11 participants during student teaching and their first year of teaching, and video plus artifacts from four rounds of analysis of pupil work and subsequent Critical Friends Group meetings. We have additional data from several participants that extends into their second year of teaching.

We used this data, particularly the classroom observations, to identify patterns of less and more sophisticated versions of each dimension on the MBI learning progression. Noting when partial practices were taken-up, when just the language but not the practice was appropriated, and when teaching practices were stifled or pulled in new directions by school context influences. These beginning and intermediary practices are described in the lower and middle anchors for each dimension. For example, for rows 4.1 and 4.2 we used our observations to detail how participants partially appropriated practices related to the building of scientific models—several participants used students' initial ideas to construct a scientific model but did not successfully layer theoretical constructs onto these models. As a second example, in rows 2.2, 3.2 and 9.1 we accounted for one of our contextual findings—many of our teachers felt pressure to teach to mandated assessments or from textbooks that emphasized the design of scientific experiments rather than the underlying explanation for a phenomenon. We also used our observations to add specific examples to the upper/ theoretical anchor.

How Teachers Use Learning Progressions

One of the fundamental differences between LP's for students and LP's for teachers is that the latter are designed not only for teacher educators to design preparation experiences, but they are for use by teachers themselves. We propose that teachers can 1) locate elements of their own practice within the learning progression and 2) use the "next levels" on those continua to imagine what their practice could become. Before we discuss how teachers in our study used LP's to talk about what advances they might make in their practice, we address the prerequisite capability of teachers accurately identifying where they are currently on a given continuum. To accomplish this, we believe that it may be beneficial for teachers to initially use a "reduced" version of the learning progression. The full version, in its complexity, may overwhelm the cognitive resources of the beginning teachers in making sense of their classroom practice. We developed a reduced learning progression, comprised of only four dimensions which we believe are core to ambitious pedagogy (See appended—Reduced MBI Learning Progression). We hypothesize that in teachers' second year of professional work they may be able to use the full learning progression in collaborative settings to identify more detailed assessments of where their practice is currently, and what the next level of practice looks like.

This past year, we asked our participants to identify where their practice fell on the four dimensions of the Reduced MBI Learning Progression. We found that with very few exceptions, our participants could not only accurately self-identify where their teaching was along several dimensions, but could also describe instances from their teaching in which they deviated from a level of sophistication they normally "occupied" (this deviation to a lesser level of sophistication was often due to a lack of familiarity with the subject matter for a particular unit, or because they were required to teach a particular unit without much modification). Teachers could re-tell stories of pedagogical shifts, describing when and how they adopted a new practice or when they started regressing based on earlier progress. Moreover, many used the progression to state where they would like to improve their practice during their second full year of teaching; most participants asked to keep copies of the learning progression as a reminder of how they would like to advance their practice. Some of these individuals also commented that they would use different levels of practice with students, depending upon how ready their students were to engage in a type of inquiry or task (this idea was echoed by another cohort of teachers, see paragraph below for a specific example).

Not all individuals talked about improving their practice merely as a result of identifying where they were on the LP. Some individuals were quite satisfied where their practice fell on the various dimensions and used the LP to justify their current practice.

Table 1 shows results from an analysis of 9 of the 11 teachers who used the Reduced MBI LP following their first year of teaching (two of the teachers did not complete the portion of the interview that asked individuals to locate their practice on the LP). The teachers were placed into two groups, those who used the LP as a vision tool and those who did not use the LP in any particular way that might help advance their practice.

Table 1. *Unproductive (-) and productive (+) uses of the reduced MBI Learning Progression by first year teachers.*

		CURRENT PRACTICES & VISIONS			FUTURE VISIONS			
		- Locates self in lower anchors on the LP (citing limited abilities of self or students) but satisfied with practices	+ Raises questions about where they "ought to be" on the LP	+ Justifies location in upper anchors based on core commitments (and not wanting to be located in a lower anchor)	+ Describes generally a desire to change practice	+ Describes a specific vision-to-practice gap or a missing link for moving forward on the LP	+ Imagines a student learning dilemma that has yet to be worked out & hypothesizes about student learning	+ Making Connections among Multiple Dimensions and Setting New Goals
Group 1: Uses the LP to create visions	Simon					1		
	Rachel			3		2	3	
	Sarah			1,2,3				1,2,3
	Barbara			1		2	1	
	Emily			2,4			3	
Group 2: Uses LP to locate practice not visions	Elena	1,2			4			
	Kelly	2,3						
	Patricia	1,4	2		1			
	Adam	1,2,3,4						

The table above illustrates how first year teachers were able to use each dimension of the reduced MBI LP. The four ambitious practices described in the reduced learning progression are:

1. Selecting and treating big ideas as models
2. Working with science ideas in the classroom
3. Pressing for explanation
4. Working with students' ideas

Group 1: Using the LP to Create Visions of Current and Future Practices

This group of teachers tended to use the LP in three productive ways: 1) to justify the location of themselves—not just their practice, but themselves as a teacher—in the upper anchors based on their personal teaching and learning core commitments, 2) to specify what might be the missing links in their practice that currently prevents them from moving forward on the LP, and 3) to raise questions and student learning dilemmas they are currently working on or have yet to work out. One teacher also used the LP to clarify the links among the ambitious form of each dimension on the LP (drawing connections among ideas in the right hand column).

Justifies Location in Upper Anchors Based on Core Commitments and Not Wanting to be in Lower Anchors

Four of the five teachers used the opportunity to clarify and justify for themselves (and perhaps the interviewer) who they are/are not as teachers and how it maps onto the upper anchors in the LP. They also describe not wanting to be the kind of teacher who resides in the lower anchors. For example, Rachel describes being frustrated that her location on the LP has regressed during her first year of teaching as compared to student teaching.

> Rachel: [referencing LP dimension # 3] I know that there is a couple times when I have waffled over here [pointing to lower anchor] and I have been unhappy about that. I think that is definitely my goal. But yeah, that is where my mind sits. I think planning wise, thinking wise, and capability wise I have the capability of kind of being mostly being here and working towards that [upper anchor], but reality wise for the past six months I gotta say I am here. I don't like being there.

She literally puts herself and her "mind", rather than her practice on the scale by referring to where she is and where she does not want to be located. Emily also describes where she likes and dislikes reside on the LP but she does so by also describing her core teaching beliefs behind her location.

> Emily: [referencing LP dimension # 4] I definitely elicit it [student ideas], the only thing I don't do with those ideas, and I think it's a good thing, especially at the beginning of an activity, is I don't answer them. I don't answer their ideas. I don't go about trying to give them the correct answer to whatever it is they're thinking. I try to let them struggle with it, get through with an activity, and let them answer themselves. And oh my gosh is that hard. Because you know, that's the moment when you think oh, I'm going to be the teacher and I'm going to tell them the right answer right now. And that's not the good teacher. That's not the science teacher. That's not…you know, if we're going back to the vision, I'm not envisioning myself telling them the right answer every time they ask me a question. Because a good teacher lets them figure out their answer using data and evidence. And not telling them what their answer is.

Emily's description reads like a proclamation of who she is and is not as a teacher. Both Emily and Rachel put a firm "stake" in the upper anchors. In this way, it is possible that the LP offers a way for some teachers to express for themselves and others a statement about their pedagogical identities. The language and structure of the LP supports these statements.

Describes a Specific Vision-To-Practice Gap or a Missing Link for Moving Forward on the LP

This group of novice teachers also uses the Learning Progression to think about future curricular visions, imagining what might be possible and imaging "next steps." This means that the teachers not only accurately locate themselves on the LP but can also assess the gap between cells on the LP as well as what pedagogical moves it might take to move forward on a dimension of the LP. In the first example, Barbara considers how she can move away from one of the lower anchors that solely focus on "the scientific method" as a way of working on science ideas in the classroom. She attempts to fill a gap between this lower anchor and other cells on the LP that ask students to reason with science ideas by considering a practice of her department head.

> Barbara: [referencing LP dimension # 2] Reflecting on this year I have been trying to think about how I can get away from that [the scientific method] so much because I have heard a lot of feedback from the students saying like gosh, we do this every single time. The same kind of set up and routine and I have been trying to get away from that. I am looking at sort of how our department head

> teaches and he, from what I have seen, he doesn't do a lot of like, you know, for every experiment or whatnot, he asks a couple questions and students just sort of try to answer those questions instead of coming up with this whole process of what is your hypothesis for this? What is some data that you can collect for this? He just asks questions and the students should answer and then that leads into an experiment eventually. I am trying to think of how I can go about doing that, but it is still something I am trying to wrap my brain around.

It is a vision she has yet to fully work out but she at least has some concrete ideas about how she might move forward. The way Barbara talks about this future vision makes it sound like it was, at least in part, a vision she was working on prior to interacting with the Reduced MBI LP. It is possible that the LP simply surfaced this move she was considering making but it is also possible that interacting with the LP might provide further justification for working toward this future vision. Simon, on the other hand, sounds like he is piecing together missing pedagogical links as he interacts with the LP. Here he considers the use of all-encompassing scientific models to move from the "Process focus" cell to the "Theory focus" cell on the first dimension of the LP.

> Simon: [referencing LP dimension # 1] I think I've been tending to try to do this more because I see that as being the way that kids are going to understand like this. I think, gosh, I wish I just had a couple more weeks in school. Not really because I want to get out of here. But at the same time like I wish that I had more time for them to really like drop just this huge model of everything that they've learned this year and see how many connections they could make between like energy and forces in motion and then how like…I mean, if I had more time it would be really neat to tie in like thinking about water and then thinking about its effect on the earth. But then thinking about like our need for it and then thinking about how it ties into the weather. Because gosh, it seems like science, like at certain levels you have to break it apart to understand it. But like then you lose track of the fact that like all these things fit together.

Simon imagines an alternative ending to the school year in which he has students draw relationships among key ideas students learning in the form of scientific models. While Simon and Janet have different motivations for moving toward an upper anchor—Simon imagines better supporting students' understanding of science and Barbara considers how she can best respond to students' concerns—they both show ways in which they can piece together an idea of how to move from one cell to the next (considering that strategies for moving from one cell to the next on the LP are not specified as part of the Reduced MBI LP).

Imagines a Student Learning Dilemma that Has Yet To Be Worked Out and Hypothesizes about Student Learning

The teachers in this group not only tended to use the LP as a way to imagine how they might move forward on the LP but also to imagine student learning dilemmas that need to be considered prior to whole-heartedly endorsing the upper most anchor on the LP. In this way the novice teachers took a critical stance toward the LP and problematized forward movement on the LP by considering how students learn. Both Rachel and Emily locate themselves as being on the upper anchors of the third dimension of the LP (Pressing for Explanation) but pause to consider how students learn scientific explanations. Rachel describes how she mentally works out a causal explanation but then considers to what extent students should be able to tell a full causal story for what happened in an investigation.

> Rachel: [referencing LP dimension # 3] I think I sometimes really struggle with that of, even with myself, of okay in my mind what is causing something to happen and I can usually sort through that pretty okay, but where I really get stuck is now what should I expect from kids? I do think that they have to do that, but what does that look like for a 15-16 year old. It shouldn't look the same, but I don't know how it should look. Then you can take it the next step once you have figured out how should it look, okay now how do you help them get there? I haven't gotten close to that one I think.

Rachel describes needing an understanding of how to calibrate learning for high school students. This seems like a productive dilemma to consider since she has to reason with the depth of scientific explanation she would like to hold her students accountable to. Similarly Emily questions how to scaffold students to "why" explanations (the upper anchor) and states that she needs to be in lower levels of the LP to map onto how students learn to develop why-level explanations.

> Emily: [referencing LP dimension # 3] Okay, so here's my dilemma right now. Before I can get to the "why" I have to do the "what" and the "how." So on a guided worksheet on even a multiple choice test, I mean, really I should be testing for the "why." Yeah, I want to ask the "why," but I'm not sure that they got the "what" and the "how." So until I get sure, I'm sure and positive that they got the "what" and the "how," I can't really feel confident about going into the "why" without them knowing the "what" and the "how." So that's my like…so I'm stuck on "what" and "how" for now until I can figure out how to get "what" and "how" done confidently so we can actually get to the "why."

Both Rachel and Emily use their interaction with the LP to express a dilemma that they have yet to work out in their teaching. They are skeptical of the upper anchor and question what it means for student learning if they place themselves squarely in that cell. Their interaction with the LP might support the idea that LP have the potential to surface new and potentially productive lines of thinking for the teachers to explore. Some of the challenges the teachers raise remain problems that we have yet to address and are described in the "Unanswered Questions" section of this paper. Perhaps answers to these student learning dilemmas lie not in a teacher learning progression but in a student learning progression.

More recently, with another cohort of 18 pre-service teachers, we tested whether beginners could identify where the practice of more experienced educators fell on the LP. Overwhelmingly, they were able to successfully identify where this practice was located. In addition they were able to describe how an intermediate level on the third dimension of the LP, exhibited by one of the observed teachers, was not an indication of instructional shortcoming (asking students for a "how" explanation), but rather a strategy to get a class of students set up for the next level of questioning in a subsequent lesson (pressing then for evidence-based causal explanations). In this case, as in the case with Group 1 of the first year teachers we interviewed, the LP was used as a tool for hypothesizing about practice and student learning.

Making Connections among Multiple Dimensions and Setting New Goals

Only one teacher was able to use the LP to make connections among ideas in the upper anchors. She used the opportunity to reason through the relationships between having a "theory focus" for dimension 1, an "epistemic fluency/MBI focus" for dimension 2, a "causal explanation focus" for dimension 3 and "adapting instruction" for dimension 4. In this way she was the only person to describe the ambitious practices as integrated and she was the only person to read down a column not across a row. After doing this Sarah rapidly set a new goal to simultaneously work on multiple dimensions in the upcoming school year. She begins by stating that she imagines herself as the kind of teacher who works in the upper anchors of the LP.

> Sarah: [referencing LP dimensions # 1-4] Well I always wanna get to the top level. So it kind of goes hand in hand with the pressing for explanations like I would say that I probably do a lot of process focus and then have been thinking a lot about theory focus this year especially in biology… about using um evolutionary theory as like an overarching theory that we can hook ideas onto. I guess like…the theory focus and then the fluency those kind of go together too. They're like…if you're using a theory you're also using a…I mean a theory is an explanatory model so um…I guess it makes me think that what I really should be working on is when I'm planning my units for next year to really figure out how to include more of this idea of model testing or kind of revisiting ideas and um…adjusting thinking as we go through a unit. So I guess that would be a goal for next year. Well I feel like if you work on theory focus and the fluency then that's also going to increase the amount of causal explanations that are happening because causal explanations are part of creating a theory and so if you're doing all of that then they should all move together I would think. And so I think it's really important for them [students]…if I'm working towards having this theory focus or fluency then it's really important that those aren't just separate things that somehow they're making those connections between the ideas like building a framework and hanging their little ideas on it. Which is part of how that whole theory of how students learn.

Sarah uses the LP as a way to further develop sophisticated ideas about teaching and learning science. It may be that Sarah accepts the tools we provide without question but it is more likely that her goals for teaching and learning are tightly aligned with the descriptions of teaching and learning advocated for in the LP. In this way she can start interacting with the LP in a different way because she is constantly searching for language and structures to help her better articulate a sophisticated theory of science teaching and learning. This alignment might also be what afforded her the opportunity to immediately set a new goal for herself. A goal she has consistently worked on in her second year of teaching.

Summary

This group of teachers used the Reduced MBI LP to not only locate themselves on the learning progression but they used the language and the structure of the LP to express ideas about who they are as teachers (and who they are not) as well as set ideas about who they would like to become. None of the teachers simply mentioned that they would like to move forward on the progression. They talked about working toward new visions and were able to express pieces of plans or at least starting places for enacting change. It happens to be the case these individuals were also the teachers who were more experimental with their teaching practices during student teaching and their first year of teaching. Thus making changes was not foreign and they might have had more ideas about which ambitious practices could fill the gap between their current practice and their curricular visions based on this experimentation. The teachers also raised student learning dilemmas associated with forward movement on the progression. These were dilemmas the teachers planned to take on in their next year of practice, not just complain about. In one case a teacher used multiple dimensions of the LP to generate a vision of what her practice could look like the following year. Thus the teachers used their interaction with the LP as a time to re-state, clarify, productively complicate, revise, and expand visions of what ambitious teaching and learning could look like in their classrooms.

It is also interesting to note that many of these future visions involved work on dimensions 1and 2 of the Reduced MBI LP—selecting and treating big ideas as models and working with science ideas in the classroom. These were practices teachers struggled most with during student teaching and during their first year of teaching (see Thompson, Windschitl, & Braaten, 2008 for analysis of teaching practices). More teachers, about two-thirds, were able to enact ambitious forms of dimensions 3 and 4—pressing for explanation and working with students' ideas. The degree of enactment during their first year of teaching in combination with the degree to which teachers used the LP to set goals helps clarify a potential learning progression across the four dimensions. It appears that learning about "working with students' ideas" was generally the easiest for teachers since many teachers were proficient at least the middle cell following their science teaching methods course. No teachers in this group expressed a vision-to-practice gap or student learning dilemmas related to dimension 1. Pressing for explanation was the next most approachable dimension, in part because we provided additional tools following student teaching that helped specify a learning progression (for teachers and students—see description later in the paper about other tools in the tool system). Not many of the teachers expressed vision-to-practice gaps for this dimension but for a few teachers this was the one dimension that was easy to problematize and hypothesize about potential student learning challenges. Only two teachers were able to do the most sophisticated forms of working on science ideas (dimension 2) and selecting and treating big ideas as models (dimension 1) by the end of their first year of teaching but the LP analysis suggests that this was an area teachers were trying to close vision-to-practice gaps. It also seems that if more teachers could think about the interrelationships among dimensions, as Sarah did, then teachers might have more intellectual resources to draw on when imagining sophisticated practices related to dimensions 1 and 2.

Group 2: Using LP to Locate Current Practice but NOT to Create Visions

The second group of teachers used the learning progression to locate their practice in lower anchors on the LP (citing limited abilities of self or students). They expressed satisfaction with their practices and did not express any need to alter their practice. For example, Adam locates his teaching for dimensions 1 and 3 as a matter of fact and cites first his limitations then his students' limitations in moving beyond the lower anchor for dimension 4, working on students' ideas.

> Adam: [referencing LP dimensions # 1, 3,4] Okay, definitely more on this side, but sometimes going into that. Because I'm not pressing them [students] for why and I'm just focusing on vocab… I don't think I will feel comfortable at all to go like with this one [upper anchor of dimension 4]. I think I have to be pretty advanced before that happens. I would like to know what's going to be day to day, next week, next week. I feel like, especially with the class I've never taught before I really need to have that planned out. I'd be skeptical to just let them… Yeah. And I don't know what these students are like yet. I know they are definitely considered usually underachievers.

In talking about an elective class he will teach for the first time next year, Adam cites both his limitations as a novice teacher and alludes to the fact that students might also not be capable of engaging in more open-ended conversations.

This group was also more likely to slightly inflate their assessment of their practice (particularly on the first dimension-selecting and treating big ideas as models). We think this is part because this group of teachers did not share the same common understanding of what was meant by each cell in the LP. In the interview, as well as in other interactions from the science teaching methods course through their first year of teaching, they nominally appropriated the language from the LP as compared to the other group of teachers who had wrestled with language and ideas from these cells over the course of the previous school year.

What is interesting about this group is that a few first year teachers raised questions about where they "ought to be" on the LP or described a general desire to change practice. For example Patricia puzzles over how much information to give students prior to an investigation when locating her practice on dimension 2 of the LP and expresses a desire to shift her practice when examining dimension 1 of the LP.

> Patricia: [referencing LP dimension # 2] I am never sure how much background to give. Like I don't want to give too much and have there not be anything interesting to find out in the experiment and I don't want to give too little so that it is not connected to anything.
>
> Patricia: [referencing LP dimension # 1] But, I think this is interesting because on one hand I would say that I am here, but I want more of both of these things. I feel like in many ways I just sort of go over the vocabulary. You know, I just don't worry about it so much even though this is on the left side, I would want that to be better brought to the forefront as well as the theory.

These expressions of lack of clarity or dissatisfaction seem like potential entry points that could be capitalized on.

Learning Progressions as one of many "Vision Tools" for Advancing Teacher Practice

A second idea we developed from our initial study was that of supporting teachers through a *system* of tools rather the learning progression by itself. For example, some of our participants know that they should be engaging their students in discourses around evidence-based explanations (as described on the learning progression), but they do not know what this discourse should sound like nor how to organize it in their classroom. For this purpose we have recently developed discourse tools that support teachers in having these conversations with students and, in the process, "moving" their pedagogical performance to a more sophisticated level. These include: 1) Eliciting Students' Hypotheses to Shape Instructional Decisions, 2) Making Sense of Material Activity, and 3) Pressing Students for Evidence-based Explanations. We also consider tools such as a Big Idea Tool for determining science ideas worth teaching, Rapid Surveys of Student Thinking to assess students' ideas following each discourse, and Systematic Assessment of Student Work Tools to be critical supports for advancing one's practice.

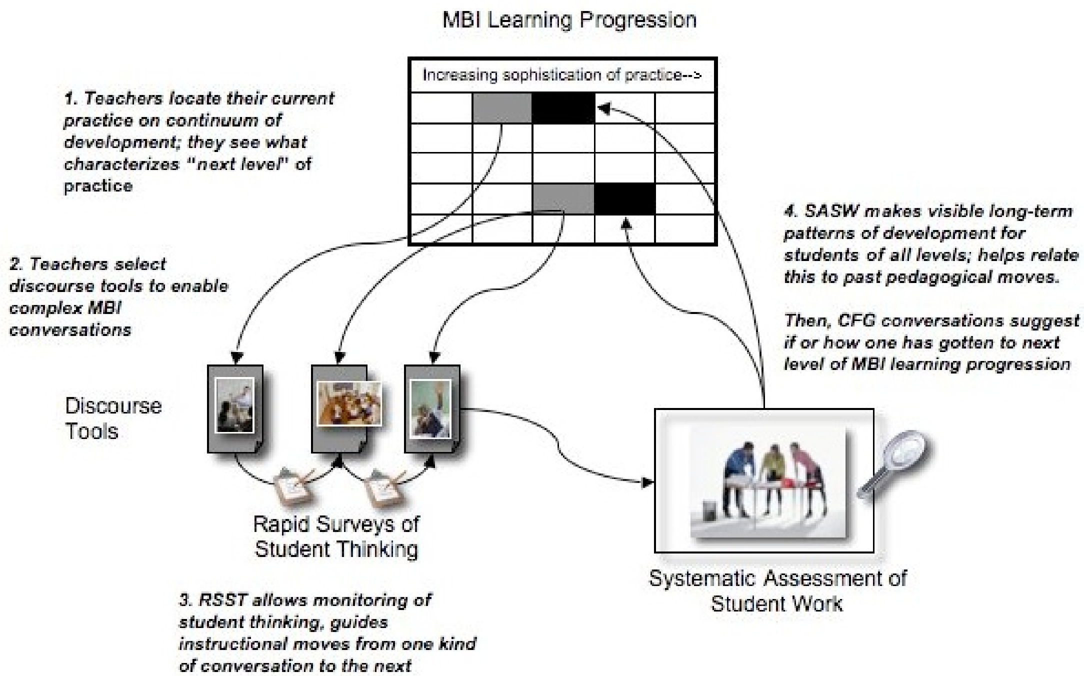

Figure 1. A system of tools designed to support ambitious science teaching.

With our current study we are examining the interactions of and influences of this suite of tools on teacher learning. To date we have only examined three of the tools in the suite—the Reduced MBI LP (at the end of the teachers' first year of teaching) and two tools from the Systematic Assessment of Student Work, SASW step 4 in the tool system (following student teaching and throughout the teachers' first year of teaching). We found that individually the SASW tools can offer powerful supports for teacher learning especially when used routinely. We used two SASW tools; one was a rubric for helping teachers analyze students' evidence-based explanations. The other was a protocol for supporting participants' collaborative inquiry around systematic analysis of their students' work. We examined teacher classroom performances on four dimensions. The one dimension of classroom performance that overlapped most directly with the use of these tools (i.e. the rubric for judging whether kids could construct evidence-based explanations) was the one area in which two-thirds of our teachers made dramatic improvements in their first year of teaching. If these two tools can support changes in practice for two-thirds of the teachers we worked with, then we are hopeful that a suite of tools will cast a broader net and help support all teachers in envisioning and enacting a sophisticated set of practices known to support student learning.

We hypothesize two important functions of the learning progression and other related tools in supporting teacher learning. First, our findings suggest that tools can be used to create visions of what is possible in the classroom. Although this was not our intention for the SASW tools, several teachers used ideas from the tools to modify their instruction, for example modifying the questions they posed to students or modifying assessment rubrics they gave to students. In this way they adopted the ideas and language behind our tools and used the ideas to envision new practices. By the end of their first year of teaching many of these ideas had made their way into the teacher's core ideas about teaching and learning. For many, the learning progression, if put in the hands of a teacher, is inherently an self-assessment tool because it asks teachers to locate their practice and assess their practice relative to more advanced practices. But it also possible that a learning progression could also be a *vision tool* that functions to guide teachers in using additional tools to close vision-to-practice gaps in their teaching.

Second, from the sociocultural standpoint, a learning progression for teachers along with other tools could form the basis of a common language that could then be used in professional learning communities to collaboratively critique and improve practice. We found that the ideas and the language in the SASW tools were taken up in a number of consequential ways. For some the language in the tools was only minimally appropriated but for others not only did they use the language of the tools to support their own images of what was possible the in the classroom but the tool supported conversations among participants during collaborative inquiries into student work thus providing a common language for teachers to use as they considered next steps in their practice.

Unanswered Questions

Regarding the development and use of our MBI learning progression we have the following questions, which we hope to answer in the next phase of our research:

1) How should a teacher learning progression be sequenced? Our full learning progression is based on a "logical" pedagogical sequence—planning, executing and reflecting—but this sequence does not reflect how all participants made adjustments to their practice. Yet most participants, through reflection, made changes to their planning and practice. Should this sequence be reflected in the learning progression? Additionally, we structured our reduced learning progression around four dimensions of ambitious science pedagogy emphasized in the science teaching methods course. Will this framework resonate better with teachers? Will they be able to switch to a different structure and more detailed learning progression as their learning progresses? What might different sequences afford in terms of teacher learning?

2) When is it appropriate to introduce a full learning progression to early career teachers? We have found that with other tools we have developed, timing is important. Teachers will most likely study and use the tool when it is given at a time that matches their skill level and that provides an appropriate challenge.

3) How can the learning progression reflect teachers' complex learning patterns rather than linear development? Participants had different criteria that they were interested in focusing on at different times. Additionally, participants' movement toward more sophisticated practices on one criterion actually spurred movement to more sophisticated levels on another criterion. How might this be reflected in a learning progression?

4) How can the LP account for teachers' understanding of when it is appropriate to use certain practices for novice students based on context (age and experience of the students, subject matter, placement of an inquiry during a school year)? At issue is the fact that we might observe teachers purposefully doing less advanced practices with their students in attempt to lay the groundwork for more advanced practices. As is our learning progression does not account for planned shifts in practice over time. A few of the teachers we worked with also called attention to this dilemma as they considered their practice in relation to the reduced MBI LP.

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For more information about our work with teachers see: http://depts.washington.edu/mwdisc/
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Full MBI Learning Progression

	Criteria	Increasingly Sophisticated Facilitation of Model Based Inquiry→		
Pre-planning for MBI: Identifying Models and Explanations	**1.** Identifying inquiry-worthy ideas (big ideas in science, potential data sources, and interest to students)	**1.1.1.** T. has a topic oriented approach to inquiry. A "thing" rather than a process or theory is object of study (i.e. cells). **1.2.1.** T. considers only first-hand experimental studies to generate data and evidence for inquiry. **1.3.1.** Relevance to students is not a lens T. uses when assessing the worthiness of study OR relevance not incorporated into the curriculum.	**1.1.2.** T. selects processes (i.e., osmosis) to be the focus for an inquiry. **1.2.2.** T. recognizes various types of inquiries and data but does not use these types in practice nor teaches Ss. how each explicitly relates to model development. **1.3.2.** T. uses relevance as initial hook to interest students in topic of inquiry.	**1.1.3.** T. selects a theory as focus for inquiry (i.e., evolution, cell theory, environmental interrelationships). **1.2.3.** T. recognizes secondary data as sources of evidence (using maps of earthquakes, fault lines) or combines both 1st hand data collection/ analysis and secondary data analysis to enrich inquiry (i.e., examining data from a stream collected by a local organization and building a stream table in the classroom) Selects comparative or correlative studies (with primary or secondary sources) OR uses a descriptive study as a pre-cursor to a comparative or correlative study. Plans to make explicit to students various types of inquiry and variations in the way each relates to models. **1.3.3.** T. elicits Ss. ideas to determine how science ideas could be relevant to Ss.—personally, locally and/or culturally. Relevance interwoven throughout inquiry and broader curriculum.
	2. Identifying how an inquiry can be about the big idea/model(s)	**2.1.** Inquiry is about a thing (i.e. batteries & bulbs) without being about a big idea (i.e., energy) or a model (i.e., diagram of energy transfers).	**2.2.** Inquiry is about unproblematic science processes (not as a set of models) or about methods used to do the inquiry. T. cannot re-envision existing inquiry or curriculum in terms of models.	**2.3.** Inquiry is about a big idea as a model or set of models. T. identifies "this is model of X" in terms of big ideas (i.e., sees difference between model of battery vs. model of energy, or, model of a pond vs. model of nutrient cycling). T. envisions how big ideas can be represented as models and examines curriculum to identify which models help students understand scientific processes. T. plans to begin unit by introducing a phenomenon on which instruction, models, and inquiry can be based.
	3. Assessing the nature and function of models being used	**3.1.1.** T. selects a model that is a pictorial or physical replication of a "thing" considered to be real. **3.2.1.** T. uses models to simplify, illustrate, or show something.	**3.1.2.** T. selects models that portray observable processes and systems or a mathematical representation or set of rules. T. portrays models as having multiple representations – there is no singularly "correct" model. **3.2.2.** T. uses model to facilitate understanding, help Ss understand what an expert knows, and/or to separate out effects and variables of a complicated phenomenon.	**3.1.3.** T. selects model that portrays theoretical processes and relationships; the model represents ideas rather than "things." T. portrays model as fallible because of the creative nature, logical limits, and underlying assumptions. T. considers the model (and/or components of the model) as investigate-able, revisable. **3.2.3.** T. uses model for two kinds of working value: a) It is generalizable and can serve to make predictions. b) It facilitates new insights into relationships, generates novel hypotheses and questions for inquiry.
	4. Planning and designing lessons with attention to Ss' engagement with models in an inquiry context	**4.1.1.** T. elicits Ss' ideas about a topic, these left as a brainstormed list of things, not like thoughtful, tentative explanations of scientific processes. **4.2.1.** T. does not intentionally plan to test ideas as models (i.e., T gives Ss Earth/Sun models to test the influence of the angle of the earth on the seasons). **4.3.1.** T. uses inquiries over a unit/ academic year, which tend to be confirmatory. **4.4.1.** T. plans to use scientific forms of talk/reasoning but does not provide scaffolds for Ss to do the same	**4.1.2.** T. elicits Ss' ideas about a scientific process but not about science ideas as models. **4.2.2.** T. plans to instruct use <u>only</u> existing models of value to a scientific domain OR focuses <u>only</u> on student-constructed models without engaging Ss in models relevant to the discipline. **4.3.2.** T. does not provide enough guidance such that the focus of the inquiry is on material activity rather than targeted learning about a topic. OR T. does not gradually turn over more responsibility to Ss over the course of an academic year. **4.4.2.** T. plans to teach everyday ways of talking about science but do not scaffold transitions between these and scientific ways of talking and reasoning	**4.1.3.** T. elicits <u>all</u> Ss' ideas about scientific models and/or elicits ideas to create a S-generated initial model. T. adapts instruction based on these ideas and chooses to emphasizes some initial ideas as leverage points for advancing content within the inquiry. **4.2.3.** T. plans to use both existing scientific and student-constructed models together, merging the two. There is a balance between teacher- or domain-generated and student-generated models (i.e., T. plans to have Ss first hypothesize about interaction in a pond system, then incorporate existing models of nutrient cycles, then perform inquiry based on class model; T. plans to have Ss investigate 3 models of the causes of the seasons and weigh evidence for each rather than just testing one parameter like angle of earth). **4.3.3.** T. makes decisions about level of guidance students need based on Ss' background experiences and sequencing during the year (open, guided, structured, confirmatory). **4.4.3.** T. assesses scientific language demands in the lesson and plans classroom conversations about the nature of models and model-based explanations and how these forms of scientific talk/reasoning differ from conversational/everyday talk/reasoning
Guiding Classroom Discourse: Pressing for Explanation	**5.** Identifying full scientific explanations and Ss' approximations of these explanations	**5.1.1.** In planning, T. does not identify full explanation(s) for phenomena being investigated. T. only plans for Ss to discuss <u>what happened</u> during the inquiry. **5.2.1.** T. does not access Ss' initial explanations in ways that inform upcoming instruction.	**5.1.2.** T. identifies explanations for scientific phenomena ahead of time but unobservable/theoretical components are tangential. T. only plans for and has Ss discuss <u>how something happened</u> during the inquiry. **5.2.2.** T. accesses Ss prior knowledge, common pre-conceptions and naïve ways of understanding phenomena but these are not used to adapt instruction.	**5.1.3** T. envisions possible models and explanations for <u>why something happened</u>. T. orients inquiry toward particular scientific models so that guided instruction about key concepts ensured. T. imagines levels of sophistication of possible explanations and guides Ss discourse toward more coherent, evidence-based explanations. T. constantly assesses student explanations before, during, and after inquiry for students of all achievement levels. **5.2.3.** T. elicits Ss' ideas about tentative hypotheses and adapts instruction to explicitly unpack Ss' preconceptions and alternate ideas for students of all achievement levels. T. anticipates components of a model that may be conceptually challenging for students.
	6. Setting up and gathering data: Aiming discourse toward a "why" explanation	**6.1.1.** T. set up for inquiry and data collection focuses on directly observable not underlying causal components. **6.2.1.** While circulating T. presses for ideas about data collection or experimental design and for "what" explanations without asking for "why".	**6.1.2.** T. set up for inquiry and data collection is purposeful but not enough focus placed on rich explanatory models. <u>After</u> an inquiry, models and explanations are used as a culminating or finished product that are revealed to Ss or as an outcome of inquiry. <u>After</u> an inquiry, T. builds in background knowledge of key science ideas or facts but not as part of explanatory models. **6.2.2.** While circulating T. presses for descriptions of how data was collected or how a phenomenon occurred.	**6.1.3.** T. set up for inquiry and data collection is purposeful and highlights tentative explanatory models as the basis for investigation and data collection. T. uses model as a touching point before, during and after an inquiry. T. strategically builds in background knowledge of key science ideas and models before, during and following an inquiry. Just in time instruction is used for fine-tuning Ss understanding of complex models. **6.2.3.** While circulating, T. poses tasks and questions that press Ss to explain patterns in data and to explain phenomena. T. can identify gaps/contradictions in student thinking related to an explanatory model (ex. noticing that Ss are only understanding temperature and volume, not pressure, when investigating the ideal gas laws).

	7. Ongoing press for coordinating evidence with explanation	**7.1.1.** Focus on experimental design, measurement, data collection. Data is not discussed as evidence because focus is not on interpreting data in terms of models and explanations **7.2.1.** T. asks Ss to describe what happened; the press might be for a describing, summarizing, or restating a pattern or trend in data without making a connection to any unobservable/ theoretical components. **7.3.1.** T. does not address uncertainty, counterarguments, or error.	**7.1.2.** T. focus is on evaluating data and on explanation but not simultaneously. Unobservable/ theoretical components are only addressed tangentially. **7.2.2.** T. helps Ss construct a logical argument including a claim, evidence, and some reasoning. **7.3.2.** T. tangentially addresses uncertainty or error. OR T. places too much focus on error such that the press for explanation is lost in a press for describing flaws in the experimental design.	**7.1.3.** T's focus is on coordinating evidence with explanations. T. can assess students' discourse in the moment and press for why explanations (move students from a what→why or how→why explanation) **7.2.3.** T. helps Ss explain why something happened by writing claims that justify the link between observable data and unobservable/ theoretical components. **7.2.3.** T. helps Ss construct an argument that takes into account counterarguments, alternative hypotheses, variance and error.
Guiding Classroom Discourse: Evaluating and Revising Explanatory Models	**8.** Revisiting or revising explanatory models based on evidence	**8.1.** No coordination of evidence and models. T. may revisit the hypothesis but this is only done for the purpose of confirming or disconfirming the hypothesis.	**8.2.** T. assists Ss in revisiting explanatory models but the focus is not on enriching or revising the model, simply reviewing the connection between evidence and the part of the model that was investigated.	**8.3.** T. assists Ss in enriching and revising models by pulling in background information that is complementary to evidence collected and targeted scientific theories. T assist Ss through multiple iterations of revisiting/revising models and explanations. T. places sense-making conversations about patterns in the data and explanations after the first round of data collection such that inquiries can be revised to be more rigorous in terms of method and theory. T. also helps Ss see how their evidence + explanations evolved and how they make sense with more sophisticated models or with multiple models. T. lead Ss in conversations about the tentative nature of data and Ss discuss one another's data in terms of models. T. also lead Ss in conversations in which students compare and contrast models and explanations
	9. Application of model/extension of model	**9.1.** T. ask Ss to write a new question based on the inquiry but do not press for the question to focus on an explanation. T. does not differentiate between questions about experimental design (such as changing one variable) and questions aimed at the underlying mechanisms.	**9.2.** T. asks Ss to write a question or make predictions without asking students to consider both evidence from the inquiry as well as the explanations.	**9.3.** T. leads Ss in conversations about designing new questions and predictions that are informed by both evidence and model-based explanations following an inquiry. T. also leads conversations about explanations and their relative attributes/generalizability and limitations.
	10. Assessing students' understanding about models	**10.1.1.** T. uses scientific models with Ss but does not lead explicit discussions about the nature and function of models with students. **10.2.1.** T. generally assesses Ss use scientific language; evaluating Ss science vocabulary use	**10.1.2.** T. leads discussions about the nature and function of models but it is not in the context of an inquiry. **10.2.2.** T. assesses if Ss can use scientific language; evaluating the depth of Ss explanations or depth of descriptions of how and why models are used	**10.1.3.** T. assists Ss in understanding about science models as objects of critique and revision, and how models are used in science. T. helps Ss move from particular to more general models with a focus on understanding the general nature and function of models. **10.2.3.** T. assesses individual Ss scientific language development, tracking development of the construction of scientific explanations, use of representational language and ability to generalize and theorize.
Reflective Practice	**11.** Evaluating one's MBI pedagogy through examination of student work	**11.1.1.** T. examines Ss work for "right and wrong" answers, not nuanced understandings of the content. Does not differentiate between grading and examining student work for understanding. **11.2.1.** While examining Ss work, T. fails to see ways in which scientific models could have been a part of their investigation. **11.3.1.** T. see examination of Ss work as unproblematic and not informative to their practice.	**11.1.2.** T. examines Ss work for nuanced understandings of the content but not in the context of models or theories. **11.2.2.** While examining Ss work, teachers have a limited view of which scientific models could have been a part of their investigation. **11.3.2.** T. sees examination of Ss work as informative to their practice. Take-aways are limited to adjustments in tasks, such as re-wording a prompt, rather than ways in which lessons can be re-worked to help Ss understand explanatory models.	**11.1.3.** T. examines individual Ss work for nuanced understandings of models or theories. **11.2.3.** T. asks questions of one's practice when examining Ss work (ex. What might be going on here that I was not aware of? Are there some subtle changes in the Ss work that I am not seeing? What more could I do to challenge students at all levels of ability? What was the nature of the instruction or questions on the assignments that might have influenced my Ss staying at the same levels? What could I do to better support under-achieving students?) **11.3.3.** T. follows through on what he/she would like to change about their teaching.

Reduced MBI Learning Progression

1) Selecting and treating big ideas as models

Topic focus	Process focus	Theory focus
In class the teacher's press is on describing, naming, labeling, identifying, using correct vocabulary.	In class the teacher chooses to focus on "what is changing" or how a change happens within a condition.	Teacher has students focus on unobservable and theoretical processes or the relationships among science concepts.

2) Working with science ideas in the classroom

Scientific Method focus	Discovering or Confirming Science Ideas	Hypothesizing about observations and descriptions	Forwarding science ideas to work on	Epistemic Fluency/ MBI focus
Teacher asks students to identify variables and describe the experimental set-up. Science concepts are played down to afford time to talk about designing experiments. Talk with students is about error and validity.	Teacher has students discovering science concepts for themselves (without much background ahead of time) OR Teacher has students use an activity as a "proof of concept." Does not include hypothesizing about these observations and descriptions.	Teacher asks students to predict what they will observe happen in the investigation. Focus is on describing how variables change outcomes.	Teacher foregrounds key science concepts and asks students to use an investigation to make sense of the concepts. Focus is on sense making between data and developing science concepts.	Teacher set up for inquiry and data collection is purposeful and highlights tentative explanatory models as the basis for investigation and data collection. Teacher uses model as a touching point before, during and after an inquiry and strategically builds in background knowledge of key science ideas and models before, during and following an inquiry.

3) Pressing for explanation

"What happened" explanation	How/ partial why something happened explanation	Causal explanation
Teacher asks students to provide a description of a scientific correlation.	Teacher emphasizes a scientific correlation and how it helps a system work.	Teacher has students use theoretical underpinnings to tell a causal story of what happened. Teacher also unpacks/scaffolds learning about the nature of scientific explanations with students.

4) Working with students' ideas

Monitoring, checking, re-teaching ideas	Elicits Ss' initial understandings	References Ss' ideas & adapts instruction
T. engages in 1-on-1 tutoring, uses mainly IRE in whole class conversations, and uses students ideas to check for understanding (got it/don't got it)	T. elicits Ss' initial hypotheses, questions, or conceptual frameworks about a scientific phenomenon.	Within and across lessons T. uses Ss' ideas to reshape the direction of classroom conversations, engineer productive classroom conversations, or pursue Ss' line of thinking across multiple lessons.