# A Learning Progression of Elementary Teachers' Knowledge and Practices for Model-Based Scientific Inquiry

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### *Abstract*

Model-based inquiry is a core component of science and a central part of scientific literacy; it is critical to reform-based science education efforts that emphasize students' participation in scientific practices (Duschl, Schwingruber & Shouse, 2007). Model-based inquiry is an instructional approach in which learners engage in scientific inquiry, focused on the creation, evaluation, and revision of scientific models that can be applied to explain and predict the natural world. Yet, few elementary school teachers know how to successfully engage their students in this practice or are supported to teach it through tools such as curriculum materials.

How might we help support teachers learn to engage their students in scientific practices? One promising approach is to design a learning progression of teachers' knowledge and skills for enacting scientific practices around critical stages in their career – preservice, induction and proficient. A learning progression must account for empirical evidence as well as target important dimensions of teacher knowledge and practice. This developmental information might enable us to determine critical aspects of learning to engage students in scientific practices and better target aspects in teacher education programs and curriculum materials.

This paper proposes a theoretical learning progression of teacher's knowledge and practices around model-based inquiry. It is based on prior work (Davis et al., 2008; Mohan, 2008; Schwarz & Gwekwerere, 2007; Schwarz et al., 2008; van Driel & Verloop, 1999, 2002; Windschitl, Thompson, & Braaten, 2008) as well as hypothesized milestones. This learning progression targets dimensions of teacher knowledge including teachers' understanding the nature and purpose of science, their understanding of student learning, and their views of effective science teaching. It also targets teachers' pedagogical practices such as lesson sequencing, setting norms in classroom conversations, and working with students' ideas. These dimensions are likely to play an important role in teacher development around science practices and may function as leverage points for predicting and supporting successful teacher practice.

## Scientific Practices, Elementary Teachers, and Model-Based Scientific Inquiry

Current work in science education has emphasized the importance of engaging learners in scientific practices — social interactions, tools, and language that represent the disciplinary norms of how scientific knowledge is constructed, evaluated, and communicated (Duschl, Schweingruber, & Shouse, 2007). Through scientific practices such as scientific inquiry, modeling, or explanations, learners come to understand the nature and uses of disciplinary knowledge (AAAS, 1990, 1993; NRC, 1996). However, scientific practices require fundamental shifts in classroom norms and activities (e.g., from listening to a teacher provide the correct scientific information, to collecting and interpreting data and connecting patterns in data with models and explanations). For effective participation in scientific practices, teachers and students need sustained guidance and support with the practices as well as the scientific ideas addressed by the practices. Such support may include curriculum materials, teacher education, and on-going professional development (Duschl et al., 2007).

Supporting teachers as they learn how to engage their students in scientific practices is critical for shifting norms and activities in the science classroom. To enable this shift to occur, teacher education must help teachers understand and appropriate productive teaching practices. Furthermore, elementary teachers play a critical role in early science learning – establishing the foundation for learners that can enable – or constrain – them from learning to participate and appropriate scientific practices. But few of them have the opportunity to learn about rich scientific practices such as model-based inquiry as those practices have frequently been targeted for middle and high school science teaching. In addition, elementary teachers face the additional challenge of teaching multiple subject areas and benefit from additional support.

Model-based scientific inquiry can serve as an appropriate and productive scientific practice for elementary teachers and their learners. Model-based scientific inquiry is a core component of science and a central part of scientific literacy. It involves engaging in scientific inquiry with a focus on the creation, evaluation, and revision of scientific models that can be applied to understand and predict the natural world (Lehrer & Schauble, 2000; Schwarz & White, 2005; Stewart, Cartier, & Passmore, 2006; Windschitl & Thompson, 2006). In using the term scientific model, I refer to representations that abstract and simplify a system to make its central features explicit (Gobert & Buckley, 2000). Scientific models are tools for embodying or expressing aspects of scientific theories and patterns in empirical data in a form that can be used to illustrate, explain, or predict an object or phenomena – for example, to characterize what happens as time passes or as events occur. Scientific models can range in form from physical representations (like a globe) to diagrammatic models (life cycle of animals; particle model of evaporation), to computational and mathematical models. Models are essential components and products of scientific inquiry as well as essential tools for scientific reasoning.

A model-based inquiry instructional approach is one that engages learners in inquiry around the development and use of models. For example, in order to investigate the question "What causes a shadow?" students could construct an initial model that might entail a picture of a shadow caused by a light and an object. They might then investigate conditions of existing shadows as well as the conditions needed to produce shadows, motivated by questions that arose when trying to figure out what to put into their diagrams. Those data would be analyzed for patterns and then used as evidence to support or disprove aspects of the model. In this case, the model could be refined to include a surface on which the shadow is projected, a light source that emits direct light rather than diffuse light, and an unblocked path for that light to travel. After revising those models to account for patterns in data and canonical scientific constructs such as the notion of light traveling as light rays, those models could generate multiple explanations for other phenomena such as why clouds sometimes make shadows or the most effective ways to play shadow tag. A model-based inquiry approach also includes a focus on understanding the nature and purpose of model-based inquiry such as helping learners understand that model-based inquiry is a dynamic process that involves iteratively revising models to be consistent with theory and evidence and that models can be used to predict and explain multiple phenomena in the natural world (Schwarz & White, 2005; Schwarz, Reiser, Davis, Kenyon, Acher, Fortus, Swartz, Hug, & Krajcik, 2008).

Thus, model-based inquiry encompasses the investigative nature of science as well as the product of the investigation – the models that that can generate multiple predictions and explanations about the world. Furthermore, focusing on modeling can help learners develop their scientific literacy by building subject matter expertise, epistemological understanding, and practices and skills such as systems thinking (Lehrer & Schauble, 2006; Lesh & Doerr, 2000; Schwarz & White, 2005). A pedagogical approach that focuses on model-based scientific inquiry also has the potential for helping teachers understand more about science, science practices, and the nature of science (Schwarz, Meyer, & Sharma, 2007). Further, model-based inquiry can support an effective reform-based vision for science teaching as an alternative to common discovery or didactic approaches to teaching elementary science (Roth, 1991) while providing a beginning repertoire of pedagogical approaches and strategies (Schwarz & Gwekwerere, 2007; Schwarz, 2008).

Nonetheless, most teachers have limited experiences and knowledge about scientific modeling or model-based inquiry (van Driel & Verloop, 1999, 2002; Windschitl & Thompson, 2006). Teachers often see models as useful for teaching information about scientific content, rather than as tools within a scientific process that can help learners understand the nature of science (Crawford & Cullen, 2004; Henze, van Driel, & Verloop, 2007; Justi & Gilbert, 2002) or as thinking tools that can advance students' model-based reasoning (Harrison, 2001; Henze, van Driel, & Verloop, 2007). Furthermore, when teachers do engage their own students in modeling, there is much variation of use (Harrison, 2001) and limitations on the epistemological richness of the pedagogy (Justi & Gilbert, 2002) such as simplifying model-based inquiry to a variation of the 'scientific method' (Windschitl & Thompson, 2006). While several science educators have worked with teachers in learning about and using model-based inquiry (Crawford & Cullen, 2004; Justi & Gilbert, 2002; Schwarz, & Gwekwerere, 2007; Windschitl & Thompson, 2006; Windschitl, Thompson, & Braaten, 2008), few have focused on elementary teachers in understanding and using model-based inquiry, though there is evidence that such an approach can be successfully used (Davis, Kenyon, Hug, Nelson, Beyer, Schwarz & Reiser, 2008; Schwarz & Gwekwerere, 2007).

The goal of this work is to help teachers learn about and productively engage their own students in model-based inquiry and to determine how beginning elementary teachers learn to engage their students in model-based inquiry at different stages in their own development. In order to address these goals, this research proposes a learning progression characterizing teacher development around model-based inquiry, guided by some empirical studies of teacher learning. A validated learning progression could potentially inform future teacher education work and how to support reform-based science practices.

## A Learning Progression of Beginning Teachers for Model-Based Inquiry

By learning progression, I refer to a trajectory which specifies how knowledge and practices can be built over time which articulates successively more sophisticated versions of knowledge and practices (Duschl et al., 2007; Smith, Wiser, Anderson, & Krajcik, 2006). A learning progression of teachers would articulate a potential trajectory that learning can follow, building on the understandings and experiences that teachers bring with them. It does not represent a developmental stage model or a unique developmental path but one of a number of paths learning can take with support.

While such trajectories have primarily focused on student learning, their potential advantages for clarifying and tracing important knowledge and practices over time make them appealing for studying the development of other expertise such as teaching. A teacher learning progression could provide a critical tool for assessing teacher development and designing effective support for teacher learning and practice – potentially improving teacher quality, informing teacher education, and developing new theories on teacher learning. Teacher progressions might also inform and be informed by student learning progressions.

Teacher education has a long history in characterizing teacher development over time (e.g., Berliner, 1994; Darling-Hammond & Bransford, 2006; Feiman-Nemser, 2001; Fuller, 1969). Most of this work, however, has characterized general pedagogical practices and dispositions rather than the development of teaching expertise in specific content areas. Additionally, recent advances in designing student learning progressions (theorizing their nature and developing assessment techniques) have enabled teacher learning progressions to become more feasible (Windschitl et al., 2008). Improving teacher quality in science is a high priority issue that can now leverage off new science education emphases, advances in student learning progressions, and research in teacher education.

One critical aspect is to determine what dimensions to target for such a progression. What elements of teacher knowledge and practice are critical for effectively teaching model-based inquiry? Which of those elements give the most leverage for learning how to support teachers in learning how to engage in such a practice? Furthermore, what elements naturally emerge from classroom environments and teachers' development? I will discuss these issues further below.

## Theoretical Framework – Teacher Learning and Progression Dimensions

Before outlining the critical dimensions of teacher knowledge and practice, I briefly outline my theoretical assumptions for teacher learning. This research adopts a socio-cognitive approach that teacher learning takes place within multiple learning communities and involves learning about and developing knowledge of content, learners, and pedagogy; developing and refining teaching practices (e.g., how to engage in particular pedagogies); building and using a repertoire of tools (e.g., learning theory, instructional models, curriculum materials etc.); and developing one's visions, dispositions, beliefs, goals and identities for teaching (Hammerness, et al., 2005). Learning occurs when teachers are encultured into communities of practice (e.g., reform-based science teaching, school-based science teaching) and appropriate the tools, practices, and discourses of those communities (Putnam & Borko, 2000; Wenger, 1998). Preservice elementary teachers bring their prior knowledge, beliefs, goals, and identities into these communities of practice (Abell, Bryan & Anderson, 1998; Van Zee & Roberts, 2001). These elements shape teacher learning and play an important role in how teachers appropriate new practices, use tools such as instructional frameworks and curriculum materials (Schwarz et al., 2008), and interact with students.

What are critical elements of teacher knowledge and practice for a learning progression? There have been thoughtful reviews and theories about such dimensions within science teacher education (e.g., Davis, Petish, & Smithey, 2006) and teacher education in general (e.g., Darling-Hammond & Bransford, 2006; Feiman-Nemser 2001). Taken together, these categories encompass teacher knowledge and views, teacher instructional practices, and the contexts, communities, and tools in which teachers learn and teach (See Table 1 below). Within each of these general categories are more specific categories of knowledge and practice. For example, a teacher's knowledge and views might include knowledge of the subject matter, knowledge of learners, views of effective teaching, as well as identities, dispositions and orientations to teaching. Teachers' instructional practices generally include practices within a teaching cycle – planning, teaching, assessing and reflecting practices. Those practices address the content, the learner, and the classroom environment (Mikeska, Anderson & Schwarz, in press). Finally, the context, community and tools include aspects such as the learning goals from the state, district and school, the curriculum materials, and school and student norms.

It is important to note that these categories of teacher knowledge, practice and context are not independent from one another. A teacher's knowledge and views will significantly impact her instructional planning and assessment practices. Similarly, a school culture and curriculum materials will impact what and how she teaches the material. In Table 1, the example knowledge and practices in red font are that are targeted by the hypothetical learning progression presented at the end of this paper – due to the data and findings available as well as their hypothesized role in model-based inquiry.

| **Categories of Teacher Knowledge, Practice, and Context** | **Examples of Knowledge, Practices and Contexts** |
|---|---|
| Teacher knowledge and views (influenced by present and past experiences and situation in context) | Knowledge of science and model-based inquiry<br>Knowledge of learners<br>Views of effective science teaching<br>Identity and disposition (e.g., how one positions oneself with respect to students, materials, colleagues) |
| Teacher instructional practices (professional teaching cycle including planning, teaching, assessing and reflecting) | Planning – (content) sequencing around big ideas including those that enable the patterns in the phenomena to be accessible in the classroom before an explanation is introduced<br>Teaching – (students) working with children's ideas in class conversations including those that help them make sense of patterns in phenomena and reason about ideas<br>Teaching – (classroom environment) establishing and enacting classroom norms including those of sharing ideas and valuing evidence<br>Assessing – monitoring children's evolving ideas and practices<br>Reflecting on those enactments |
| Context/Community/Tools | Learning goals<br>Curriculum materials<br>School norms and culture (e.g., creative or innovative pedagogy, emphasis on learning vs. classroom management) |

Table 1 – Elements of teacher knowledge and practice that might serve as dimensions of a teacher learning progression

## Brief Context & Data Sources

To determine important dimensions and to construct cells within this learning progression, I used outcomes from multiple studies. In particular, some of this work is based on preservice teacher outcomes from studies within my own methods courses (Schwarz & Gwekewere, 2007; Schwarz, Meyer & Sharma, 2007). Additional outcomes on proficient teachers derive from current work within a project developing a student learning progression of modeling practices (Davis et al, 2008; Schwarz et al, in press).

Outcomes reported from the preservice elementary teacher studies have derived from analysis of written pre-post assessments, lesson plans and interviews. Evidence from proficient teachers derives from analysis of written pre-post assessments, interviews, and video enactments of model-based inquiry teaching.

## Patterns from Preservice Teachers' Learning about Model-Based Inquiry

In order to determine where teachers begin in their learning how to teach scientific practices such as model-based inquiry, I report on results from several studies with preservice teachers learning about model-based inquiry. These studies have taken place within the semester-long introductory methods course at Michigan State University. What did such students reveal about their knowledge and views as well as their instructional practices around model-based inquiry?

In one study I conducted with preservice teachers engaging them in model-based inquiry science lessons and learning about and planning a lesson around modeling and simulation software (Schwarz, Meyer, & Sharma, 2007), analysis of their in-class work, pre-post-tests and interviews indicated that preservice teachers struggled to make sense of modeling-centered scientific inquiry. For example, at the end of the semester, they held vague notions of scientific models as "something that takes a broad idea and paints a picture for you of a difficult concept, or break something down into parts. It's a way of helping understand something that might be a little more difficult" rather than a more specific notion of a scientific model as a representation that can help externalize aspects of theories which can then make those theories accessible and testable. Preservice teachers also had difficulty understanding how inquiry and modeling were related to one another or how the computer modeling tools could be used to help students learn about or participate in the practices of science. When asked during an interview about the similarities between science and model-building, for example, rather than stating that science is an inquiry process that often involves model building, testing, and revising, one preservice teacher replied, "I don't know. I guess it [science and model-building] is very similar. I don't know. I have no idea. I know there is a correlation there, but I really don't know how."

In a different targeted study with additional support for lesson sequencing for explanation-based and model-centered inquiry, we found that while preservice teachers struggled with understanding models and modeling, they were able to use and adapt a model-based inquiry framework (EIMA) in constructing and sequencing lesson plans (Schwarz & Gwekwerere, 2007). We also found that this framework enabled them to shift their views of effective science teaching from discovery and didactic oriented towards guided inquiry.

For example, in the pre-test, the majority of preservice teachers (76%) began the semester by designing lessons that were primarily activity-driven or didactic in nature compared to 8% who designed inquiry or partial-inquiry-based lessons. At the end of the semester, half of the lessons (50%) were coded as guided inquiry or inquiry-based while 42% of the lessons were coded as didactic or activity-driven in nature. For example, one preservice teacher wrote an activity-driven and didactic lesson on her pre-test that involved students observing physical models of molecular motion and then drawing a picture or using manipulatives to show the model. This lesson was coded as both activity-driven and didactic as it involved the teacher presenting some information and students participating in 'hands-on' activities used for verification or discovery of the concepts. On her post-test, the preservice teacher designed a modeling-centered inquiry lesson plan that involved that teacher posing a question about why we have seasons, having students construct an initial model with globes to answer why we have seasons, conducting research on why we have seasons, having a science talk about why we have seasons, and revisit their initial model to determine if it could accurately explain why we have seasons. We coded this post-test as modeling-centered inquiry in the sense that there was a question posed (Engage), research to determine how the seasons occur (Investigate), and the generation of causal explanations using models (Model/Explain).

With respect to scientific modeling, we found that while preservice teachers further incorporated models within their lessons-plans at the end of the semester, they did so in some unanticipated ways. For example, while they asked students to construct or use models that embodied patterns in data or causal explanations, some preservice teachers asked students to construct models of typical objects or phenomena. Examples of such models include a model cloud when studying clouds and weather or a model lever or wheel and axle when studying simple machines. Analysis of preservice teacher journals indicates that while some preservice teachers made progress in better understanding the nature of scientific models and how to incorporate them into their lesson plans, others did not.

These data, along with others (e.g., Davis et al, 2008; Kenyon et al, 2008) indicates that overall, pre-service teachers' knowledge about the nature of science with respect to scientific modeling (from a methods course) was difficult to improve, though they made progress in understand models as a tool for inquiry, using a lesson sequencing tool and the instruction in the methods course to both change their views of effective teaching and learn how to design some lesson plans and sequences that address model-centered inquiry.

Findings indicate that some of these outcomes are dependent on the curriculum materials and cooperating teachers' classroom as well as the content knowledge and repertoire of activities that preservice teachers' have available to them. Early on in their practice, they are just starting to develop their repertoire to help students think about patterns in observations and reason around models. We have little information about enacted practice related to preservice teachers as the preservice teachers in our stage of the program have relatively few teaching experiences in the classroom and those experiences and heavily scaffolded by the classroom placements and curriculum.

### Patterns From Experienced Teachers Teaching Model-Based Inquiry

In order to develop a learning progression, we must compare preservice teacher learning with outcomes from experienced teachers learning to become proficient. Information for this aspect of the learning progression derives from analysis of data from a project engaging elementary and middle school learners in model-based inquiry (Schwarz et al., in press). Teachers from those classrooms were given professional development around enacting model-based inquiry as well as 8-week model-based inquiry unit on evaporation and condensation (Schwarz & Baek, 2008). The information reported here derives from two 5th grade teachers in the project who had been teaching 7 and 8 years in local suburban elementary schools and had strong backgrounds in science (teachers J and P). Model-based inquiry was a new approach for both teachers.

Analysis of their written pre-post assessments on models/modeling, interviews, as well as their enactments of the curriculum materials designed for the project points to key elements of their knowledge and instructional practices. For example, after a year with the project, both teachers had a moderately sophisticated understanding of models and modeling and were working on shifting classroom norms around peer interactions, sources of authority and evidence.

Teacher J began the study thinking of models as a "set of diagrams and visual representations" that did not include many things such as causal rules, theories or equations. In her post-test a year later, she broadened her ideas of models to things that can "represent a real scientific concept or phenomena." More importantly, teacher J thought of models in the pre-test as being useful "to provide real examples/experiences with something more familiar to students." In contrast, she wrote on her post-test that models were useful to "help [scientists] understand scientific concepts and real phenomena" and useful for teachers to help students "understand scientific concepts and real phenomena" and to "help them understand how things work/operate." This example indicates how she has moved to thinking of models as tools for illustrating concepts easier towards inquiry tools for scientists and tools for students to aid in their causal thinking. This response is echoed in another question asking how she uses models in her science teaching. In the pre-test, she wrote "building a series of circuits to illustrate how a house is wired." In the post, she wrote "… a solar still model to help kids understanding concepts of evaporation and condensation … and we introduced tools to aid in this understanding." Evidence from her pre/post assessments also indicates how she has a better understanding of how models are constructed (from including all parts of the target object to parts useful for understanding how that target object does what it does) as well as critiquing models with specific kinds of evaluation criteria and evidence that pointed out the strengths and weaknesses of the representations rather than just their accuracy. Finally, when asked about how she engages her students in scientific modeling, she stated in the pre-test that modeling was a "getting the kids to build their own models is a good way to engage them. Also, setting models up in the classroom will give them more incentive to become engaged." In the post-test, she wrote that she begins "with a driving question. One overarching theme and one giant question. In addition, we revisit the question daily-weekly an provide answers and add more questions. Students misconceptions are weeded out this way and their investigation is enriched by giving them ongoing validation of their own scientific concepts." This perspective is one that moves from thinking of motivation and engagement towards thinking of modeling as an inquiry process that advances students' ideas.

Teacher J's instructional practices early on paid a lot of attention to student ideas and strongly guided them towards scientific accurate ones in a teacher-student conversation. Those conversation were based on scientifically accurate ideas – often from authority sources such as textbooks. A year later, her approach using the model-based inquiry curriculum enabled students to express their own models, compare the ideas in the models with empirical evidence and one another, and advance those ideas. There were nonetheless still some challenges in the classroom practices. Students had difficultly attending to the empirical evidence and in being able to providing peer feedback to one another. Group work and providing peer feedback were not typically found in the classroom – and were based on school science norms and children's expectations (see Baek, Schwarz & Grueber, 2009).

In sum, as an experienced teacher becoming proficient at the end of a year teaching a model-based inquiry unit and having received professional development showed that teacher J understood important ideas about how to construct a model, the purpose of constructing models, how to evaluate models and encourage her students to do so, and how modeling can be engaged productively in the classroom. Overall, evidence from her pre/post tests and her practice seems to indicate that her science teaching appears to have a model-based inquiry and conceptual change orientation.

Teacher P began and ended with fairly sophisticated ideas about scientific models and modeling. Analysis of the pre/post assessment shows that he wrote of models as "'wordly workings' … that can be used to explain how things work." Teacher P understood models in the beginning as "simplifying complicated concepts for research or further testing and understanding" and then later as being useful for scientists, teachers and students to "explain, share, and change ideas." Teacher P wrote in the pre-test about how he uses scientific models in his teaching to "get students connected to the ideas I am trying to teach" and that he engages his students in modeling by "taking very large ideas and making them more handy and easy to think about. It gives students a way to explain something happening in the world in a neat concise way." In the post-test, he wrote about engaging students by "having them see some models and then perhaps get them to make a model of something totally new, ... to explain their own thinking. By constructing their own models they may begin to have a clearer understanding of their ideas and be able to easily understand and change them later." This later goal recognizes the power of externalizing ideas and working to improve them over time.

Analysis of teacher P's practices shows a hybrid or blended practices when building a class consensus model – particularly with respect to norms about the sources of authority and the importance of evidence. In the conversation constructing a consensus model of condensation, teacher P uses both school norms of conversation (IRE recitation patterns, evaluating students responses with praise, and asserting correct ideas) as well as model-based inquiry norms (giving ownership of models to students, asking students to provide reasoning for their decisions, and pointing out the need to make the models consistent with empirical evidence.)

The following classroom conversation excerpt illustrates those norms with school norms highlighted in red and modeling norms in blue. Teacher excerpts are in regular font and student statements in italics.

[Teacher P drawing the consensus model on the board]

Alright, so we have one bottle over here, and it's going to represent what? What time? Is it start? Before? Or after? Before. Ok. And here we have a bottle. …This one is after, right? Good. We have a before and after. So what happens in the beginning? What do we need to show? Aaron?...

> *Molecules… but there is no condensation. …*

… Okay, so how do you want me to show that?...What, Izaac?

> *It doesn't matter what shape. …You can draw circles, dots, anything …*

Okay, but it's your model, we can do anything. What do you want to do, though?

*I think circles*

… Okay. I've got some circles. Is that enough for right now? …What do these circles represent? What?

*Water vapor*

Water vapor? What, I mean, do, how do you want me to show this? Do you want me to just say it or what? Wendy?

*Label one of them water molecules.*

Okay, so label one of them… water molecule. Okay? Ben?

*Well, I think you should put one like right out of the refrigerator at like 40 degrees then after at, um.*

Why is this in a refrigerator? Where is the bottle at? I guess we should determine that. Where is the bottle at?

*Outside.*

It's just sitting on the counter, right? Okay. So, it's sitting on the counter. Sure, obviously to make condensation happen, we've gotta have something going on here. That's probably what Aaron talked about. … What else do we need to have? Water molecules are in the air. It's in a room and this is sitting on the counter. Izaac?

*Water in the bottle.*

Why?

[class giggles] [many voices..] *Because it makes it look good. …*

What's the point of this? Do we have to have water in this bottle? Does it matter if I have something in the bottle or not?

[many students answering at the same time] *Yes, no, yes, no, !!!*

… Whoah, stop stop! Could I have an empty bottle here?

*Yes/no!*

I could, right?

…

So what does it matter if I have something in the bottle or not? Raise your hand if you say it does not matter. It's a majority. So I'm going to leave it empty for right now, so you can decide if you want to put something in your own. What matters, then? What do I need to have on here? Think about the criteria you just came up with. If I want condensation to happen, what needs to be there, Maddy?

*Water vapor?*

We've got it. Why is there no condensation?

*It evaporated*

What evaporated?

*The water*

Okay. …Why does there have to be water in the cup?

*I don't know.*

Wendy?

*As long as the bottle itself is cold or hot, it doesn't matter if there is anything there or not.*

Remember, what is condensation coming from?

*the air*

It's coming from the air. Does it matter what's inside the bottle?

*no*

No! Remember, base this on what? … We need to base what we're making on what?

*Evidence*

On the evidence. So what did we see in our investigations? Andrew?

*Um, we saw in our investigations that um, the condensation came from the outside after it, it's already evaporated.*

It's coming from the outside, it's coming from the air. So what do we need here in our before picture to let us know that condensation will happen in the after picture? Julia? What else do we need in our model? …

[long pause with no responses]

What else is missing? … Colin?

*Something cold*

Ooh, something cold! Perfect. So what's going to be cold?

[lots of children talking]

Oh, the bottle could be cold. Why?

[many at the same time] *Because it was just in the refrigerator!*

We just pulled it out of the refrigerator. … So how do we want to represent that this bottle is cold?

*Write cold in the middle.*

Oh, there you go. Cold. Can I just write cold here?

*Yeah. [Other students talk like saying "draw icicles!"]*

Okay. It's cold. Is this going to ensure that condensation is going to happen?

No?

What else needs to be there? Did we say it has to be cold to make condensation *happen or to occur?*

No.

What did we say has to be there?

*A temperature change*

Not a temperature change, but a temperature what? [He motions with his hands]

*difference*

Difference. So how can we represent that there is going to be a temperature difference in our model?

Calina? Calina, what do you think?

*Warm*

Warm over here? [the after picture] Why would we do that?

…

Okay, so if there was a temperature difference between these two bottles, where would condensation end up?

*Um, warmer. Well the bottle's not warmer…*

No, it's not. It's not warm. The bottle has to be what?

*The bottle is cold.*

It has to be cold.

Notice that there are both school-science and modeling norms enacted in this conversation. With respect to school science norms, we see that the teacher primarily engages in an initiate, response and evaluate (IRE) pattern of talk with students and there is no cross-talk or debate between students. We also see evidence that at times, the teacher is 'fishing for correct responses' and moving on even when it is not clear whether students might not understand or know the answers (e.g., 'Could I have an empty bottle here? I could, right?'). Finally, the explicit purpose of the conversation is aimed at generating the model more than advancing the underlying ideas as can be seen when teacher P states "What do we need to show?" and "What do we need to have on here?" rather than "What do we want our model show and why?"

Nonetheless, teacher P makes very strong modeling-oriented moves. Teacher P navigates the content with his students in a sophisticated manner, helping them pay attention to the evidence in their prior experiments (e.g., "What did we see in our investigations?") and helping them to understand whether or not the object that will show condensation on the outside needs to have liquid inside (e.g., "So what does it matter if I have something in the bottle or not?"). Furthermore, he repeatedly gives students some sense of ownership over their models (e.g., "It's your model") as he helps them work through their ideas by asking them to justify their decisions with reasons as well as empirical results (e.g., "Why would we do that?").

In addition to classroom conversations around these critical elements, Teacher P's worked on helping his students participate in classroom norms around peer evaluation and revision of their models in small groups. Nonetheless, students struggled a great deal with engaging in this modeling practice. They had difficulty understanding the evaluation criteria/norms as well as applying them to one another in a social setting in which the goal of the process was to improve one another's models rather than demonstrate that one had the correct idea or the best drawing. Teacher P worked with students in practicing these norms, but found this difficult without further support from the curriculum and practice in other subject matter contexts.

Overall, Teacher P and teacher J were fairly successful in enacting model-based inquiry – though with some challenges. We suspect that strong content knowledge, a greater understanding of scientific modeling, support from a relatively strong curriculum, professional development and a strong attention to students, their ideas and the advancement of those ideas as well as their encouragement of student ownership were particularly helpful. We suspect that working in additional opportunities in the curriculum for cross-student debate of models with/against evidence and further explicit discussion about the purpose of models and their construction to help us better explain and predict **future** situations would also be helpful.

## Theorized Learning Progression

In using outcomes from studies across preservice teacher learning as well as analysis of experienced teachers' learning, I've created a learning progression around model-based inquiry in Table 2. This table also includes hypothetical results from induction teachers in blue font. I also note that the learning progression includes data and patterns discussed from other research as noted in the references.

| Progression Dimensions | Preservice Teacher Knowledge & Practice | Induction Teacher Knowledge & Practice | Proficient Teacher Knowledge & Practice |
|---|---|---|---|
| **Knowledge of Science** | • Understands science as a collection of facts and big ideas to be learned about the world. Thinks of scientific inquiry as an unproblematic process of obtaining information from observations in the world and application as a process of using that information to explain the everyday world. Thinks of scientific models as visual aids for understanding information and the purpose of modeling as communicating ideas in a simpler and more visual fashion (Davis et al, 2008). | • Begins to understand the role of inquiry and application in science - that explanations and models are based on experiences and patterns from those experiences. Understands that scientific models play a role in helping people make sense of difficult ideas in science, but not how they can be used to generate new ideas; Understands that asking children to construct models is productive, and has difficulty understanding evaluation and revision practices, particularly how evidence and models are related. | • Understands the role of inquiry and application in science, the centrality of models in inquiry and application, and the relationship between patterns in data and models (Davis et al., 2008). Understands that models are generative tools that are revised with new knowledge and that the model-based inquiry is generative for learners. |
| **Knowledge of Science Learners** | • Understands how students learn science as accumulating information about the world from teachers, books, etc. Often believes that students know little about the world and what they do know is based on misconceptions that need to be 'fixed.' They are unfamiliar with how children think of models or learn through model-based inquiry (van Driel & Verloop, 1999, 2002). | • Understands that students learn science through making sense of their experiences and many have misconceptions about the world. They begin to see the variety and strategies of students' ways of knowing about the world but mainly in contrast with canonical science rather than as tools to leverage. They begin to see how model-based inquiry can benefit learners through multiple 'hands-on' experiences and visualization. | • Understands how students learn science through making sense of the patterns in their experiences with the world. Knows learners have a rich repertoire of ways of knowing about the world (e.g., via narratives, principles, models, etc. that have different purposes) that can be leveraged for learning in new ways. Understands how children begin to use MBI in their science learning (Hennessey, 2002; Lehrer & Schauble, 2000; Schwarz, et al., 2008); Understands the practices within MBI such as constructing, evaluating, revising and using models and reflecting on their purpose and evaluation. Recognizes the benefits of MBI for helping learners understand science and participate in scientific |

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|---|---|---|---|
| | | | practices and discourses. |
| **Views of Effective Science Teaching** | • Views effective science teaching as discovery through hand-on exploration, didactic presentation of information, or presentation of information supported by hands-on materials (Schwarz & Gwekwerere, 2007). Views lesson sequencing as covering a new science topic for each lesson. | • Views effective science teaching as providing experiences with hands-on materials that addresses the topic or learning goal and builds these ideas over time. Views lesson sequencing as a logical progression of themes with important ideas needing greater coverage. | • Views effective science teaching as guided, model-based inquiry and application rather than discovery/didactic or hybrids of these approaches. Views lesson sequencing as building units around a few important big ideas that need multiple experiences with inquiry and application for understanding. |
| **Lesson Planning and Sequencing Strategies** | • Sequences instruction in an unproblematic fashion around obtaining initial student ideas about the topic, defining terms and information, providing hands-on activities, and summarizing information and big ideas about the topic. (Schwarz & Gwekwerere, 2007) | • Sequences instruction with a topic-themed question or issue, elicits students' initial ideas on the topic, organizes activities for students on the topic, provides information and definitions on the topic, provides follow-up activities or discussions, and summarizes what students should know about the topic. | • Sequences instruction in a robust and flexible fashion, sometimes using model-based inquiry, including a driving question that problematizes the science topic, eliciting students' ideas and constructing initial models, collecting and analyzing data to test models, comparing/contrasting data to those models, introducing other scientific models and information, revising models to account for evidence and information, and applying models to problem-solving contexts. |
| **Class Conversation Norms & Strategies** | • Norms are oriented towards ensuring that the teacher's scientific information is heard and that children's ideas are shared.<br>• Uses classroom management strategies to ensure that only one person talks at a time. | • Norms are oriented around sharing, obtaining the correct scientific information, and equitable participation. Interns begin asking students to build on one another's ideas and possibly provide reasons for their ideas.<br>• Uses strategies such as probing questions and connecting student ideas. Finds it challenging to support learners in productive student conversations. | • Norms are oriented around valuing diverse ideas and ways of knowing, and evaluating and revising ideas to account for evidence and theory. Makes the classroom and disciplinary norms explicit to the children.<br>• Uses strategies such as asking probing questions, asking students to support their answers with reasons, connecting student ideas, attributing ideas to particular learners, and providing space for discussion among learners (Mohan, 2008). |
| **Working With Children's Ideas in Conversations** | • Engages in class conversations to organize children and provide information. | • Engages in class conversations to provide information as well as to share children's ideas and ways of knowing. Uses conversation about patterns in data (if it exists) to share or verify those patterns; May discuss consensus models to share or assert the correct scientific model; May help the students apply models in other contexts. | • Engages in class conversations to elicit children ideas/models and compare/contrast those ideas; helps children interpret patterns in data and probes for understanding of these patterns; helps children contrast models with data/evidence, compare and contrast models, build consensus models, and apply models in other contexts. |

Table 2. Hypothesized Learning Progression for Teachers' Knowledge and Practices for Model-Based Scientific Inquiry

## Conclusions

Analysis of our own data and from outcomes of other research indicates that beginning preservice teachers typically view scientific inquiry as an unproblematic process of obtaining information from observations in the world, scientific models as visual aids for understanding information, and the purpose of modeling as communicating ideas in a simpler and more visual fashion (Davis et al., 2008). They begin by desiring to enact classroom norms ensure that the teacher's scientific information is expressed and that children's ideas are shared. In contrast, proficient teachers view scientific inquiry as an investigation process and begin understanding that models can be used as generative thinking tools for science and learning. Experienced teachers becoming proficient in model-based inquiry enact instruction with norms consistent with model-based inquiry though they also struggle to create consistent norms in class conversation and peer evaluation/revision with respect to source of authority and evidence.

## Future work

The goal of this learning progression is to provide benchmarks of important aspects of teacher development around a scientific practice that may be useful for guiding teacher preparation programs and curriculum materials development. Knowledge of science, science learners, pedagogical skills in lesson sequencing and establishing norms in class conversations as well as support from curriculum materials are likely to help teachers engage in model-based inquiry and support students' thinking and reasoning along the way. Nonetheless, additional issues remain. In addition to determining important dimensions of knowledge and practice that are likely to provide the greatest leverage points for teacher development, we must also continue to analyze the role of context and community in the development of teacher practice. For example, teachers must be helped to address needs and requirements of their school cultures along with the scientific practices – for example, by seeing model-based inquiry as enabling better assessment of students' thinking and participation as well as content to be learned (e.g., Mikeska et al, in press). Specific techniques that enable teacher support might also make a difference. Examples of such techniques might include video exemplars and reflective assessment tools focused on student' sensemaking of patterns in phenomena and reasoning around the use of models as well as analysis of their own discourse techniques. It is hoped that further testing and revision of such a learning progression that accounts for these aspects will advance teacher practice as well as students' scientific practices.

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