Chapter 12
A Modeling-Based Inquiry Framework for Early Childhood Science Learning

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Three four-year olds, Zachary, Christopher and Brianna, hunch over a set of colorful wooden blocks. For a silent minute they stare at the pile of blocks. Suddenly, Zachary grabs a block, examining it carefully before placing it in the middle of the floor. Christopher selects another block and carefully places it on top of the first block. Soon Brianna joins in, adding blocks both on top and from side to side. The children's eyes light up as Christopher adds a wooden ramp to the side of the structure. He picks up a small ball and rolls it down the length of the ramp. He then gives the ball to Brianna and watches as she rolls it repeatedly down the ramp. Several minutes later, Zachary reaches over and puts some blocks under the ramp, changing its elevation. By now the children's structure is swaying precariously. Ideas begin to flow simultaneously: "You have to balance it," "Get a smaller block," "Put more blocks on the other side." Then the unthinkable happens with the slow collapse of the children's block tower. Zachary begins to remove the blocks, creating a new fence-like structure with a larger base, explaining, "This is where the cows go." The three children are a bundle of energy as they build up and take apart the blocks, with little concern for creating a lasting structure.

While Zachary, Christopher and Brianna may not be gathering evidence to revise their block structure in a systematic way, their model changes as they try out new ideas. Like Zachary, Christopher and Brianna, young children never get tired of exploring their world and figuring out how things work. The questions they ask

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of themselves and each other are in essence the beginning of scientific thinking. Kincheloe, Steinberg, and Tippins (1999) described how as a child, the young Albert Einstein spent hours building with prefabricated blocks and cards. As he combined the objects of his play, he learned about spatial relationships, balance and symmetry in unconscious ways. In the process of constructing block and card houses, he rearranged these objects of play in ways that achieved a new synthesis or understanding.

In this chapter, we frame children's engagement in learning about the natural world as a process of model construction and reconstruction, a process that we, following Giere (1988, 2002, 2004), believe recapitulates science itself. Giere describes described science as a process of modeling in which various domains and sub domains of knowledge are embodied in families of models that represent theoretically important features or dimensions of experience. Within Giere's framework, we derive hypotheses from our models that allow us to test similarities between our models and the natural world and to test ideas about how models relate to each other. Additionally, Suppes (1960, 1962) suggests suggested that models of experimentation and of "data" mediate our decision making about how our theoretical or content models fit the world.

For our purposes, a scientific model is a dynamic analog that selectively represents the structure and behavior of some part of the natural world. A model may contain iconic as well as symbolic (linguistic or mathematical) representational elements and may be distributed, existing both in the mind and as an external inscription. Models are dynamic in that they can be "run" to generate explanations of behavior or predictions about future behavior.

Modeling in the early childhood years is about selectively representing salient features of our interactions with our world. As young children engage in activities where they explore and modify their world, they are guided by not only new information constructed through their ongoing interactions, but also their pre-existing models of the physical world, which developmental research suggests appear early in the first months of life, are abstract, can model structural and causal relations, and are malleable through experience (Baillargeon, 2002; Spelke, 1991, 2000). Einstein's example has important implications for early childhood educators. Teachers can protect children from the reductionist principles of rote memory and mechanics that eventually lead to the fragmentation of knowledge by helping them make connections between their daily experiences and what they are learning. The use of models and modeling processes is one way to help children make sense of their natural world.

Engaging children in more mindful, inquiry-driven, modeling activity in the science classroom helps them understand the cultural dimensions of models and modeling. When one considers scientific modeling as a cultural process and models as its products, certain aspects of modeling activity and of the models its produces need to be highlighted in the teaching and learning of science. Although the cognitions of individual scientists who are part of the community of practice contribute to the modeling processes and the models themselves, the modeling enterprise is shaped by the interactions among the members and institutions of the community.

Scientific models serve important intersubjective aims of communicating, replicating, evaluating, and building upon or revising ideas in the context of scientific inquiry. We propose that science education needs to create ways of constructively replicating these cultural practices for science learners at all level. From this perspective, science learning in young children should be viewed as socially negotiated and embodied in specific cultural practices (Boyd & Richerson, 2005; Rogoff, 1990; Roth, 2005).

Models and Modeling in Science Education Reform

For decades, efforts to reform U.S. K-12 science education have emphasized modeling-based conceptual understanding and reasoning. In *Project 2061 Benchmarks for Scientific Literacy* (American Association for the Advancement of Science & Project, 2061), "models" is one of four common themes deemed essential for K-12 science curriculum. More recent reform documents such as *A Framework for K-12 Science Education: Practices, Cross-cutting Concepts, and Core Ideas* (National Research Council & Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education [NRC], 2012) reflect a view of young children having the capacity to engage in scientific practices, suggesting that children in early grades develop and use models:

> Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system. Young students should be encouraged to devise pictorial and simple graphical representations of the findings of their investigations and to use these models in developing their explanations of what occurred. (p. 58)

A Framework for K-12 Science Education highlights modeling as a fundamental scientific and engineering practice that requires children to draw on knowledge constructed in multiple contexts. It also explains how the use of models and modeling at an age-appropriate level can help children build explanations of phenomena that extend beyond their understanding: "Science often involves the construction and use of a wide variety of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observables and imagine a world not yet seen" (NRC 2012, p. 50).

A multiplicity of researchers, incorporating a diversity of perspectives, have proposed structuring science learning as recursive modeling activities in which children are encouraged to continually construct, evaluate and reconstruct models. For example, Lesh & Doern (2003) describe a modeling cycle that begins with introducing children to a model-eliciting problem and evolves through a series of develop-test-revise cycles. These scholars note how children, as they refine their models to achieve more consistency and coherence, often notice unexpected implications of a particular representational choice or an additional feature of their world that the model fails to account for. A similar approach, taken by The Engineering in Elementary program (EiE), developed by the Boston Museum of Science, encourages children to ask, imagine, plan, create, and improve as part of a modeling process (Cunningham & Hester, 2007). Looking across various conceptualizations of modeling, several basic tenets appear to be common to all. There is an inherent emphasis on the potential for modeling to impact children's epistemic goals, such that they learn to pose, evaluate and pursue worthwhile questions of their own, rather than searching for answers to others' questions. Another principle reflected in many of the modeling cycles is the idea of children as producers of knowledge who craft their identities as inventors of models, rather than consumers of knowledge or simply users of existing models. Furthermore, such perspectives do not delineate learning about "content" and "process" as distinct and separable components. Rather the development of content and process is inextricably melded as children construct and reconstruct models.

Indeed, research supports the idea that there are entry points in young children's experiences with the physical world that allow for productive science instruction. For example, research has shown that children from 3 to 7 years of age believe that tiny invisible particles (e.g., particles of sugar or salt) can exist in aqueous solutions even though they are too small to be visible to the naked eye, and that properties of solutions, such as taste or drinkability, may be affected by these particles (Au, Sidle, & Rollins, 1993; Rosen & Rozin, 1993). Macdonald and Bean (2011) have shown that second graders who participate in informal museum-learning programs show an understanding of microscopic material entities that can be studied indirectly. Current perspectives on science learning suggest that students' models of physical phenomena evolve gradually and that productive instruction often facilitates young children's construction of a series of intermediate models that approximate some, though not all features of normative scientific concepts (Mazens & Lautrey, 2003; Wiser & Smith, 2008).

In this chapter, we outline a modeling-based inquiry framework for exploring young children's science learning and share results of a research project in which we are engaged that have yielded important theoretical information about the nature of young children's conceptual development in science. Our research projects explore how the scaffolding of model-centered classroom discourse during inquiry learning helps young children articulate physical science models and develop an understanding of models and modeling.

A Modeling-Based Inquiry Framework for Early Childhood Science Learning

Our theoretical framework is grounded in a view of science learning as a process of domain-specific knowledge construction (Brown, 1990; Carey & Spelke, 1994; Gelman & Brenneman, 2004). From classic developmental theories, we draw upon the tenet that children are active learners (Bruner, 1996; Piaget, 1955; Vygotsky, 1962). However, the domain-specific view implies that learning in particular conceptual domains such as science entails the development of distinct domain-specific conceptual constructs, reasoning processes, and patterns of activity. In this context, thinking with and about rich content becomes a central concern for learning and for instructional design. Our approach is consistent with the National Research Council report advocating that science instruction should be organized around “big ideas” (Smith, Wiser, Anderson, Krajcik, & Coppola, 2004). A core theoretical assumption of our framework is that science learning is situated in specific cultural contexts and practices and is socially negotiated (Boyd & Richerson, 2005; Brown & Campione, 1994; Rogoff, 1990; Roth, 2005). This assumption is consistent with a vast body of research in science studies on the historical and current practices of science (Giere, 1988; Knorr-Cetina, 1999; Kuhn, 1962, 1977; Laudan, 1990; Thagard, 2003, 2004).

Following Giere (1988, 2004), we conceptualize science as a process of constructing, testing/evaluating, and reconstructing models of the world. Giere suggested that knowledge in various domains and sub domains of science is embodied in families of models that represent theoretically important aspects of the external world. Consistent with recent efforts to bridge cognitive and situated/socio-cultural perspectives on knowing and learning (e.g., Cobb, 1994; Vosniadou, 2007), we do not draw sharp distinctions between models as knowledge internal to the learner (i.e., in the mind) and models as external representations created by the learner with the aid of cultural tools (e.g., drawings, computer simulations, 3-D Models).

Modeling-Based Inquiry with Young Children

We believe that PreK-2 science instruction should be designed to facilitate students’ understanding of the relationships among domain models, and their ability to use models generatively (Frederiksen, White, & Gutwill, 1999; Gobert, 2000; Grosslight, Unger, & Smith, 1991; Justi & Gilbert, 2002). The nature of the learning tasks that are assigned to students and the ways of assessing student learning can have a significant impact on the flexible application or transfer of knowledge to varied contexts. Thus in our work, we have employed the instructional approach of guided inquiry (Brown & Campione, 1994; Magnusson & Palincsar, 1995). Our instructional approach follows a set of design principles for inquiry-based pedagogy that include the integration of the cognitive (science concepts and scientific inference processes), epistemic (knowledge validation and evaluation), and social (understanding the sociocultural norms and practices of science) dimensions, as recommended by a national panel of science education experts (summarized in Duschl & Grandy, 2008).

Our goal is to develop instruction through which young students experience science as a set of cultural practices supporting shared norms for co-constructing, evaluating, and revising knowledge (Knorr-Cetina, 1999; Kuhn, 1962, 1977; Laudan, 1990; Samarapungavan, Patrick, & Mantzicopoulos, 2011). The central idea is that early science learning is supported by discourse-rich interactions among students and between students and teachers.

Our Framework for Implementing Modeling-Based Inquiry

Our modeling-based inquiry implementation framework is an adaptation and extension from key features of *Practices of for K-12 Science Classrooms from the Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (*NRC 2012*)*. The dimensions that we focus on are:

1. Engage learners in posing/addressing scientific questions centered on core disciplinary ideas (Aligns with Practice 1 from Framework, 2012).
2. Develop metamodeling awareness by explicitly using the language of models and modeling and drawing learners' attention to the constructive representational aspects of models such as decisions about what features /aspects of the world to model (Aligns with Practice 2 from Framework, 2012).
3. Facilitate learners' ability to plan and carry out investigations (Aligns with Practice 3 from Framework, 2012).
4. Engage learners in analyzing and interpreting evidence to evaluate their models (Aligns with Practice 4 from Framework, 2012).
5. Facilitate learners' articulation of model-based explanations (Aligns with Practice 6 from Framework, 2012).
6. Facilitate the comparison, evaluation, and revision of models based on the outcomes of investigations (Aligns with Practice 7 from Framework, 2012).
7. Engage learners in communicating what they have learned (Aligns with Practice 8 from Framework, 2012).

Our prior research and that of others has shown that the scaffolding of science discourse during inquiry is critical to facilitate students' developing intersubjective understandings of the processes of model articulation, evaluation, revision, and communication (Roth & Welzel, 2001; Samarapungavan, Mantzicopoulos, & Patrick, 2008; 2011; Seymour & Lehrer, 2006; Windschitl, Thompson, & Braaten, 2008a, 2008b). In the following section, we provide an example of how teacher-scaffolded inquiry discourse supports children's inquiry-based modeling in the science classroom—illustrating four of the dimensions of the framework: (a) articulating a model; (b) identifying evidence with which to make a prediction; (c) communicating model, and (d) collecting and analyzing evidence.

Examples from Science Classroom Discourse

Our example is drawn from a kindergarten science unit in a project called the Science Literacy Project (SLP) (Mantzicopoulos, Patrick, & Samarapungavan, 2005). Detailed descriptions of the SLP curriculum are beyond the scope of this chapter but have been detailed in several prior publications (e.g., Samarapungavan et al., 2008; Samarapungavan et al., 2011). This unit entitled, *What is Science?*, introduced children to the key themes of the SLP curriculum: (a) Science is the study of the natural world; (b) Everyone can do science; and (c) Scientists learn about the world through planned and carefully conducted processes of inquiry. The focus of this unit was to introduce children to scientific inquiry through simple experiments with dissolving, to help them decide which of several substances (salt, sugar, lemonade mix, beans, a plastic paper clip, an iron nail, etc.) will or will not dissolve in water. The lesson starts with the teacher scaffolding children's predictions as they worked in small groups (4–5 students). Each group was seated around its own work table with materials for the experiments and their science notebooks and pencils out. It is important to note that the kindergarten science lesson occurred about three weeks into the start of the school year and was the *first* SLP lesson. The students (5–6 year olds) were novices, both in terms of their experiences of formal schooling in general and of school science learning. The teacher was in her first year of participation in the SLP project and had had no systematic prior experience with inquiry-based science teaching beyond the week of professional development she received through SLP workshops prior to the start of the intervention. She was also new to the school district and to kindergarten teaching. Prior to assuming her current position, she taught 4th graders in an affluent private school in another U.S. state. The examples we use followed from an earlier segment of the lesson in which the teacher explored children's ideas of dissolving with an introductory whole class activity and discussion centered on mixing and stirring lemonade mix in a pitcher of tap water. It is important to keep in mind that the main purpose of this initial unit was to give young children a sense of what it means to engage in scientific inquiry, rather than to build scientific models of dissolving. In the excerpts that follow, the teacher is engaged in several interactions that scaffold young learners' ability to identify, collect, and interpret evidence to evaluate their models.

Articulating a Model as a Context for Inquiry

As the children began to consider whether salt will dissolve in water and started to use the word "dissolve" in their conversations, the teacher encouraged them to articulate their models of what it means to dissolve something (see Excerpt 1). In this process, she focused their attention on what changes they expected to observe when they said something is dissolving. In response, the students started talking about the changes that accompany dissolving, referring to the lemonade activity as they did so:

Excerpt 1

1	*Leticia:*	*Dissolve (pointing to salt)*
2	*Teacher:*	*Dissolve?*
3	*Leticia:*	*Yeah*
4 5	*Teacher:*	*What's that mean? Tell me your ideas, what do you think? What do you think Jonathan?*
6	*Jonathan:*	*Um*
7 8	*Teacher:*	*What do you think it means to dissolve? Remember the lemonade? We got the lemonade [[and she's pouring it.*
9	*Marcello:*	*[[Oh yeah]]*
10 11	*Ethan:*	*(pointing to the lemonade that the teacher is pouring out of the pitcher for each child). It dissolved.*
12	*Matthew:*	*It dissolved to a different color.*
13 14	*Teacher:*	*What did you say? It dissolved (repeats after Leticia who is inaudible) it dissolved into the water? What does that mean? What did it do?*
15	*Leticia:*	*It changed colors.*
16	*Teacher:*	*It changed colors you said that, that's good.*
17	*Ethan:*	*I changed it.*
	…	
18 19 20	*Teacher:*	*Well let's think of more reasons, I like the way that Eth- Alexa was comparing it to the lemonade mix that's very good. Okay. Boys and girls, if you think, we're gonna go ahead and make our predictions.*

At this point in the lesson, the children's model of dissolving focuses on the color of the substance and color change. The teacher encourages students' model articulation through non-directive questions. In this initial phase, the teacher's discourse is simply focused on having the students lay out their ideas and explanations without concern for their accuracy. This is appropriate in the early phases of modeling-based inquiry.

Identifying Relevant Evidence

As the children continued the lesson, the teacher helped them identify evidence that they would collect about whether various substances will dissolve in water by scaffolding their predictions about what will happen for each substance (Excerpts 2a and 2b). The children responded by making their predictions about whether or not the salt and the beans will dissolve in water. The teacher also called upon children to explain/justify their predictions:

Excerpt 2a

Teacher:	*This, boys and girls look up here (holding up a science notebook). This is the front of your binder, this is the back of your binder, open your binder from the front. Okay, and then you can look through it. Okay. Today we're gonna make some predictions. So each of you at your table will get some salt and some beans (she is showing the salt and bean cups). Okay.*
Students:	*[Salt. Bean]s*
Teacher:	*Good job. Okay right here. Now boys and girls we get to make a prediction. Okay so we get to guess what's going to happen. Sergio, listen up. We're gonna take a guess, we're gonna predict and see if the salt will dissolve. Now I'll pass some salt around, 'cause I want you to take a good look at it. I'll put some on your table. I want you to take a good look at it. Don't put it in your mouth; don't stick your fingers in it; just look at it.*
Sergio:	*I can't see*
Teacher:	*And see what it looks like and I want you to guess if it will dissolve in water. Pass it around.*
Eric:	*You can't look that long*
Teacher:	*Remember we talked about* PREDICTIONS*. When we do science, we can use what we know, or maybe what we have seen before to make* PREDICTIONS *– make a guess about what we think will happen to something. What are your predictions about the salt and the beans? Let's share our predictions. Boys and girls raise your hand if you think—if what -tell me what you think about the salt, if you think it will dissolve or not. Adrianna, what do you think?*
Adrianna:	*It will.*
Teacher:	*You think it (the salt) will dissolve, why do you think it'll dissolve?*
Alexa:	*'Cause that (pointing to the box with lemonade mix used earlier), the powder was kinda white.*
Teacher:	*Yeah, because it -it was maybe the—when, yeah maybe 'cause it's it looks like the powder did (referring to lemonade mix from earlier) didn't it?*
Eric:	*(nods) Mmm hmm*
Teacher:	*So it's a little different from the powder though isn't it? It's a different color. What's everybody else think? ((pause)) Do you guys think it'll dissolve in water? [[If we put it in water?*
Sergio:	*Yeah*

Excerpt 2b

1	*Students:*	*(taking the beans and looking at them)*
	…	
2	*Teacher:*	*Okay, so what are your predictions?*
3	*Eric:*	*I think it will.*
4 5	*Teacher:*	*You think it will. Eric? (to class) Eric thinks it will dissolve. Why do you think it'll dissolve?*
6	*Eric:*	*I can see white.*
7 8	*Teacher (to class):*	*Eric can see white. Do you think that everything's that white will dissolve?*
9	*Eric:*	*Yeah.*
10	*Teacher:*	*If you put a golf ball, is a golf ball white?*
11	*Students:*	*Yeah!*
12 13	*Teacher:*	*Uh huh. If you put a golf ball in water is it gonna [[is it gonna dissolve?*
14	*Matthew:*	*No!*
15	*Teacher:*	*Are you still gonna be able to see it?*
16	*Students:*	*[No, yes.]*
17 18	*Teacher:*	*Yeah, but that's good, you're thinking. That's very good. What are your o what's everybody else think?*

Both Alexa and Eric apply their color-focused dissolving model to the prediction—that is, they think the salt and the beans will dissolve because they are white, like the powder they saw dissolve earlier. For example, Alexa (*Excerpt 2a*, lines 22–27) introduces the idea that white powders dissolve in water by drawing an analogy between the salt which she predicts will dissolve and the lemonade mix which she describes as "kinda white" which dissolved in an earlier part of the lesson. In an attempt to move the focus away from color as the relevant evidence for whether or not something would dissolve in water, the teacher responds by saying, "*…So it's a little different from the powder though isn't it? It's a different color.*" *(Excerpt 2a*, lines 31–32). Later, Eric again picks up on the theme of whiteness as a marker for whether or not something will dissolve, (*Excerpt 2b, lines 6–9*). The teacher then introduces a thought experiment by asking the students to imagine a white golf ball and asking whether it would dissolve in water (Excerpt 2b, lines 10–18). We interpret these teacher-student interactions as productive exemplars of moves to identify what counts as relevant evidence in the context of modeling-based inquiry for young science learners. The key aspects of the teacher's discourse here are that she never tells the students that they are wrong or that color is not relevant. Rather, she tries to draw their attention to phenomena that do not fit well with their initial models and in asking them to recognize these discrepancies, she helps them reconsider their initial models.

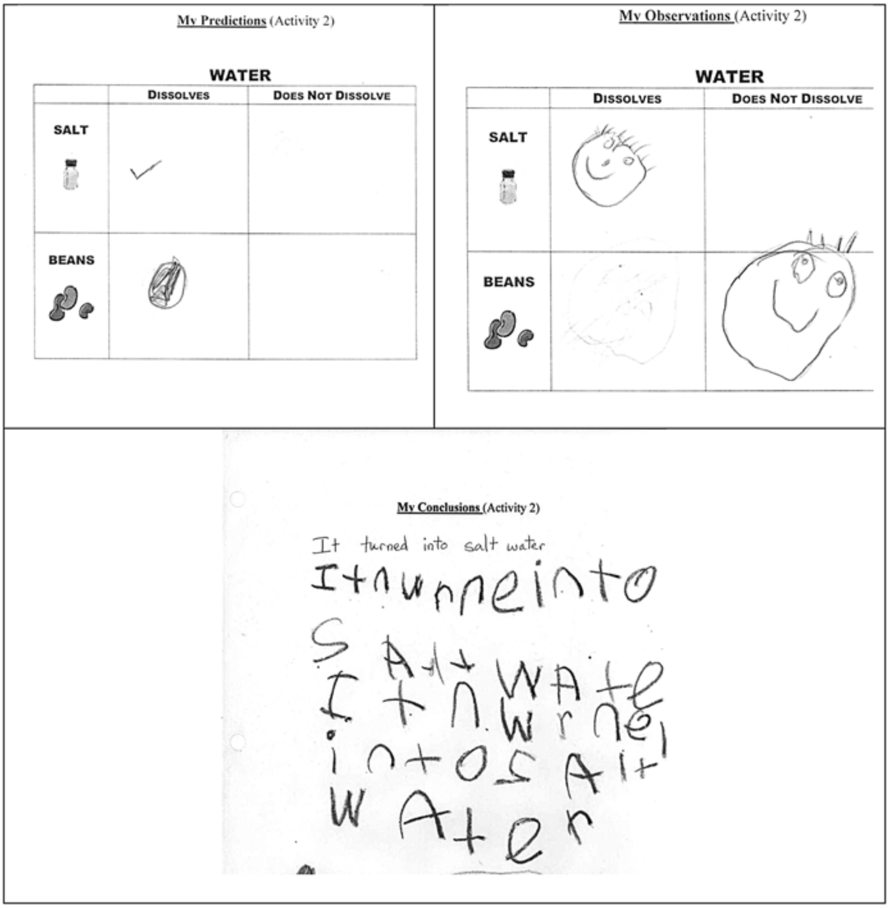

Fig. 12.1 Entries from Eric's science notebook for unit 1

Using Inscriptional Tools to Support Inquiry

Another key feature of modeling-based inquiry is the use of inscriptional tools to scaffold children's model articulation, evaluation, and revision. *Excerpt 3* illustrates how the teacher used inscriptional tools, in this case science notebooks, to facilitate learners' ability to identify, collect, and interpret evidence to evaluate their models. Figure 12.1 provides an example of the science notebook entries that children made as they engaged in the processes of inquiry. The notebook contains Eric's records of his initial predictions that both the salt and the beans would dissolve in water, his observations that the salt dissolved but the beans did not, and his conclusions (e.g., dissolving the salt in the water made it "turn into salt water").

Excerpt 3

Teacher:	Look here, look what it looks like (shows page of science notebook in Fig. 12.1). Do you think that's gonna dissolve? You think that's gonna dissolve or not dissolve? If you think it's gonna dissolve put a mark. What do you think, do you think it's gonna dissolve or does not dissolve? Okay, do you think it'll dissolve? So then put a smiley face right here. If you think it'll dissolve, put a smiley face right there. Great job with your predictions (said to the whole class). Very good, I see smiley faces all over. Very good, Logan's even writing his name on the paper.

In order to understand the significance of Fig. 12.1 and Excerpt 3, it is important to note that this is the first lesson of the year's science curriculum for the kindergarteners and takes place within three weeks of the start of the school year. The young students have just begun formal instruction on reading and writing at school but the teacher is already engaging them in practices of scientific literacy as they record and communicate their predictions, observations, and conclusions through modeling-based inquiry. For example, Fig. 12.1 shows that Eric initially predicts that both the salt and the beans will dissolve in water, but then records his observations that the salt did dissolve but the beans did not and concludes that the salt turned "into salt water" but the beans remained whole in the water (drawing). The children are given the freedom to use a combination of words and drawings to articulate their ideas throughout inquiry.

Collecting and Interpreting Evidence

Excerpt 4a and *Excerpt 4b* illustrate how the teacher engaged in children in collecting and interpreting evidence as they continued their investigations of dissolving. The teacher started out by explaining the procedure for mixing the salt in the water. She and the teaching assistant continued to scaffold the students as they mixed the salt and beans in the water with hints and prompts (see exchanges in *Excerpt 4a*, lines 1–12). The teacher supported the children as they engaged in collecting and interpreting their evidence by asking them to describe what they were observing and to explain their observations. For example, in *Excerpt 4a* (lines 4–12), the teacher engaged the children in describing and interpreting their observations of what happened to the beans, once they were mixed in the water and whether they dissolved on the water. Riley and Rose indicated that the beans did not dissolve, with Rose explaining that she could still see the beans after they had been mixed in the water (*Excerpt 4a*, line 9). In contrast, John said the beans would eventually dissolve but they just needed more time to get wet (*Excerpt 4a*, line 13). The teacher scaffolded a similar conversation about evidence with another group (see *Excerpt 4b*, lines 1–17). In that exchange, Matthew observed that the salt dissolved right away (*Excerpt 4b*, line 2) while Ethan notes that the beans are not dissolving (*Excerpt 4b,* lines 5–11). The teacher then asked the children if the beans were changing in any way (*Excerpt 4b,* line 12). Leticia and Matthew responded by saying the beans were changing colors (*Excerpt 4b,* lines 13–14). At this point Alexa, who was in a different group (Group 2) but listening in to Group 3, told Mathew that she thought the beans would eventually dissolve if they just kept stirring (*Excerpt 4b,* lines 17). Although, the complete lesson transcript is not presented here because of length, the teacher did allow the children more time to stir the beans until they eventually concluded that the beans will not dissolve in the water. These examples illustrate how our instructional approach helps teachers to scaffold children's sense making in the context of modeling-based inquiry.

Excerpt 4a

1 2 3	*Teacher:*	*And then stir it. Good job. (to Riley) What do you think? They (points to the beans in the water) dissolve? (Riley shakes her head to indicate no.) They're not?*
4 5	*Teacher's Assistant:*	*What do you (John) think? Does it look like they're dissolving? Do you observe them dissolving? (no response from John)*
6	*Riley:*	*(Shakes her head to indicate no.)*
7 8	*Teacher's Assistant:*	*No? Why not?*
9	*Rose:*	*I can still see [[them*
10	*John:*	*It will. It will.*
11 12	*Teacher's Assistant:*	*You think so still?*
13	*John:*	*Yeah, [[it (the beans) just it just has to get wet.*

Excerpt 4b

1	*Teacher:*	*Okay, what do you guys notice, what are you observing?*
2	*Matthew:*	*[[The salt, the salt dissolved right away.]]*
3	*Ethan:*	*[[The beans]]*
4	*Teacher:*	*The beans? What about the beans Ethan?*
5	*Ethan:*	*They ain't.*
6	*Teacher:*	*They what?*
7	*Ethan:*	*They ain't.*
8	*Teacher:*	*They aren't what?*
9	*Ethan:*	*Disserving*
10	*Teacher:*	*They're not dissolving?*
11	*Ethan:*	*No*
12	*Teacher:*	*Are they changing?*
13	*Leticia:*	*Changing colors, yeah.*
14	*Matthew:*	*Changing colors!*
15	*Teacher:*	*They're changing colors?*
16	*Matthew:*	*Yeah! A little, but they're not but it's change colors.*
17	*Alexa:*	(from another group, to Mathew) I think they will solve (dissolve)
18	*Teacher's Assistant:*	You still think they might. I don't know, the salt didn't take that long to dissolve, though did it?
19	*Leticia:*	*Yeah!*
20	*Alexa:*	[[Just keep stirring, see if that will ((inaudible))*]]*

One important feature of the lesson was that the children's inquiry did not follow a proscribed linear path from posing questions, to planning, to collecting and interpreting evidence etc. Rather, children cycled back and forth fluidly between posing questions, making predictions, engaging in explanation, and collecting and interpreting evidence. This is illustrated towards the end of *Excerpts 4a and 4b*, where the children were engaged in *c*ollecting and interpreting data on whether or not the salt and the beans dissolve when mixed in water. Both John (*Excerpt 4a*, lines 10–13) and Alexa (*Excerpt 4b,* lines 17, 20) thought that the beans had not had sufficient time to dissolve in the water. Alexa introduced the prediction that if the beans are stirred some more, they will dissolve. This kind of fluidity in inquiry is consistent with our view of modeling-based inquiry as complex and non-linear.

The results of the SLP project (Samarapungavan et al., 2011) provide support for the integration of modeling-based inquiry in science instruction with young children. Samarapungavan et al. (2011) showed that children engaged in modeling-based inquiry as part of the SLP intervention developed richer and more sophisticated science knowledge and also developed a better understanding of the processes of scientific inquiry than their comparison peers in demographically similar comparison classrooms which implemented routine (non-modeling-based) science instruction. Children in comparison classrooms typically learned science by reading fictional and informational text that incorporated science (usually stories about dinosaurs or farm animals) or sometimes by watching television shows or movies with science content. Learning was typically focused on vocabulary acquisition rather than developing conceptual models (see Samarapungavan et al., 2011, for a more detailed description). For example, the children in the SLP intervention outperformed their comparison peers on the end-of year Science Learning Assessment (SLA). The group differences were statistically significant ($p<.01$) and the effect size as measured by Cohen's D ($ES=2.25$) was large.

Discussion and Implications

As our own example presented above and the research of others we have cited shows, young children indeed are capable of engaging in modeling-based science learning through inquiry. They can articulate, evaluate and revise their models and communicate with and about their models as they participate in scientific inquiry. While research on models and modeling-based science teaching and learning in early childhood settings is still in its infancy, in recent years researchers have emphasized that when young children engage in modeling-based science inquiry, they not only better understand important aspects of the activity of scientists at an early age, but they also develop more sophisticated and robust science knowledge. Collectively, the current body of empirical work on young children's learning through modeling confirms the promise of the recommendations embodied in the current science education reform documents including the A *Framework for K-12 Science Education* (2012) for the *Next Generation Science Standards* (Achieve, Inc, 2013).

Implications for Classroom Practice

That said, the successful implementation of modeling-based inquiry instruction with young children requires activities that find entry points in children's phenomenological experience and prior knowledge for model articulation, elaboration, and revision. As noted in the introduction to this chapter, the cognitive research on the development of young children's knowledge of the natural world in infancy and the preschool years is a rich source of information on such entry points. The processes of modeling in young children develop in tandem with other key domains of skill and knowledge including literacy and numeracy as these skills are actively engaged in the processes of modeling science phenomena. This requires the refinement of teachers' existing pedagogical content knowledge to develop a repertoire of productive strategies for facilitating student science discourse. For example, teachers need to be able to "see" the emerging science in children's classroom discourse (Hammer & van Zee, 2006). Developing a more fine grain-grained understanding of productive discourse strategies and how these may be supported during instruction is vital to effective preservice teacher education as well as inservice teacher professional development in the primary grades.

Another implication for implementing early childhood modeling-based science inquiry instruction involves assessment. Modeling experiences offer opportunities for children to ask unique questions and see connections between concepts. Yet high stakes assessments and evaluation procedures typically discourage the kind of conceptual thinking that is the centerpiece of modeling-based inquiry. In many cases, the continued emphasis on memorization of isolated pieces of information, starting at an early age, trivializes learning. It is an educational imperative for assessment to be viewed as an extension of the process of learning, rather than something that isolates children from knowledge.

Finally, the cultivation of a vision of the role that modeling might play in early childhood science contexts, must necessarily include a discussion of how teachers can be supported as learners. In an educational climate where the deskilling of teachers often results from test-driven or pre-packaged (teacher proof) curriculum materials, modeling-based inquiry approaches must first be viewed as valuable and worthwhile. Kenyon, Davis & Hug (2011) note that both prospective and practicing teachers have limited experience in scientific modeling practice, and particularly its application in early childhood settings. In this regard, teachers may not understand the purpose of models, how to engage young children in modeling experiences, or the role of discourse in communicating children's understandings of everyday phenomena. Windschitl and Thompson (2006) link the use of modeling to teachers' understanding of the nature of science, suggesting that their use of modeling-based inquiry may be constrained by the extent to which they hold to a belief in the scientific method. As schools attempt to solve the educational problems that confront them in the twenty-first century, there is an urgent need for transcending concrete and formal ways of thinking—modeling-based inquiry has the potential to draw inspiration from children's lifeworlds in building curricula that unlocks relationships between everyday phenomena.

Implications for Future Research

As we reflect on the implications of modeling-based science instruction for research, we return to Albert Einstein. At an early age, Einstein's sense of wonder was engaged when his experiences with everyday phenomena conflicted with what was already established in his mind. Anyone who has had the opportunity to observe and interact with young children will have quickly noticed how they spend much of their time asking questions about their world. Yet far too often children quickly learn how to answer questions without inquiring further. Modeling-based inquiry science teaching and learning has the potential to support dynamic rather than static science education practices that recognize the inherent value in children's questions. In this sense, it requires teachers to build on children's abilities to ask questions before being asked. The use of models and modeling in early childhood settings clearly presents a unique combination of benefits and challenges for practitioners, giving rise to many questions for further study: How do teachers create classroom learning environments that position children at an early age to think about their own thinking? What patterns of argumentation are evident in young children's classroom discourse about modeling? What are the scope and limitations of various types of models in early childhood science learning contexts? How do young children's modeling practices develop and change over time? How do teachers understand modeling-based inquiry science instruction for early childhood learners? How do teachers' understandings of the processes of model-based inquiry influence their instructional practices and discourse strategies? As Crawford and Jordan (2013) pointed out, questions range from considerations of modeling as a practice to the notion of "how we test ideas using models in our own research" (p. 120). In the midst of our consideration of some of the implications of models and modeling for research and practice, we emphasize the importance of ultimately using contextualized approaches to better understand the impact on student learning.

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