International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

Fostering Third-Grade Students' Use of Scientific Models with the Water Cycle: Elementary teachers' conceptions and practices

Tina Vo, Cory T. Forbes, Laura Zangori & Christina V. Schwarz

International Journal of Science Education, 2015
Vol. 37, No. 15, 2411–2432, http://dx.doi.org/10.1080/09500693.2015.1080880

Fostering Third-Grade Students' Use of Scientific Models with the Water Cycle: Elementary teachers' conceptions and practices

Tina Vo[a*], Cory T. Forbes[a,b], Laura Zangori[c] and Christina V. Schwarz[d]

[a]*Department of Teaching, Learning, and Teacher Education, College of Education and Human Sciences, University of Nebraska–Lincoln, Lincoln, NE, USA;* [b]*School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE, USA;* [c]*Department of Learning, Teaching, and Curriculum, College of Education, University of Missouri–Columbia, Columbia, MO, USA;* [d]*Department of Teacher Education, College of Education, Michigan State University, Lansing, MI, USA*

Elementary teachers play a crucial role in supporting and scaffolding students' model-based reasoning about natural phenomena, particularly complex systems such as the water cycle. However, little research exists to inform efforts in supporting elementary teachers' learning to foster model-centered, science learning environments. To address this need, we conducted an exploratory multiple-case study using qualitative research methods to investigate six 3rd-grade teachers' pedagogical reasoning and classroom instruction around modeling practices (*construct*, *use*, *evaluate*, and *revise*) and epistemic considerations of scientific modeling (*generality/abstraction*, *evidence*, *mechanism*, and *audience*). Study findings show that all teachers emphasized a subset of modeling practices—*construction* and *use*—and the epistemic consideration of *generality/abstraction*. There was observable consistency between teachers' articulated conceptions of scientific modeling and their classroom practices. Results also show a subset of the teachers more strongly emphasized additional epistemic considerations and, as a result, better supported students to use models as sense-making tools as well as representations. These findings provide important evidence for developing elementary teacher supports to scaffold students' engagement in scientific modeling.

Keywords: *Elementary teachers; Scientific modeling; Water; Elementary science; Case study*

*Corresponding author. Department of Teaching, Learning, and Teacher Education, College of Education and Human Sciences, University of Nebraska-Lincoln, Lincoln, NE 68583, USA. Email: tina.vo@huskers.unl.edu

Modeling is a core scientific practice for supporting students in conceptualizing, investigating, and explaining natural phenomena, as well as for persuading others about their conclusions (Gilbert, 2004; Harrison & Treagust, 2000; NGSS Lead States, 2013). While scientific modeling is emphasized in the elementary grades, past research has highlighted the challenges elementary students experience when engaging in modeling (Lehrer & Schauble, 2010; Manz, 2012). Yet, when elementary students are provided both curricular and instructional supports to engage in the practices of modeling, they can learn to use models effectively to reason about complex processes and the dynamics that underlie large-scale systems. One such system is the hydrologic cycle, a core topic introduced in the elementary grades (NGSS Lead States, 2013). However, prior research has shown early learners often have difficulty conceptualizing and explaining water-related phenomena, particularly subsurface dimensions of the water cycle, that is, groundwater (Forbes, Zangori, & Schwarz, 2015; Gunckel, Covitt, Salinas, & Anderson, 2012; Prain, Tytler, & Peterson, 2009). Students therefore require opportunities to engage in the practices of modeling to learn about the hydrologic cycle.

Teachers' roles in supporting and scaffolding students' engagement in scientific modeling are crucial (Kahn, 2011; Windschitl, Thompson, & Braaten, 2008). While research has begun exploring elementary students' engagement in scientific modeling (e.g. Abell & Roth, 1995; Lehrer & Schauble, 2010; Manz, 2012), including those related to water-related phenomena (Forbes et al., 2015; Schwarz et al., 2009; Zangori, Forbes, & Schwarz, 2015; Prain et al., 2009), relatively little work has explored how elementary teachers foster students' model-based reasoning through instruction (Akerson, Cullen, & Hanson, 2009; Akerson et al., 2008; Akerson, White, Colak, & Pongsanon, 2011; Henze & van Driel, 2011). Further, previous studies have found the water cycle to be a challenging concept for both preservice and inservice teachers, as well as students (Gunckel et al., 2012). More research is therefore needed to support elementary teachers in learning how to engage students in scientific modeling. Here, we explore third-grade teachers' ideas about scientific modeling and the ways in which they engage their students (ages eight to nine) in model-based sense-making about the hydrologic cycle through a multiple-case study grounded in qualitative research methodology. We specifically ask:

(1) How do third-grade teachers conceptualize scientific modeling in teaching and learning about water-related phenomena?
(2) How do third-grade teachers support students' model-based reasoning about water-related phenomena through their instructional practice?

Theoretical Framework and Background Literature

Scientific Models and Modeling

Scientific modeling is a core scientific practice in science learning environments (NGSS Lead States, 2013). Students should use models, or abstract representations of real-world phenomena, to focus on key processes and make accessible the less easily observed components and mechanisms that underlie the natural systems. As Gilbert (2004) identifies:

> [Models] function as a bridge between science theory and the world-as-experienced ('reality') … They can be used to: make abstract entities visible … provide descriptions and/or simplifications of complex phenomena … [and] be the basis for both scientific explanations of and predictions about phenomena. (p. 116)

Models then serve as critical reasoning tools for students to learn about complex systems (Harrison & Treagust, 2000). Prior research indicates that engaging in scientific modeling can positively influence elementary students' conceptual understanding of disciplinary concepts (Abell & Roth, 1995; Schwarz et al., 2009, Forbes et al., 2015; Lehrer & Schauble, 2010; Manz, 2012). However, fostering productive engagement in the practices of modeling often requires a shift in science learning environments from a primary emphasis on hands-on investigations, which typically emphasize data collection, to learning experiences that involve advancing ideas through a process of model-based analysis, discussion, and revisions (Windschitl et al., 2008).

Scientific modeling comprises two fundamental components. First, students engage in *constructing*, *using*, *evaluating*, and *revising* models, or modeling practices (Gilbert, 2004; Justi & Gilbert, 2003). Students initially *construct* models in response to an investigation question that prompts them to focus on phenomena that occur within a complex system. These constructed models are explications of students' mental models about the phenomena. Students then *use* their models to engage in scientific inquiry and scientific practices, such as making predictions, testing, or generating scientific explanations about different processes, and communicating their findings and ideas. Students also *evaluate* their models through comparisons to empirical data, and/or to an expert, scientific model, or to peers' models of the same phenomena. Model evaluation involves topic- and community-specific criteria for the nature of effective models and practices of scientific modeling. Finally, students may *revise* their models to reflect changes in their thinking brought about through new evidence generated through investigation or examples being presented. Revisions are closely related to model construction but with an additional component of self-reflection and metacognition. This set of task-oriented modeling practices represents what students do with models and is reflected in instructional models for scientific modeling (Abell & Roth, 1995; Schwarz, 2009; Schwarz et al., 2009; Forbes et al., 2015; Kenyon, Davis, & Hug, 2011; Lehrer & Schauble, 2010).

Second, scientific modeling is guided by goals and values, or epistemic considerations, consistent with those of science. Underlying epistemic considerations—*generality/abstraction, evidence*, *mechanism*, and *audience* (Berland et al., in press)—define the 'how' and 'why' of modeling practice (Schwarz et al., 2009; Forbes et al., 2015) and foreground the ways in which models serve as scientific tools. They describe why students, teachers, and scientists use models scientifically and how models support students in engaging in complex reasoning about phenomena. *Generality and abstraction* refer to how students choose to represent information along a continuum from abstract to concrete and the connections they make between their models, their evidence, and the physical world. This allows individual concepts to be situated in different grain sizes, ensuring they align with information across different contexts. For example, students should recognize the same processes underlie condensation on a mirror and cloud formation. *Evidence* signifies how students ground their models in evidence. *Mechanism* emphasizes ways students engage in modeling practices to generate and reason about cause and effect within a system. Attention to this consideration is important for students to identify or theorize about the underlying causes of system processes and how various system components interact. Finally, *audience* is students' attunement to whom a model is for, including themselves, for whom models serve as reasoning tools, as well as others, for whom they will use their models to communicate their ideas.

Teachers' Support for Scientific Modeling

Elementary students require scaffolding to successfully engage in scientific modeling (Abell & Roth, 1995; Zangori et al., 2015; Gilbert, 2004; Gunckel et al., 2012; Lehrer & Schauble, 2010; Manz, 2012; Prain et al., 2009). By introducing the practice of scientific modeling as a key component of effectively designed elementary science learning environments, the *Next Generation Science Standards* (NGSS Lead States, 2013) have placed new demands on elementary teachers to provide support for students to engage in modeling. However, research has shown scientific modeling is challenging for teachers because it requires both content knowledge and pedagogical content knowledge, as well as prior experiences with model-based curricula (Akerson et al., 2011; Gilbert, 2004; Marquez, Izquierdo, & Espinet, 2006). While many elementary teachers turn to curricular resources to support their science instruction, few such resources are explicitly designed to expand teachers' professional knowledge and instructional capacities (Davis et al., 2014). This issue is exacerbated because little is known about how teachers can best scaffold elementary students to engage in scientific modeling (Zangori et al., 2015).

Since there is a perceived link among teachers' knowledge, instruction, and student learning, elementary teachers should possess robust knowledge about both the practices and epistemic considerations of scientific modeling to foster student learning (Berland et al., in press; Justi & van Driel, 2005). Research has indicated that elementary teachers, both preservice and inservice, often lack a deep understanding of the purpose of modeling, which may hinder their ability to foster model-based instruction in the classroom (Akerson et al., 2009; Berland et al., in press; Crawford & Cullin, 2004; Danusso, Testa, & Vicentini, 2010; Justi & van Driel, 2005; Justi & Gilbert, 2003; Oh & Oh, 2011). These include difficulty in determining what elements should be included in representations in order for students to reason about scientific phenomena (Gilbert, 2004). When teachers understand how and why models support student learning, evidence suggests they may actively engage students in scientific modeling to foster their conceptual growth.

The body of work focused on supporting both inservice and preservice teachers' ideas about modeling has suggested tentative links between perception and practice, indicating that teachers need to develop their own knowledge about modeling in order to cultivate meaningful modeling opportunities for students in the classroom (Schwarz, 2009; Kenyon et al., 2011; Oh & Oh, 2011; Windschitl & Thompson, 2006). Past research has shown that an important way to improve preservice teachers' understanding of scientific models and modeling is by presenting information more holistically, creating tasks which involve teachers' current practices around models, and modeling and fostering reflection on those practices that allow teachers to explicitly link their own actions to those of their students (Justi & van Driel, 2005; Windschitl & Thompson, 2006). When teachers have opportunities to engage in the practices and epistemic considerations of modeling with their students and explicitly reflect on their knowledge and experiences with the practices of modeling, they are more likely to engage students in constructing scientific models (Berland et al., in press; Crawford & Cullin, 2004; Kenyon et al., 2011).

Research has illustrated multiple pathways to support teachers' learning and implementation of modeling practices. Supporting teachers' growth in terms of both understanding and engaging in model-centered instructional practice requires 'sustained discourse on epistemological ideas' (Windschitl et al., 2008, p. 362). Engaging preservice and inservice teachers in professional development, structured classroom experiences making the processes of modeling explicit, and/or contact with experts may support their ability and/or confidence to scaffold students' scientific modeling in the classroom (Berland et al., in press; Justi & Gilbert, 2003; Windschitl & Thompson, 2006). With preservice teachers this includes creating and scaffolding specific modeling experiences which allow student-teachers to explicitly learn about and engage with modeling through activities and reflection that support their eventual implementation of scientific modeling in the classroom (Schwarz, 2009; Crawford & Cullin, 2004; Danusso et al., 2010; Kenyon et al., 2011; Windschitl et al., 2008). Research on inservice teachers recommends similar supports through long-term professional development efforts with additional emphasis placed on teachers thinking about scientific modeling (Akerson et al., 2008, 2009, 2011; Justi & van Driel, 2005). However, the ways in which elementary teachers understand and require support in enacting model-based teaching and learning remain largely unexplored.

Methods

This study was conducted during the first year of a four-year National Science Foundation-funded project grounded in design-based empirical research (see also Forbes et al., 2015). The goals of the project are twofold: to (a) promote third-grade students' (ages 8–9) engagement in the practices of modeling for hydrologic cycling through enhancement of curriculum materials and instruction and (b) investigate associated instructional, curricular, and student learning outcomes. This study involves six teachers in a single Midwestern state in the USA. We use a multiple-case study research design (Creswell, 2006) to explore teacher conceptions about, and instructional practices to support, students' scientific modeling to learn about the hydrologic cycle.

Table 1. Profiles of third-grade teachers and classrooms

	Alana	Yvonne	Janet	Clarisse	Melissa	Lenore
Number of students	18	22 (11)[a]	23	26	21	22
Teaching experience (years)	1	23	13	11	22	21
School district	A	A	B	B	C	C
Free reduced lunch	75%	5.4%	76.1%	17.4%	24.5%	24.5%

[a]Indicates a mixed second-/third-grade classroom with (#) indicating number of third graders.

Participants and Instructional Context

Six third-grade teachers—Alana, Yvonne, Janet, Clarisse, Melissa, and Lenore (see Table 1)—were purposefully sampled (Patton, 2001) from suburban, urban, and rural school districts with student populations that included underrepresented demographic groups and widely variant socioeconomic profiles. All teachers were female and were selected based on the grade they taught (third-grade), their use of the Full Option Science System *Water* (FOSS, 2009) module as part of their normal science curriculum to address local, state, and national science standards, and their diverse school demographics (Table 1).

The FOSS *Water* unit is produced by a commercial publisher in the USA and contains 'four investigations focused on investigating properties of water, changes in water, interactions between water and other earth materials, and how humans use water' (FOSS, 2009, p. 1). However, there are few opportunities in the unit for students to use models to make connections between the discrete water-related phenomena they investigate and broader systems processes associated with the water cycle. To supplement this unit, each teacher utilized pre- and post-unit lesson plans developed in collaboration with the project team. These lessons were designed to help teachers introduce scientific modeling and provide students opportunities to engage in modeling practices. Teachers were encouraged to modify and enact the supplemental lesson plans in light of their own priorities, needs of their students, and demands of their classroom contexts. The sequence of enactment is shown in Table 2. With the exception of the pre- and post-supplemental lessons, the remainder of the *Water* unit remained as designed.

Data Collection

Data for this project were collected during the 2012–2013 academic year throughout the 8–10-week period in which teachers enacted the *Water* unit. Data collection began one week prior to the beginning of the unit and concluded one week after the unit was completed. Data were collected in individual classrooms asynchronously over the course of an academic year due to variation in timing of implementation of the unit determined by the teachers' building- and district-level instructional schedules.

Data sources include video-recorded classroom observations, teacher interviews, and other miscellaneous instructional artifacts. First, each of the six teachers was

Table 2. Instructional sequence in the supplemented FOSS Water Unit

Lesson name	Description
Pre Supplemental (Researcher Developed)	Modeling lesson with integrated modeling activity focused on the water cycle
Water Observations (FOSS Developed)	Multi-lesson investigation on the properties of water, how water interacts with different surfaces and materials, surface tension, and water on a slope
Hot Water, Cold Water (FOSS Developed)	Multi-lesson investigation of the properties of water when heated, cooled, and frozen and on how density impacts water
Water Vapor (FOSS Developed)	Multi-lesson investigation of evaporation and condensation
Water Works (FOSS Developed)	Multi-lesson investigation of how water moves through earth materials
Post Supplemental (Researcher Developed)	A review of scientific modeling and post-modeling activity related to the finished Water Unit

observed enacting unit lessons at least four times during the *Water* unit ($n = 38$). Each observation lasted approximately 40 minutes. All observations were video-recorded by the project team. Second, teachers were interviewed before and after the unit and at least three times during the unit, typically upon completion of each of the observed lessons ($n = 40$). Interviews were semi-structured (Merriam, 2009) and, on average, 30 minutes in length (interview length range: 16–52 minutes). Each interview was also audio-recorded and transcribed verbatim, at which point all identifiers were removed and replaced with pseudonyms. Interviews were based upon pre-developed, semi-structured interview protocols (Merriam, 2009). Pre- and post-unit interviews were designed to elicit teachers' conceptualizations and definitions of modeling practices and epistemic considerations. Post-lesson interviews emphasized teachers' reflections on how these elements of scientific modeling emerged in classroom activity during their enactment of lessons from the *Water* unit, as well as particular strategies they employed to scaffold students' scientific modeling. Additional instructional artifacts and products were also collected, including student work samples, SMART Board presentations, and lesson plans with teacher notes.

Data Coding and Analysis

All data were transferred to Atlas.Ti for analysis. To analyze study data, codes were articulated to align with the study's theoretical framework and underlying literature (Abell & Roth, 1995; Berland et al., in press, Forbes et al., 2015; Schwarz, et al., 2009; Harrison & Treagust, 2000). The coding matrix, included in Appendix A, was derived from an empirically grounded learning performances framework for students' model-based explanations for water developed as part of the project (Forbes et al., 2015). Codes in the matrix emphasize both epistemic considerations (*generality/abstraction evidence*, *mechanism*, and *audience*) and modeling practices (*construction*, *use*, *evaluation*, and *revision)*. Coding was performed by the first author in two passes. First, data were coded to identify teachers' talk and classroom practices associated with students' engagement in scientific modeling. Next, the entire data set was coded again to identify teachers' talk and instructional practices around the epistemic considerations. A 10% sample of the data was jointly coded by the first and third author. We established initial interrater reliability at 90% and after discussion reached 100% agreement.

To analyze the data, code queries were performed for each cell of the matrix in Appendix A. Queried data were categorized by an individual teacher to identify and isolate trends in teachers' ideas about modeling and associated classroom practices during enacted unit lessons. The analyses led to the development of single-case descriptions for each teacher that summarized patterns in her conceptions of scientific modeling and classroom practices to support students' model-based reasoning. These teacher trends were eventually compared across teachers to identify similarities and differences among all six teachers. We analyzed the data through pattern matching to develop a cross-case synthesis (Creswell, 2006). This cross-case synthesis helped identify patterns in teachers' ideas and practices related to practices of modeling. A reflexive, iterative process (Patton, 2001) was used to help triangulate different patterns in teachers' conceptions (RQ #1) and instructional practices (RQ #2).

Results

Overall, study results indicate that all six teachers associated specific modeling practices with student sense-making about water. Their conceptions and instructional practices were most strongly associated with the practices of model construction and, to a lesser extent, model use rather than model evaluation and revision. We found critical differences among the teachers' conceptions and practices associated with epistemic considerations. Our results indicate these three teachers' emphasis on epistemic considerations was observable in their classroom practice. Students in these three teachers' classrooms were afforded different opportunities than those in classrooms of teachers' who prioritized the modeling practices alone. This subset of teachers who paid attention to both the modeling practices and epistemic considerations engaged students in modeling to represent and illustrate their ideas as well as account for evidence and posit explanations for water-related phenomena.

RQ1. Teachers' Conceptualization of Modeling Practices and Epistemic Considerations

In research question one, we asked, 'how do 3rd-grade teachers conceptualize scientific modeling in teaching and learning about water-related phenomena?' Our results indicate that all six teachers exhibited a baseline understanding of scientific models as representations of natural processes. However, their conceptions of the epistemic considerations underlying scientific modeling varied greatly. While all six teachers emphasized *generality/abstraction* across model *construction* and *use*, only three teachers also consistently identified *evidence* and *mechanism*. Our results indicate that these three teachers' emphasis on these additional epistemic considerations led them to also focus on supporting students to use models in the classroom as a conceptual tool for reasoning about water systems.

Teachers' shared conceptions of scientific modeling. We observed consistency in the teachers' ideas regarding models and modeling. All six teachers recognized the modeling practices c*onstruction* and, to a lesser extent, *use*, when they described how a model can serve as a static representation of a natural process. They identified that models, as representations, could be *constructed* by students to depict observations, experiments, or from curriculum materials. All teachers articulated views about constructed models emphasizing drawings with labels depicting a data summary or illustration, such as a drawing of different sized water drops flowing down a slope with indicators of speed, or a before and after picture of a puddle on a sunny day with labels and indicators of what was occurring. Janet, for example, said:

> … I feel [that] if the kids could draw a model that they would need to have been taught how to make sure there are labels of everything that they're doing and adding those extra details instead of just drawing a picture … (JP:6 12)

In Janet's quote, she addressed model construction, as students would be creating a model, as well as a representational expectation, because she would expect students to 'label everything that they're doing' (JP:6 12).

Yvonne similarly reflected on her students' knowledge, saying, 'I think most of them were able to effectively represent the condensation and the precipitation process, because many of them put the clouds and labeled it condensation' (Y_postmodel, 2.12.13.12). Here she describes evaluating her students' construction of a model and labeling transforming a picture into a model. This idea of scientific modeling as a well-labeled representation was present within the ways all six teachers described scientific modeling in the classroom. For example, as Clarisse said, 'Kids learn better if they're [modeling]. If they are either drawing what they have thought through or drawing what you're talking about and labeling it they get a better understanding about that process' (C_unit_interview_1_11_2013). All six teachers discussed the benefits of having students construct models of students' personal understandings, identifying main ideas (e.g. condensation, precipitation, evaporation) in their models, and viewed modeling as a way to access their students' conceptual understanding.

The teachers also focused on how students might *use* their models within their classrooms. For example, all of the teachers discussed *using* the models to depict the water cycle and its component parts (e.g. evaporation, condensation, precipitation, flow). Melissa, for example, noted, ' … I think it's kind of nice that we're letting them draw their own [model], because they can tell you why and that's using their past experience and building on to connect to' (M_Postmodeling 1 lesson interview). This idea that models could be used to tie together students' ideas 'building on to' what students already know represents how each teacher discussed the ways in which their students might use scientific models to connect prior experiences with classroom investigations.

We also consistently observed evidence that teachers provided attention to the epistemic consideration of *generality/abstraction* as a way for students to relate models to the real world. Their discussions around this epistemic consideration were embedded in their reasoning about the modeling practice of *construction*. For example, Lenore discussed how she might use models to emphasize *generality/abstraction*:

> After I make those predictions, first hand if I visual[*sic*] or model what I thought I'd knew and then do my experiments, do whatever I need to do and then at the end, this is what it looks like now. I think it is a good reference back to where we started, and what we learned along the way and now we understand. (L_modeling lesson 2 interview)

Here, Lenore articulates how she would construct a model to represent her experiences and then how that model could be connected to experiments conducted in class. By using a model to connect both her experiential knowledge and her experiments, she identifies a bridge between the abstract and concrete. Alana also spoke about this idea, saying, 'I think [modeling's] very effective. This seems probably the ideal situation, in just that they do a smaller model to the real-world and compare that. I think that would be an excellent way to infuse models into science' (A_unit interview). She suggests one of the purposes of models would be to bridge smaller, more concrete experiences, like experiments, to larger 'real-world' phenomena.

Janet discussed her ideas of *generality/abstraction* in more tangible terms, describing what she might have students do in terms of making a model for how water moves down a slope. Her students had finished an investigation centered on different-sized drops of water running down plastic trays and recording how drop size influenced the rate of downhill movement. She was asked if modeling fit into the lesson, to which she replied:

> The only thing I kind of thought about was, as a continuation on it, having them draw [a model] having them draw a diagram of a hill. Or give them different pictures of a hill and tell which one would they go down fastest and explain why. (J_Post1_2_23_2013)

Here we see Janet describing a specific model she might ask the student to draw rather than having them to create their own. She believed this would connect students' experiment with water trays to their experiences seeing water run down hills. All the teachers hypothesized that models could help create these types of connections for students. However, the primary purpose of models for these teachers, at times, focused on students' ability to depict the teachers' ideas, list vocabulary, and write definitions that teachers would create.

Extended conceptions of scientific modeling. For three teachers (Alana, Janet, and Lenore), their discussion of scientific models and modeling emphasized model *construction, use,* and *generality/abstraction* discussed in the previous section. However, the other three teachers (Clarisse, Melissa, and Yvonne) also identified how models would support students in reasoning about complex phenomena. These three teachers expressed a desire for their students to become aware of the less easily observed elements of the water cycle, such as gravity and groundwater (*mechanism*) and also make connections between the water cycle and individual investigations (*evidence*). These teachers discussed that models provided students the opportunity to understand complex systems more deeply by allowing students to connect their experiences and experiments to the larger water cycle.

Much like the other three teachers, Clarisse, Melissa, and Yvonne articulated their goal for students was to be able to explain the connection between classroom models and broader hydrological processes (*generality/abstraction*), but also expressed that models should additionally give students a more complex understanding of how water functions at different grain sizes and scopes, including elements of *mechanism* and/or *evidence*. Yvonne, for example, said:

> I think most of them have seen a picture of the water cycle somewhere or have talked about it. But, may not have really thought about it. So, I think that seeing that model, doing the investigation, and then actually creating a model again in their own way … for some of them [would] clarify that. (Y Post model 2.12. 13.12)

Yvonne postulated students may develop a deeper understanding by making connections between the larger water cycle model and students' experiments and personal model; acknowledging *generality/abstraction* and how models could be used to visualize a hidden *mechanism* within a system.

Similarly, Clarisse emphasized students needed to draw complete processes including driving forces, which is also an acknowledgement of the importance of *mechanism*, saying:

> [The students] can draw the arrows and they can, I think some of them were very good at looking at their picture and then being able to answer the questions that helped them with that process … so then they began to draw the arrows back up to the clouds and one boy was like, 'The sun is here. What is the sun for you?' (CP4:4)

Here, Clarisse articulated her ideas about how a constructed model is used as a representation, but also as a vehicle for explanation and comparison, documenting how a student might ask questions to grow their understanding of how others represent a model. Clarisse went on to describe how the students would be able to take their experience and use them to engage with their models (CP4:4). This identifies her ideas about the epistemic considerations of *mechanism* and *generality/abstraction* alongside the modeling practice of *use*.

Melissa discussed how she perceived the epistemic consideration of *evidence* and *generality/abstraction* should be influencing her students when they are constructing models. She said:

> Modeling makes more sense than just reading about it and hearing about it. They're actually seeing it and being part of it … Once they hit something where, I would say, once they've connected something, and then they're at a blocking point, they're going to have to stop until they can get some more information or to expand on that. (M unit interview 10_5_2012)

There are two important elements to notice in Melissa's comment. First, she described *generality/abstraction* when she wants students to relate a stream table model with an actual river. Secondly, she mentioned how that relation is limited without the use of *evidence*. In this quotation, Melissa described how she thought evidence is needed to help students move their models forward presumably when constructing/revising future stream table models. While all six teachers in the study emphasized the importance of *generality/abstraction*, these three teachers also began including elements of *mechanism* and *evidence* as important parallel epistemic considerations.

These teachers' attention to additional epistemic considerations, *evidence* and *mechanism,* in their students' modeling practices was often paired with a more articulated and robust view of scientific modeling in the classroom. While all the teachers recognized the value of students' models for assessing students' thinking, this subset of teachers also thought about models as cognitive tools. Melissa, for example, said:

> They can explain why they think something happens and using details, not just because I think it's going to be this way. Using some detailed information … They wanted to show it with model … They were wanting to do that with model. (M_postlesson_11_9_2012)

Melissa wanted students to discuss using their models as a reasoning tool and to use detailed information as evidence to ground their model-based explanations. In this quotation she is connecting a modeling practice with an epistemic consideration by wanting and expecting her student to use models to discuss evidence.

Clarisse also hoped her students would use their models for discussion and application. After teaching a lesson focused on how water moves through different earth materials, she discussed what she wanted to do next with students, 'I'd like to see if they could apply the model that we did here, with the real world in telling me what the water does in nature, in some different spots' (C_post_2_8_2013). This comment shows that Clarisse sees the value and connectedness of *using* models to understand *generality/abstraction* and demonstrates her understanding of the importance and connectedness between *using* models to understand *generality/abstraction*.

Yvonne similarly reflected how she changed a lesson to accommodate modeling and in doing so reflected on her extended understanding by saying:

> … I changed [the lesson] to put it on, to make [the lesson] a discussion and having them, instead of having them record it in their notebooks of model not model, putting it up on the smart board and having that discussion together as they were moving back and forth … , most of them would write it one place or the other and not really think about it and I thought they could learn from each other's thoughts in that discussion. (Y_interview11.12.12)

By creating a consensus model Yvonne was engaging students in the modeling practice of *evaluation* while having students justify and clarify their ideas to an *audience* of their peers. Taken together, these examples illustrate the ways in which Clarisse, Melissa, and Yvonne conceptualized the role models could play for students to not only represent their thinking, but also support their sense-making about water over time.

Summary of RQ1. In answering research question 1, we identified particular conceptions of scientific models and modeling shared by all six teachers. Their initial ideas about modeling focused primarily on model *construction* and *use*, as well as the epistemic consideration of *generality/abstraction*. These modeling practices and epistemic considerations provided all the teachers the foundation for an emphasis on within-investigation modeling tasks. However, we observed a subset of three teachers who also considered the epistemic considerations of *mechanism* and *evidence* and in students connecting their ideas and experiences to processes underlying the water cycle.

RQ2. Supporting Students' Modeling in the Classroom

In research question 2, we asked, 'how do 3rd-grade teachers engage in instructional planning and instruction to support students' model-based reasoning about water-related phenomena?' Teachers' observed instructional practices largely aligned with their conceptions described in response to research question 1. All teachers engaged in common instructional strategies that focused on the modeling practices of *construction* and *use*. Focusing on these practices tended to foster a classroom science context that emphasized specific students' representation of ideas associated with discrete water-related phenomena. However, Clarisse, Melissa, and Yvonne utilized additional instructional supports that reflected their additional emphasis on epistemic considerations of *mechanism* and *evidence*. These teachers' classrooms were more frequently defined by student discussions and questioning to support them in grounding their models in evidence, as well as to help students interpret and explain phenomena.

Baseline support for scientific modeling. All six teachers engaged in instruction to afford students opportunities to engage in modeling practices. This allowed them to support students to develop conceptual understanding of water-related science concepts. They used various collaborative activity structures, such as think-pair-share or small groups, to enable their students to discuss their models and to use their individual models to help develop a consensus model for the class. However, teachers who only exhibited a baseline understanding of the modeling practices and considerations (Alana, Janet, and Lenore) tended to focus more time on guiding and shaping student interpretations to create a final consensus model that was *right*. They also often explained to students why elements should or should not be included in the model rather than letting the students negotiate the inclusion of the concept themselves. Filtering students' ideas was a common theme among these three teachers.

Consider Alana as an example. She enacted this idea of heavily guided modeling practice toward the correct idea in her classroom instruction. Her instruction focused on watching students work in the classroom and commenting on the models they created for their experiments, saying 'Alright, so yes! That's right!' (A1017:18:55), if their models matched hers and asking students to copy what they saw from her model if differences emerged 'Can you look at the board? … What did we just talk about, show me here [points to student paper]' (A_obs4.). This enactment matches what Alana discussed in research question one where she hopes to use models to identify when to redirect students when their work 'is completely off' (A_unit interview). Alana found benefit in using the models for evaluation purposes, and was attentive to what students modeled and would often guide them toward answers she considered *correct*. Students in her classroom did not evaluate each other's models in any of her observed enactments. Instead, she would walk around the room evaluating their models for them.

As another example, Lenore worked to create a consensus model with her students (L1218b/c:27:28/0:10). However, in the discussion, she primarily asked students yes/no or vocabulary questions such as 'Could water evaporate over here?' and 'What do you call that stuff that's coming down?'. After students gave appropriate single-word or short sentence answers, Lenore would fill out the context saying 'Sure, wherever there's water, it can be evaporated' (L1218b) thereby filtering and guiding her students' ideas to construct a consensus model. Lenore told students different concepts she wanted them to know instead of guiding them to come to their own conclusions about water.

Janet's classroom was very similar with students primarily working alone. During class discussions, such as creating a consensus model, students seemed to offer their ideas to the teacher rather than the class, while Janet acted as a filter for what might or might not be appropriate to go into the class's final model. When Janet reflected on an instance of students modeling in her classroom (J_postmodel2post2.15.2013) she said 'I don't think they did it as well as I would've liked. I guess in my head I picture more labels along with [the models] … I think maybe more labels, or arrows, or movements … '. This statement indicates she has a concept of what the students' models should look like and enacted the lesson so that her students' models matched what she identified as correct.

Extended classroom practices in support of scientific modeling. Three of the teachers who had extended conceptions of scientific modeling (Clarisse, Melissa, and Yvonne) enacted lessons that provided more support for their students, such as guiding questions, recaps, summaries, and included time for discussions related to students' modeling. These teachers added or augmented the existing curriculum to align with the needs they perceived for their students; attending to some components of the epistemic considerations such as *mechanism* and *evidence*. While all presented information to students, these three teachers (Clarisse, Melissa, and Yvonne) created supports and space for students to generate their own models and allotted time for small groups of students to explain and discuss their models. They extended the FOSS unit by bringing in models at different times within their respective investigations. The teachers who emphasized these additional epistemic considerations (Clarisse, Melissa, and Yvonne) in their interviews also typically deviated from the unit to incorporate extra elements, such as incorporating previous student work, including more examples and non-examples they found, or creating entirely new experiences about models, modeling, and the water cycle.

For example, during Clarisse's pre-modeling lesson, she had her class list examples of times when they thought they had made or used models to engage them in a discussion about what was, or was not, a model. One boy raised his hand and answered, 'making a bridge out of toothpicks', to which Clarisse asked for clarification on why he thought it was a model. He stated 'It can hold weight and break and they can see.' Clarisse rephrased his explanation to say, 'So scientists build a model to show how something reacts or interacts with something in this case is saying how the bridge will handle weight [writes it on the smartboard] … ' (C.Model1a:12:20). By drawing on the students' past experiences she was able to actively engage students in the modeling lesson, and steered conversations toward why the scientist had created the model (*construction*) and to what purpose (*mechanism*). In this manner, she leveraged her conceptualizations about modeling practices and epistemic considerations to scaffold students' understandings.

Observed implementation of the teachers' regular unit lessons provided additional evidence for Clarisse, Melissa, and Yvonne's effective facilitation of students' discussions about modeling and the purpose of modeling. Yvonne, for example, devoted significant time to student discussions within her classroom, giving students both general and specific questions to answer within their pairs or small groups. Some discussions started out specifically asking about the experiments they had completed, 'So, which drop fell faster?' and then, after a few minutes, she transitioned students to a broader question 'What would this look like on a hill?' (YP:3 5). By making these transitions, Yvonne had students focus on connecting their experiments to the real world, or the epistemic consideration of *generality/abstraction* by linking to the experiment she brought in elements of students' *evidence* into the conversation. These teachers also often referenced the water cycle poster provided in the *Water* unit as a point of comparison for students' ideas and discussed connections between student models, experiences, experiments, and the poster itself.

Another example occurred at the end of the *Water Vapor* investigation when Melissa developed a physical model to create rain in her classroom using a cold pan and an electric kettle. She discussed the different parts of the FOSS Water investigation while she showed students that water vapor would rise from the kettle and then condense on the bottom of the cold pan and fall to the floor as precipitation. She had *constructed* a physical model for them to see. While she discussed experiments the class had previously completed she repeated the demonstration and had students compare her model of the water cycle to their own experiences having students work with how they might represent *generality/abstraction* within their own models. Melissa guided students through a discussion where the class concluded that electricity acted as the heating source for the water in the kettle. She then drew an analogy of how this occurs much like the sun acts as the force behind evaporation in the ocean. This demonstration identifies Melissa incorporating the epistemic consideration of *mechanism* because she is trying to explicitly point students toward an unseen force within water phenomena. Students were able to bring in their models and experiences while negotiating the physical model with their peers and teacher.

Finally, Yvonne also provided students opportunities for discussion. Recall the early example when she reflected on her use of consensus modeling to elicit students' ideas. Yvonne believed that students' experiences with the water cycle outside of the classroom were critical to their scientific modeling and learning within the unit. This is evident in her enactment of the unit. For example, when first introducing modeling to her students (Y_modeling_unit_11_12), Yvonne modified the lesson to connect to students' experiences, changing examples like the Grand Canyon to a local venue students had recently traveled to on a field trip. In her follow-up interview, Yvonne mentioned that while some of her students might have traveled to the Grand Canyon, she wanted to make sure all of her students could relate to the discussion, leading to her change (Y_11.12.12). These changes led to a discussion linking students' experiences and the class modeling lesson. Along with adding more opportunities for discussion she also made other small changes to the lesson, focusing students' attention on different *mechanisms*. She claimed 'it seemed like they got more content [referring to gravity] out of it this time than they have before because we followed [modeling] up with the water going down through the gravel, through the soil, through the sand' (Y_11.12.12). In this example Yvonne has rearranged her lessons so a focus on modeling gravity was followed by an investigation which provided an opportunity for the students to observe water moving down through earth materials in real time. While nothing else might have changed except the ordering, these small changes demonstrate that Yvonne is trying to link students' experiences with modeling, paying attention to *generality/abstraction* as well as highlight the *mechanism* of gravity through using models. By using these types of extension modeling activities for their students, these teachers created more scaffolding for their students by leveraging their understanding of the epistemic considerations to modeling.

Summary of RQ2. In response to research question two, we observed distinct patterns in the teachers' instructional practices to provide opportunities for students to engage in scientific modeling that were consistent with their conceptions articulated in response to research question one. While all of the teachers in this study included elements of modeling practices in their teaching, three of the teachers exhibited extended support for students around the epistemic considerations and modeling practices (Clarisse, Melissa, and Yvonne). While these three teachers still attended to the modeling practices of *construct* and *use*, they also emphasized the epistemic considerations of *generality/abstraction*, *mechanism*, and limitedly to *evidence* in their enactment of the *Water* unit. This subset of teachers created more opportunities for students to discuss and evaluate each other's work as compared to Alana, Janet, and Lenore, who more often guided student discussions toward a particular conclusion and were focused on teacher evaluations.

Synthesis and Discussion

In this study, we begin to investigate tentative relationships between elementary teachers' conceptualizations of scientific modeling and their model-based instructional practices when teaching science. This work is grounded in prior research emphasizing the crucial role teachers play in orchestrating model-based science teaching and learning across the grades (Berland et al., in press, Forbes et al., 2015; Schwarz, 2009; Gilbert, 2004; Harrison & Treagust, 2000; NGSS Lead States, 2013; Windschitl et al., 2008). Specifically, it leverages previous research on inservice elementary teachers (Abell & Roth, 1995; Akerson et al., 2008, 2009, 2011) to understand teacher conceptions and instructional practices related to scientific modeling within a disciplinary domain focused on water. Since teachers play a crucial role in fostering model-centric science learning environments, it is crucial to learn more about their knowledge and practices in order to support their model-based teaching at the appropriate age band (Akerson et al., 2011; Henze & Van Driel, 2011; Justi & Gilbert, 2003; Kahn, 2011; Oh & Oh, 2011). Thus far, research exploring elementary teachers' ideas about scientific modeling, as well as their instructional practices to support early learners' model-based reasoning, is limited. This work helps provide a baseline for better understanding elementary teachers' ideas and instructional practices for model-based teaching and learning.

First, both modeling practices and epistemic considerations are crucial underlying components of scientific modeling in science learning environments, including at the elementary level (i.e. Berland et al., in press; Forbes et. al., 2015; Zangori et al., 2015; Akerson et al., 2008; Crawford & Cullin, 2004; Henze & van Driel, 2011; Justi & van Driel, 2005; Justi & Gilbert, 2003). Our results contribute to this body of work by examining to what degree elementary teachers engage in these practices and considerations around modeling. Study findings highlight modeling practices and epistemic considerations that elementary teachers consider and prioritize in their pedagogical reasoning. While teachers in this study articulated ideas about many facets of scientific modeling, they most strongly emphasized modeling practices in lieu of epistemic considerations. Throughout their interviews, all six teachers emphasized the construction and use of models, as well as how models reflect and represent the real world. This finding is perhaps not surprising since it reinforces other research which has shown a starting point for K-12 teachers engaged in model-based teaching also revolves around the construction and representational nature of models, particularly at the preservice level (Schwarz, 2009; Crawford & Cullin, 2004; Danusso et al., 2010; Kenyon et al., 2011; Windschitl & Thompson, 2006). However, while 'construction' and 'use' may be perceived as drawing, labeling, and discussion, Oh and Oh (2011) point out, a crucial element of teachers' roles in supporting students' thinking is to help them link representations to their mental models through emphasis on underlying epistemology, as well.

We did observe a subset of study teachers, however, who emphasized epistemic considerations of *evidence* and *mechanism* in their ideas about modeling in the classroom. Interview data illustrated these three teachers' discussion of evidence and mechanism as important facets to modeling, suggesting an elaborated and more robust set of conceptions around scientific modeling. Prior research has documented a variety of challenges teachers confront when they attempt to engage in instruction to support students' scientific modeling. These include their own mastery of science content, how scientific tools are used, age-appropriate pedagogical approaches for science, as well as prior experiences with scientific models and the modeling process (Akerson et al., 2011; Gilbert, 2004; Marquez et al., 2006). By identifying specific epistemic considerations that some, but not all, teachers emphasized, study results provide important insights into additional dimensions of scientific modeling through which to support teachers and help them to overcome these challenges. Together, this body of literature highlights the need for teachers to have a robust understanding of the purpose, evidentiary basis, and explanatory and communicative dimensions of modeling, all of which are embodied by the epistemic considerations drawn from previous work (Schwarz et al., 2009) and utilized in the present study.

Second, we observed consistent trends between teachers' ideas about scientific modeling and their instructional practices to support students' model-based reasoning about water. Evidence suggests the variation observed in teachers' ideas correlated with and may have led to observed differences in classroom instruction, affording students differential opportunities to engage in scientific modeling. As ascertained through observational evidence of teachers' classroom instruction, a subset of three teachers utilized additional supports within the FOSS Water unit to help students move beyond identifying models as exact representations of reality and toward understanding that models are evidence-based explanatory tools. Given the alignment between teachers' interviews, video-recorded lesson enactments, and other associated data, we tentatively posit the possibility that their ideas about scientific modeling may influence their instructional practice, thus lending support to the argument in current literature that teachers' understandings of modeling are related to their instructional practice (Oh & Oh, 2011). Additionally, our research highlights *how* the teachers utilized their own conceptions of scientific modeling and associated pedagogy to foster model science learning environments. Teachers who exhibited greater understanding of the epistemic considerations drew in more support for their students, in the way of extra examples and increasing the number of small and large group discussions around water models and scientific modeling. Together, these findings reinforce the importance of teachers' understanding of both the practices and epistemic considerations that define scientific modeling, building upon prior work at the middle and secondary levels (Henze & van Driel, 2011; Justi & van Driel, 2005; Justi & Gilbert, 2003; Kahn, 2011; Marquez et al., 2006).

Implications and Conclusion

Elementary students must learn to use models to reason about complex natural systems such as the water cycle (NGSS Lead States, 2013). Scientific modeling provides students the opportunity to simplify large abstract systems, such as the hydrologic cycle, so that they may focus their sense-making on key processes and relationships. Therefore, engagement with modeling provides elementary students opportunities to challenge their pre-existing ideas in understanding the how and why of water cycles at a global scale (Forbes et al., 2015; Gunckel et al., 2012; Prain et al., 2009). However, despite growing evidence early learners can productively engage in modeling practices (Forbes et al., 2015; Schwarz et al., 2009; Zangori et al., 2015; Manz, 2012), opportunities for them to do so are typically not provided in elementary science learning environments. It is important that elementary teachers know, understand, and incorporate scientific modeling into science learning environments so that students can engage in sense-making about complex systems, such as the hydrologic cycle. Results from this study begin to shed light on how, why, and to what extent elementary teachers foster model-based science learning environments to support early learners in model-based reasoning about the water cycle. They have important implications for supporting teachers to learn to cultivate model-centered elementary science learning environments.

First, professional development and preservice elementary science teacher education should support inservice and preservice teachers in building understanding of the nature and purpose of scientific models as pliable reasoning tools that are used to interpret observations, formulate claims, and negotiate meaning in social settings (Akerson et al., 2008; Windschitl et al., 2008). Teachers need time to engage with models and modeling as learners, to use their own constructed models as knowledge-building tools, and engage with their models in ways that facilitate their epistemic understanding of the nature and purpose of models. This requires extended opportunities to engage with different representational resources such as concrete models (e.g. hands-on investigations) as well as abstract models (e.g. 2-D representations) to begin to craft ideas about the ways in which modeling serves as a bridge between observation and theory (Akerson et al., 2009; Oh & Oh, 2011). One way to provide these experiences is to create authentic modeling projects for inservice and preservice teachers using authentic student artifacts and embedding elements of content and reflection. Further, preservice teachers' knowledge about the nature and purpose of scientific modeling may be built through including model-based teaching and learning in science content courses where model usage is tied to epistemic considerations and pedagogical practices. Once teachers begin to build an understanding of the nature and purpose of scientific modeling, then they may be better prepared to facilitate model-based learning in their classrooms.

Second, teachers need appropriate tools with which to support elementary students to engage substantively in scientific modeling in the classroom. Curriculum materials should not only provide resources for teachers to engage students in model-based learning, but also instructional rationales for why such practices are warranted in model-based science learning environments (Davis et al., 2014). Embedding educative elements into curriculum materials to help teachers understand practices and epistemic considerations underlying scientific modeling could help teachers to better support students' model-based reasoning. This might include providing vignettes within curriculum materials that identify ways to include epistemic considerations of modeling into their lessons. Recent research has begun to suggest that, with support, early learners are capable of using models to reason scientifically and build knowledge about natural phenomenon (Lehrer & Schauble, 2010; Manz, 2012). Therefore, teachers require curricular tools that engage their students in the practices of modeling AND provide them with instructional resources for the 'how' and 'why' of modeling. In this manner, they are supported in fostering model-based learning in their classrooms as well as building their own understanding for how and why they should provide these opportunities to their students.

These results also help lay the foundation for future investigations of elementary teachers' learning and developing capacities to support students' model-based reasoning about water over time. Over the next several years, we will continue working with these teachers to plan, implement, and study ongoing revisions to the unit that afford students meaningful experiences using models to learn about water. This work will ultimately afford opportunities to conduct empirical work that may establish links between curricular interventions, teachers' instructional practices, and student outcomes related to scientific modeling in particular disciplinary domains. Such work will play a crucial role in providing early learners with rich opportunities to experience with the natural world through engagement in the scientific practice of modeling.

Acknowledgements

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We appreciate the interest and cooperation of Christopher Soldat, Julie Foltz, Sheila Barron, and the students and teachers who made this research possible. An earlier version of this paper was presented at the 2014 meeting of the National Association for Research in Science Teaching in Pittsburgh, PA and 2015 meeting of the American Educational Research Association in Chicago, IL.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

This material is based upon work supported by the National Science Foundation [pDRL-1443223].

References

Abell, S. K., & Roth, M. (1995). Reflections on a fifth-grade life science lesson: Making sense of children's understanding of scientific models. *International Journal of Science Education*, *17*(1), 59–74.

Akerson, V. L., Cullen, T. A., & Hanson, D. L. (2009). Fostering a community of practice through a professional development program to improve elementary teachers' views of nature of science and teaching practice. *Journal of Research in Science and Teaching*, *46*(10), 1090–1113. doi:10.1002/tea.20303

Akerson, V. L., Townsend, J. S., Donnelly, L. A., Hanson, D. L., Tira, P., & White, O. (2008). Scientific modeling for inquiring teachers network (SMIT'N): The influence on elementary teachers' views of nature of science, inquiry, and modeling. *Journal of Science Teacher Education*, *20*, 21–40. doi:10.10007/s10972-008-9116-5

Akerson, V. L., White, O., Colak, H., & Pongsanon, K. (2011). Relationships between elementary teachers' conceptions of scientific modeling and the nature of science. In M. S. Khine & I. M.

Saleh (Eds.), *Models and modeling: Models and modeling in science education* (pp. 221–237). New York, NY: Springer Science + Business Media.

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (in press). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*. doi: 10.1002.tea.21257

Crawford, B., & Cullin, M. (2004). Dynamic assessments of preservice teachers' knowledge of models and modelling. In K. Boersma, M. Goedhart, O. de Jong, & H. Eijkelhof (Eds.), *Research and the quality of science education* (pp. 309–323). Dordrecht, Netherlands: Springer.

Creswell, J. W. (2006). *Qualitative inquiry & research design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Danusso, L., Testa, I., & Vicentini, M. (2010). Improving prospective teachers' knowledge about scientific models and modelling: Design and evaluation of a teachers' education intervention. *International Journal of Science Education*, *32*(7), 871–905. doi:10.1080/09500690902833221

Davis, E. A., Palincsar, A. S., Arias, A. M., Bismack, A. S., Marulis, L. M., & Iwashyna, S. K. (2014). Designing educative curriculum materials: A theoretically and empirically driven process. *Harvard Educational Review*, *84*(1), 24–52.

Forbes, C., Zangori, L., & Schwarz, C. (2015). Empirical validation of integrated learning performances for hydrologic phenomena: 3rd-grade students' model-driven explanation-construction. *Journal of Research in Science Teaching*, *52*(7), 895–921. doi:10.1002/tea.21226

FOSS: Water-Overview. (2009). *FOSS: Water unit* (2nd ed.). Retrieved from https://www.fossweb.com/delegate/ssi-wdf-ucm-webContent?dDocName=D1424929

Gilbert, J. K. (2004). Models and modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, *2*(2), 115–130.

Gunckel, K. L., Covitt, B. A., Salinas, I., & Anderson, C. W. (2012). A learning progression for water in socio-ecological systems. *Journal of Research in Science Teaching*, *49*(7), 843–868.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education*, *22*(9), 1011–1026. doi:10.1080/095006900416884

Henze, I., & van Driel, J. (2011). Science teachers' knowledge about learning and teaching models and modeling in public understanding of science. In M. S. Khine & I. M. Saleh (Eds.), *Models and modeling: Models and modeling in science education* (6th ed., pp. 239–261). New York, NY: Springer Science + Business Media.

Justi, R., & van Driel, J. (2005). The development of science teachers' knowledge on models and modelling: Promoting, characterizing, and understanding the process. *International Journal of Science Education*, *27*(5), 549–573. doi:10.1080/0950069042000323773

Justi, R., & Gilbert, J. (2003). Teachers' views on the nature of models. *International Journal of Science Education*, *25*(11), 1369–1386. doi:10.1080/0950069032000070324

Kahn, S. (2011). What's missing in model-based teaching? *Journal of Science Teacher Education*, *22*, 535–560. doi:10.1007/s10972-011-9248-x

Kenyon, L., Davis, E., & Hug. B. (2011). Design approaches to support preservice teachers in scientific modeling. *Journal of Science Teacher Education*, *22*(1), 1–21.

Lehrer, R., & Schauble, L. (2010). What kind of explanation is a model? In M. K. Stein & L. Kucan (Eds.), *Instructional explanations in the disciplines* (pp. 9–22). New York, NY: Springer Science + Business Media. doi:10.1007/978-1-4419-0594-9_2

Manz, E. (2012). Understanding the co-development of modeling practice and ecological knowledge. *Science Education*, *96*(6), 1071–1105.

Marquez, C., Izquierdo, M., & Espinet, M. (2006). Multimodal science teachers' discourse in modeling the water cycle. *Science Education*, *90*(2), 202–226.

Merriam, S. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey-Bass.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.

Oh, P., & Oh, S. (2011). What teachers of science need to know about models: An overview. *International Journal of Science Education*, *33*(8), 1109–1130. doi:10.1080/09500693.2010.502191

Patton, M. Q. (2001). *Qualitative research and evaluation methods*. Thousand Oaks, CA: Sage.

Prain, V., Tytler, R., &. Peterson, S. (2009). Multiple representation in learning about evaporation. *International Journal of Science Education*, *31*(6), 787–808. doi:10.1080/09500690701824249

Schwarz, C. V. (2009). Developing preservice elementary teachers' knowledge and practices through modeling-centered scientific inquiry. *Science Education*, *93*(4), 720–744. doi: 10.1002/sce.20324

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learner. *Journal of Research in Science Teaching*, *46* (6), 632–654. doi: 10.1002/tea.20311

Windschitl, M., & Thompson, J. (2006). Transcending simple forms of school science investigations: Can pre-service instruction foster teachers' understandings of model-based inquiry? *American Educational Research Journal*, *43*(4), 783–835.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92* (5), 941–967. doi:10.1002/sce.2025

Zangori, L., Forbes, C. T., & Schwarz, C. V. (2015). Scaffolding 3rd-grade students' model-based explanations about hydrologic cycling through curricular and instructional supports. *Science & Education*, *24*, 957–981. doi:10.1007/s11191-015-9771-9