

# Development of an Empirically-Based Learning Performances Framework for 3rd-Grade Students' Model-Based Explanations about Hydrologic Cycling

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**Abstract:** Elementary students should engage in the articulation, negotiation, and revision of model-based explanations. However, scientific modeling remains underemphasized in elementary science learning environments and more research is needed to understand early learners' engagement in domain-specific modeling practices. To address this need, we are engaged in design-based research to foster and investigate 3rd-grade students' model-based explanations for hydrologic phenomena. First, we developed an empirically-based learning performances framework that integrates relevant science content and modeling practices. This framework a) grounds the iterative adaptation and enhancement of a commonly-used curricular unit and b) lays the foundation for ongoing development of an associated learning progression. Second, we report on findings from analysis of 3<sup>rd</sup>-grade students' model-based explanations around the water cycle. Results indicate that elementary students generate mechanism-based causal claims and highlight target concepts and modeling practices emphasized in students' model-based explanations for hydrologic cycling.

## Study Rationale and Contribution

To become scientifically-literate, students must learn to reason about complex, global issues such as water resource management and sustainability at an early age (American Association for the Advancement of Science [AAAS], 2007; National Research Council [NRC], 2012; 2007). Early learners' understanding of the nature of water, how it cycles and changes state, and its relationship to human activities, are all necessary to help them make sense of everyday experiences and to serve as a foundation for their learning about other Earth systems and water-related global issues with scientific, social, and economic dimensions. However, past research has shown that early learners often struggle to understand hydrologic phenomena (e.g., Bar, 1989; Henriques, 2002). Elementary students therefore need greater support for learning about hydrologic systems.

To develop conceptual understanding of hydrologic systems, students must engage in theory-driven scientific practices focused on the articulation, negotiation, and revision of model-based explanations (Braaten & Windschitl, 2011; NRC, 2007; Windschitl, Thompson, & Braaten, 2008). Modeling is a core scientific practice advocated in the *Next Generation Science Standards* (NRC, 2012) in which models, or working representations of complex natural systems, are used to reason scientifically about system-specific phenomena. Modeling practices, however, remain underemphasized in K-12 science, particularly in the elementary grades, despite growing evidence that, with scaffolding, elementary students can effectively engage in scientific practices (Hapgood, Magnusson, & Palinscar, 2004; Hardy, Jonen, Möller, & Stern, 2006; Herrenkohl & Cornelius, 2013; Lehrer & Schauble, 2006; Manz, 2012; Metz, 2004; McNeill, 2011). Investigations of elementary students' model-based reasoning, particularly about the water cycle, are largely absent from the literature. More research is therefore needed to inform the design of elementary science learning environments that afford students opportunities to develop and use models to formulate explanations.

To begin to address these issues in the field, we are engaged in three years of exploratory research and development to foster and investigate 3<sup>rd</sup>-grade students' model-based explanations about the water cycle. We draw upon work on scientific modeling (Lehrer & Schauble, 2006; Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008), content- and practice-based learning progressions (Alonzo & Steedle, 2008; Lee & Liu, 2010; Mohan, Chen, & Anderson, 2009; Stevens, Delgado, & Krajcik, 2010), and heuristics for curriculum materials development (Krajcik, McNeill, & Reiser, 2007; Shin, Stevens, & Krajcik, 2010) to articulate a domain-specific student learning performance framework that integrates science content and scientific practice (i.e., modeling). Such learning performances are critical to ground the design of curricular, instructional, and assessment dimensions of classroom interventions. In this paper, we report on work from Year 1 of the project: a) the empirical development of learning performances and b) analysis of student artifacts to investigate their use of models to formulate evidence-based explanations for hydrologic cycling. We ask two research questions: 1) *what are measureable levels of 3<sup>rd</sup>-grade students' model-based explanations about water?* and 2) *how do 3<sup>rd</sup>-grade students formulate model-based explanations for target concepts related to water?* This work foregrounds elementary students' learning as constituent component of their discipline-specific epistemic practices and therefore exemplifies the ICLS 2014 conference theme of 'learning and becoming in practice'.

## Theoretical Framework

### Students' Model-Based Reasoning

The hydrologic cycle is a foundational model-based scientific concept highlighted throughout the K-12 science curriculum (AAAS, 2007; NRC, 2012). Models are defined as abstracted, multi-modal representations of natural systems, not exact recreations, which are used within communities to illustrate, predict, and explain system-specific scientific phenomena. They are used extensively by hydrologists, climate scientists, meteorologists, and soil scientists to make predictions about, investigate, and explain hydrologic cycling. Past research has shown, however, that students possess a diverse set of pre-existing ideas about hydrologic phenomena, ideas that are often times inconsistent with scientific explanations (e.g., Bar, 1989; Henriques, 2002). Model-based investigative practices can support students in constructing, negotiating, and revising explanations for scientific phenomena in a variety of scientific disciplines. Students' *construction*, *evaluation*, and *revision* of models of hydrologic cycling can help them make their thinking visible, but such models also serve to shape their reasoning about water systems through *use*. As such, models act as both *representations* and *tools*, not only serving as records or artifacts of sense-making activity, but also playing a critical role in shaping reasoning activity itself. Past research has shown that elementary students often have difficulty engaging in model-based reasoning around scientific phenomena (Lehrer & Schauble, 2006; Schwarz et al., 2009). They may emphasize singular events or phenomena in their models rather than interacting systems. Even when students do focus on broader systems, they may not connect system-specific phenomena to empirical data. While developmental limitations are often viewed as obstacles to young students' learning, the authors of *Taking Science to School* (NRC, 2007) note that "young children have a repertoire of cognitive capacities directly related to many aspects of scientific practice, and it is problematic to view these simply as a product of...development" (pg. 44). Recent empirical research provides evidence that, with scaffolding, early learners can engage productively in scientific modeling (Lehrer & Schauble, 2006; Manz, 2012).

### An Integrated Learning Performances Framework for Model-Based Explanations

A comprehensive framework is required to both foster and assess students' formulation of model-based explanations in effectively-designed elementary science learning environments. Empirically-tested learning progressions have been developed to account for students' conceptual understanding in various content domains (e.g., Alonzo & Steedle, 2008; Lee & Liu, 2010; Mohan, Chen, & Anderson, 2009; Stevens, Delgado, & Krajcik, 2010). However, knowing and doing are mutually constitutive – what the learner knows influences what he/she does, and vice versa. The practice-based nature of learning is encapsulated by *learning performances* (Krajcik, McNeill, & Reiser, 2007; Shin et al., 2010), or behavioral claims that specify how students engage in scientific practices to employ their conceptual knowledge. A learning progression is comprised of individual learning performances that represent domain-specific scientific practices. The learning progressions community has begun to acknowledge the need for learning progressions that not only account for students' *conceptual understanding*, but also their engagement in *scientific practices* (e.g., Schwarz et al., 2009; Shin et al., 2010). While a small number of researchers have explored practice-based learning progressions, including those for elementary students' modeling practice and model-based reasoning (Lehrer & Schauble, 2006; Schwarz et al., 2009), much more work is needed to articulate practice-based learning progressions that account for BOTH epistemic and conceptual dimensions of elementary students' domain-specific learning.

We have generated a hypothetical learning performances framework for students' use of scientific models to formulate explanations for target concepts around the big idea that all geosystems are the result of energy flow and mass cycling (AAAS, 2007; NRC, 2012). As related to water, the three concepts underlying the big idea targeted in this project are *water exists in different forms below, at, and above the Earth's surface* (Concept 1); *water on Earth is in motion and cycles at a global scale* (Concept 2); and *the cyclical movement of water on Earth shapes and impacts the geosphere* (Concept 3). Students are afforded opportunities to generate and use models of the water cycle to formulate evidence-based explanations for each of these concepts. Epistemic dimensions of scientific explanation include *components*, *sequence*, *explanatory process*, *mapping*, and *principle* (Schwarz et al., 2009). The learning performances framework is shown in Table 1.

Table 1: Learning performances framework for students' model-based explanations about hydrologic cycling

	(1) Forms of water	(2) Water in motion	(3) Water/geosphere interactions
Components	The properties of water enable it to exist in 3 forms - liquid, vapor/gas, and ice – depending on temperature. Temperature affects the state of water. This relationship explains why	The cyclic motion of water above, on, and within the Earth is largely determined by the force of gravity and geospheric components	Just as water's movement is influenced by the geosphere, water in turn shapes the geosphere as it moves over and through it. Many landforms and geospheric features we observe everyday are
Sequence			
Explanatory Process			
Mapping			
Principle			

Components	water is found all over the Earth in different forms.	with which water interacts.	a result of these processes.
Sequence			
Explanatory Process			
Mapping			
Principle			

Together, these features comprise mechanism-based explanations (Braaten & Windschitl, 2011; NRC, 2012) for water-related phenomena. The framework in Table 1 foregrounds how students attend to scientific ‘mechanisms’, or the “unobservable, theoretical components” (Braaten & Windschitl, 2011, p. 662) that bring about an observable effect. The *components* feature emphasizes both visible and non-visible elements of the phenomena. *Sequences* establish temporal relations between system sub-processes. *Explanatory process* emphasizes mechanisms that explain process sequences. *Principle* involves a generalization about the phenomena that relates to abstracted components of the model. Finally, *mapping* emphasizes explicit statements that explain how the representation or components in the representation relates to the physical phenomenon. A model-based explanation occurs when students use systems representations to build on their existing knowledge to understand ‘how’ and ‘why’ they observed what they did (e.g. the mechanism). Consistent with this view, the purpose of explanation construction in the science classroom is for students to make sense of how the world works by connecting the cause and effect of natural phenomena with its underlying mechanism (explanation).

## Method

The 3-year project is grounded in design-based empirical research. Empirical findings are used in an iterative manner to inform the design and implementation of curricular and instruction interventions to foster students’ construction of model-based explanations about water.

## Participants and Context

In Year 1 of the project, six 3<sup>rd</sup>-grade elementary teachers were recruited from schools in a Midwestern state. 179 eligible 3<sup>rd</sup>-grade teachers taught kit-based elementary science curriculum materials provided and managed by a regional educational services unit (ESU). Project teachers were selected using purposeful, maximum-variation sampling (Patton, 2001) in consultation with ESU staff to identify experienced teachers from urban, rural, and suburban settings serving students from underrepresented demographic groups with widely variant socio-economic profiles. Participant teachers already used the Full Option Science System (FOSS) Water module through the ESU. While FOSS units are reasonably well-developed, the Water module does not engage students in substantial modeling to situate domain-specific conceptual understanding targeted in unit investigations within broader, systems understandings of hydrologic cycling. We therefore engage in *construct-centered design* (CCD - Shin et al., 2010) and use the learning performances framework to enhance the FOSS Water module to more effectively foster students’ model-based explanation-construction. CCD is based upon empirically-tested heuristics for learning progressions-based curriculum development (Krajcik, McNeill, & Reiser, 2007) and involves four steps. First and second, we define the content and articulate learning performances (Table 1) that provide the conceptual and epistemic underpinnings of module development. Third, we use learning performances developed in Step 2 to design an accompanying modeling task that is integrated into the existing module. In Year 1, we employed a limited version of the modeling task where students construct models at the beginning at the end of the unit only. Fourth, the full version of the modeling task will be developed and implemented in Years 2 and 3 based upon empirical results from Year 1.

## Data Collection

Data collection occurred during the enactments of the modified FOSS Water module in each participant teacher’s classroom. To investigate 3<sup>rd</sup>-grade students’ model-based explanations for water, we draw upon a number of data sources. First, we collected pre- and post-unit student modeling tasks ( $n_{pre}=112$ ,  $n_{post}=107$ ). The modeling task is designed to elicit student learning performances in Table 1 through diagrammatic, concept-process models in which students draw upon a variety of text-, numeric-, and image-based elements. Students are prompted with the question, ‘What happens to rain when it reaches the Earth’s surface?’ and asked to use their existing ideas to *construct* a model of groundwater cycling. Students concluded the module by *evaluating* and *revising* their models. Students were also asked to justify their modeling decisions through scaffolded written responses. Second, clinical interviews were conducted with five students from each classroom in conjunction with their pre- ( $n=30$ ) and post-unit models ( $n=30$ ). Students were purposefully selected (Patton, 2001) by the research team and the six participant teachers to represent a continuum of academic achievement and classroom engagement. The clinical interview protocols were designed to elicit student reflections on their water cycle models and written responses around each of the learning performances in Table 1.

## Data Analysis

Data analysis involved both quantitative and qualitative methods. All audio recorded interview data was transcribed, student artifacts scanned and digitized, and all data imported into ATLAS.ti, a widely-available qualitative data analysis suite, for coding. Student interview data was coded using the learning performances framework in Table 1. This coding process involved 15 codes, one for *components*, *sequence*, *explanatory process*, *principle*, and *mapping* for each of the three target concepts. Joint coding was performed on a 10% data sample. Inter-coder reliability was 85% before discussion and 100% after discussion. Code queries were conducted to isolate data for each of the codes representing learning performances in Table 1. Within each data subset, analyses focused on the identification and articulation of measureable ‘levels’ for each component of students’ model-based explanations about the three concepts in Table 1. Qualitative analysis involved an iterative process of data reduction, displaying, and verification to identify learning performance levels. The levels of a learning performance represent varying degrees of sophistication for domain-specific, model-based explanation-construction. The learning performance levels were then used to develop a scoring rubric as a scaled measure of students’ understanding of the three target concepts as evidenced in the models and written responses in the modeling task. The rubric allowed for examination of the learning performances at three levels of sophistication (Levels: 0 – 3). Students’ pre-unit and postunit modeling tasks were scored using the rubric. The student data was nested per teacher which required a multi-level model analysis (Littell, Milliken, Stroup, Wollonger & Schabenger, 2006). The analysis was conducted in SAS using a double-factor repeated-measures mixed-model ANOVA. The dependent variable was the postunit models while the independent variables were the dimension, concept, and the interaction between dimension and concept. The ANOVA formula is  $Y_{ijk} = \mu + \alpha_j + \beta_k + (\alpha\beta)_{jk} + e_{ijk}$  where  $i$  is the pre or postunit models,  $j$  is concept,  $k$  is dimension, and  $e$  is the error in the dependent and independent variables. Statistical-significance of the interaction term indicates that some combination of dimension and the concepts affect the models (Kleinbaum et al., 1998).

## Results

### Defining Levels of Learning Performances

Analysis of the student interviews yielded three definitive levels for each of the learning performances illustrated in Table 1. In this paper, we discuss learning performance levels for each of the epistemic features of model-based explanation in Table 1 for Concept 1 to illustrate ranges of students’ model-based explanation-construction and distinguishing characteristics of the learning performance levels.

For a model to illustrate dynamic interactions within a system, it must first include the relevant *components*. For Concept 1, students should recognize that water exists in three forms – liquid, ice, and vapor – and that water is represented in these three forms at various points throughout the water cycle. Further, an important underlying characteristic of mechanism-based explanations is accounting for unseen/unobservable forces that drive observable cause and effect. The three levels of the *components* learning performance for Concept 1 emphasize student understanding of both visible and non-visible phases of water. At Level 1, students include at least one representation of VISIBLE water in a naturally occurring form (rain, surface water, ice, clouds, etc.). At Level 2, students include multiple representations of both visible and non-visible water. Non-visible water forms would include water vapor. Finally, at Level 3, students include multiple visible and non-visible water forms, including subsurface groundwater. Level 3 understanding is illustrated by the following interview excerpt:

- S: When the water hits a tree it grows and then when it takes it out, it takes water from the tree and the surface runoff I did a tiny mountain right there and then the water falling down.  
I: That’s your hill with the surface runoff?  
S: Then the rain goes up to the ground and then it goes up like the last one. Its evaporation, condensation and then precipitation happens when there’s cold and hot air up there. When it starts to get plus and minuses there’s lightning and thunderstorm and everything.  
(P:46:31:42)

At a Level 3, students identify both visible and non-visible atmospheric and geospheric components of the water cycle which, as illustrated in the sample student quote, is an enabling factor in their articulation of process and mechanism for hydrologic system dynamics.

For a model to illustrate mechanisms for system processes, it must first also include the relevant *sequence* of these processes and their constituent parts. For Concept 1, students should recognize that water goes through phase changes between its three forms – liquid, ice, and vapor – and that phase change occurs throughout the water cycle. The three levels of the *sequence* learning performance for Concept 1 emphasize student understanding of both what phase changes occur and the directionality or order in which they occur. For the *sequence* dimension of Concept 1, Level 1 understanding involves simple description of at least one phase

change, for example, from water vapor to liquid water in the form of precipitation. At Level 2, students began to recognize multiple phase changes that occur at places in the water cycle and how one sequentially leads to the next. However, students do not illustrate understanding that phase changes can occur in multiple directions. At a Level 3, students begin to describe phase change in multiple directions. Level 3 understanding is illustrated by the following interview excerpt:

I: ... do you think there is water up in the sky all of the time? How does it get up there?

S: Yes, it evaporates...which means that little tiny, that you can't see, water droplets come out of the oceans, lakes, rivers, and ponds, and they go up into the clouds. And, when there is too many water droplets in the clouds, it starts to rain or snow. (P6:48:55)

In the Level 3 example student quote, the student describes both evaporation and precipitation simultaneously. While condensation is also an important process in part of the water cycle, no student described it as a stand-alone, mediating phenomena that leads to cloud formation.

Building upon students' model-based reasoning of both system *components* and *sequence*, students should articulate a mechanism-based *explanatory process* for system processes represented in their models. For Concept 1, students should recognize that varying temperature impacts phase change as an unseen causal mechanism. The three levels of the Concept 1 *explanatory process* learning performance emphasize student understanding of relationships between related constructs and their underlying mechanisms. For the *explanatory process* dimension of Concept 1, Level 1 understanding involves simple description of the process, such as components or sequences, indicative of the absence of a formal mechanism, without which there is no explanation-construction occurring. For example, students might recognize ice in polar regions and that it can melt without referencing temperature. At Level 2, students began to recognize a relationship between temperature and phase change. At this level, it is an associative relationship, however, not a causal one, in that students may associate changing temperature with phase change but not attribute one to the other. At a Level 3, students begin to represent temperature as a direct, causal agent that explains observable phase change as part of the water cycle. Students' explanations are grounded in models that represent temperature in some way as a critical element of the water cycle. Level 3 understanding is illustrated by the following interview excerpt:

S: I put the pluses for hot and I put some pluses there you can't see the minuses much that I put up there for cold. That also creates rain, it helps rain fall.

I: The minuses, the cold helps rain fall?

S: Yes but usually the hot on the bottom. Yes but when the hot is on the top of the cold on the bottom that actually creates rain too. See? Usually it's the other way around and that's also why it creates rain. (P 1: 3053:3059)

As illustrated in the excerpt, the student describes heat causing evaporation and cooling causing condensation/precipitation, which he/she represented in the model as +s and -s.

A critical element of model-based explanations involves students' making connections between their representation of the phenomena and the phenomena itself. This component, referred to as *mapping*, involves students explicitly articulating how their model, or elements of their model, relates to the natural system. The three levels of the mapping learning performance for Concept 1 emphasize students' relating their representations of forms of water to the natural world. At Level 1 understanding, students simply state that some aspect of their model is intended to represent some component of the system. At Level 2, students provide some rationale for how or why their model represents the natural system. For example, students may state that clouds are grey because they're full of water as they have observed on rainy days. At a Level 3, students articulate explicit rationales for representational elements of their models and how they map onto the real-world phenomena. Level 3 understanding is illustrated by the following interview excerpt:

I: You said condensation was something you learned about in class...where is that in your model?

S: In the test we did in [class], I drew the cloud and cut the cloud in half and showed you the little water droplets in it. That side had more. That side had less. Then I made a little circle and a little line to connect it with a bigger circle to show that when it was condensing and ...two of the little gas water droplets were coming together and getting bigger in there and turning into rain drops and falling. (P 4: 1574:1599)

In the Level 3 example student quote, the student describes how he/she represented evaporation and condensation to illustrate phase change underlying these processes.

Finally, an important aspect of model-based explanations involves students generalizing from their model about an underlying scientific *principle*. While specific *components* and *sequences* represented in the model *map* onto real-world phenomena, and model elements illustrate *explanatory processes* for these systems, students should also be able to derive generalized principles about system-specific phenomena. The three levels

of the *principle* learning performance for Concept 1 emphasize students' relating their representations of forms of water to forms of water in the natural world. At Level 1 understanding, students may identify a generalized scientific principle, but do so either erroneously or inconsistently. For example, students might attribute gravity to phase change or incorrectly state that increasing temperature causes water to freeze. Level 2 understanding involves some accurate articulation of a relevant scientific principle but relating it incompletely. At Level 3, students correctly and fully match components of the model with an underlying scientific principle. Level 3 understanding is illustrated by the following interview excerpt:

- S: Usually, water that stays there usually goes deeper into the ground.  
 I: Why does it go deeper?  
 S: The big drops probably are heavier so it goes down faster so it, so like the air can't push it up again. And the small drops go down slower because and because they're lighter and they're, um, the air can push them up easier (P24: 827:881)

In the Level 3 example quote, the student describes a fundamental cause and effect relationship that explains the presence of subsurface groundwater – that the downward force of water in large volumes can more easily move through Earth materials. However, the student does not attribute this to gravity or other explanatory processes, thus illustrating principle as an epistemic commitment distinct from explanatory process.

### Students' Model-Based Explanations for Hydrologic Cycling

To address research question #2, we analyzed students' pre- and postunit modeling tasks for the five epistemic features of mechanism-based explanation construction (Table 1). First, analysis suggests that there was no statistically-significant difference between epistemic features (Table 1) represented in the students' pre- and postunit models. However, a statistically-significant difference was observed between pre- and postunit models for each Concept 1,  $F(2,3147) = 7.12, p < .0001$ , Concept 2,  $F(2,3147) = 6.77, p < .0001$ , and Concept 3,  $F(2,3147) = 21.61, p < .0001$ . These results indicate that while the students did not include additional epistemic features within each concept from pre- to postunit models, the features they did represent for each concept increased in sophistication over the course of the unit. In the postunit models, we found a significant interaction between features of epistemic dimensions and concepts,  $F(8, 1355) = 45.67, p < 0.0001$ , when controlling for the pre-unit model scores. We used paired-samples t-tests to make *post hoc* comparisons between concepts for each feature to ascertain which epistemic dimension contributed most to differences observed between target concepts in postunit modeling tasks. The results indicate statistical significance for *mapping*,  $t(1355) = -5.16, p < 0.0001$ , and *sequence*,  $t(1355) = -11.53, p < 0.0001$ , between Concept 1 and 2. Students' engaged in more sophisticated representations of Concept 2 ( $\bar{x} = 1.08$ ) than Concept 1 ( $\bar{x} = 0.76$ ) due to a stronger emphasis on representation of *sequences* and *mapping* for Concept 2. Further, differences between epistemic features for Concept 3 compared to both Concept 1 and 2 were all statistically-significant. This result is due to the less frequent representation of Concept 3 ( $\bar{x} = 0.08$ ) in students' models. Together, these results suggest that students' models emphasized water movement more so than the forms of water. Further, representations of interactions between water and Earth materials (Concept 3) were rare. Students' representations of target concepts increased in sophistication during the unit. Differences in representations of target concepts in students' postunit models were largely attributable to two epistemic features: *sequence* and *mapping*.

Findings from qualitative analysis for research question 2 illustrate two dominant themes. First, findings show that students' efforts at *mapping* most frequently emphasized water in motion above ground and their connection of their representations to the physical world did not typically change from pre to postunit models. Students expressed that their 2-D drawings were insufficient for 'realistic' representations of precipitation and were concerned that they were unable to represent all of the pieces of this process that they felt were necessary in the 'real world'. This was most frequently observed in students' attempts to represent the presence of the sun prior to rain, in which students would draw the sun, and then the 'absence' of the sun during rain, which often involved students drawing over the sun. When asked why the sun was initially present and then drawn over they identified that in the 'real' world, the sun is originally visible but "when it rains, it gets all foggy and clouds start to turn gray and then it [the clouds] just covers up the sun" (P 1: 3377:3386). In their manner of including then removing the sun, they were attempting to map accurately the processes they observed occur during precipitation rather than identifying their drawings as abstractions of the physical world (Figure 1).

Second, we found that *sequences* underlying students' model-based explanations relied on combining scientifically-accepted mechanisms (e.g. gravity, temperature) with their pre-existing mechanisms (e.g. alternate conceptions). These mechanisms most frequently explained the "hidden" sequences of evaporation. While students articulated in both their pre- and postunit models that temperature change was necessary for water to 'leave clouds' and gravity was necessary for water to 'fall to the ground', they also relied on and incorporated alternate conceptions for *how* and *why* water returns to the sky from the clouds. Most frequently students' sequences of water vapor returning to the sky were drawn as one large quantity moving as a single entity from



the ground surface to a large dark cloud. Their mechanism for this movement was represented and articulated as tubes reaching from the ground to a specific cloud. For example, while Caroline represented that an increase in temperature was the mechanism for liquid water to change its state to water vapor, her mechanism for water vapor returning to the sky was “invisible helium tubes” that “take the water vapor and bring it up to the cloud” (Figure 1, P54:037). Additionally we found some students were unable to conceptualize how water might return to the sky so they did not include sequences for water’s return. They articulated mechanisms for water to remain on the because the Earth ‘holds’ water by “sucking” or “absorbing” water to store (N.EM2, W.S1M1).

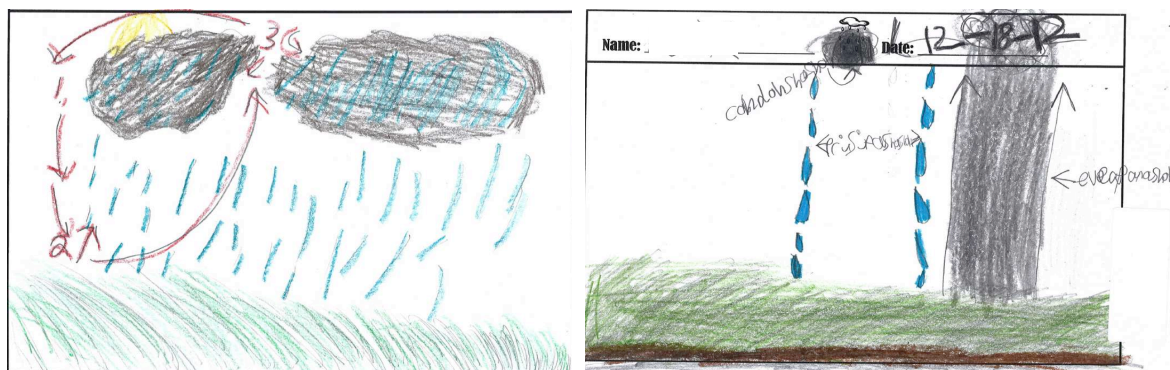


Figure 1. Student model of ‘hidden sun’ (S9:N) and ‘evaporation’ (W:S17)

## Conclusions and Implications

Scientific modeling is a core scientific practice highlighted in the *Next Generation Science Standards* (NRC, 2012). Modeling practices, however, remain underemphasized in K-12 science, particularly in the elementary grades (Windschitl, Thompson, & Braaten, 2008; NRC, 2007) and, as a result, little research exists to guide efforts to foster epistemically-rich, model-centric elementary science learning environments. This study leverages and makes contributions to research on model-based science teaching and learning (Lehrer & Schauble, 2004; Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008) and content- and practice-based learning progressions (Alonzo & Steedle, 2008; Lee & Liu, 2010; Mohan, Chen, & Anderson, 2009; Stevens, Delgado, & Krajcik, 2010) through the development of a learning performances framework and empirical findings from its use to investigate 3<sup>rd</sup>-grade students’ model-based explanations for hydrologic cycling.

Past research has illustrated aspects of the water cycle, a core subject in the K-12 curriculum (NRC, 2012), that are often challenging for students (Bar, 1989; Henriques, 2002). Though recent research has shown that elementary students can learn to effectively engage in scientific practices, including scientific modeling, to develop conceptual understanding (Hapgood, Magnusson, & Palinscar, 2004; Hardy, Jonen, Möller, & Stern, 2006; Herrenkohl & Cornelius, 2013; Lehrer & Schauble, 2006; Manz, 2012; Metz, 2004; McNeill, 2011), little work has been conducted to investigate students’ formulation of model-based explanations for hydrologic cycling. Findings from this study highlight the range of ideas evident in students’ model-based explanations for system processes that underlie the water cycle. Results suggest 3<sup>rd</sup>-grade students emphasize sequences of water movement and statements that map representations of water movement onto real-world phenomena more effectively than for the forms of water. Further, students do not foreground the relationship between water and the Earth in their model-based reasoning about the water cycle. These findings provide insight not only into leverage points through which to foster early learners’ formulation of model-based explanations for water, but also those concepts and epistemic features for which curricular and instructional guidance would likely be most impactful. Further work is needed to explore how to build upon the domain-specific (i.e., hydrologic cycle) epistemic commitments and conceptual strengths students exhibit, as well as appropriate design and implementation of scaffolds for students’ use of models to reason about the water cycle.

This work also highlights the utility of a set of *empirically-based learning performances* (Krajcik, McNeill, & Reiser, 2007), developed from the ground up as part of a design-based research program, that can be used to both design and study discipline-specific model-centric science learning environments. The integrated learning performances framework developed here illustrates critical trends in 3<sup>rd</sup>-grade students’ model-based explanations for hydrologic cycling, such as a de-emphasis on unobservable components of water systems, bidirectionality of system processes, and rationales for representational norms. Measureable levels of model-based explanations for water cycle processes, based upon empirically-derived trends in students’ thinking, have grounded the ongoing study of the curricular and instructional components of these 3<sup>rd</sup>-grade science learning environments. Such work is necessary to inform the future development of learning progressions that a) integrate the scientific practices of modeling AND domain-specific concepts and b) are sufficiently robust to account for elementary students’ learning within the Earth Sciences, a domain within which little learning progressions work has thus far been carried out. This learning performances framework, as well as the

modeling task and findings from project research, will inform ongoing efforts to design elementary science learning environments through the development of science curriculum materials and assessment resources, as well as efforts to foster teachers' instructional practices that promote ALL students' model-based learning.

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