

# Investigating the Effect of Curricular Scaffolds on 3<sup>rd</sup>-Grade Students' Model-Based Explanations for Hydrologic Cycling

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**Abstract:** Opportunities to generate model-based explanations are crucial for elementary students yet are rarely foregrounded in elementary science learning environments, despite evidence that early learners can reason from models when provided scaffolding. We use a mixed methods design to investigate the comparative impact of embedded visual and written prompts (e.g. curricular scaffolds) on 3<sup>rd</sup>-grade students' formulation of model-based explanations for the water cycle. Students from six 3<sup>rd</sup>-grade classrooms generated models of the water cycle during an 8-week water unit. Findings suggest that students in the scaffolded group (n = 120) more frequently represented sequences of water underground than the unscaffolded group (n = 112). However qualitative results indicate the scaffolded group was also less likely to generate model-based explanations from their sequences of 'hidden' water processes. We conclude that embedded curricular scaffolds may support students to consider 'hidden' components but, alone, may be insufficient for theory building.

## Objectives and Potential Significance

Model-based explanation-construction in science learning environments involves students constructing an external representation to explain *how* and *why* a systems works (Bechtel & Abrahamsen, 2005; Lehrer & Schauble, 2010; Schwarz et al., 2009). The external representation is an abstraction of a process that represents system components, interactions, and connections. Students are then able to operationalize *how* and *why* through the underlying unobservable cause – the mechanism - of key processes that interconnect to define the system (Braaten & Windschitl, 2011; Machamer, Darden & Craver, 2000). Though generating model-based explanations is a powerful practice, it is rarely foregrounded in elementary science instruction or widely available science curriculum materials, despite evidence that students are capable of engaging in these practices *when supported to do so* (Gunckel, Covitt, Salinas, & Anderson, 2012.; Lehrer & Schauble, 2010; Manz, 2012; Schwarz et al., 2009). Most often when students engage with models in elementary science learning environments, they serve as illustrations, demonstrations, or summaries of processes, but are not used or considered as a *way of learning* (Abell & Roth, 1995; Windschitl, Thompson, & Braaten, 2008).

In this study, we draw upon Sherin and colleagues' emphasis on 'learning artifacts' (2004, pg. 406) to explore the comparative impact of curricular, task-based scaffolds on 3<sup>rd</sup>-grade students' model-based explanations about sequences underlying the water cycle, a complex system comprised of many constituent processes. The *Next Generation Science Standards* (NRC, 2012) identify the hydrologic cycle as a core conceptual strand across the elementary grades that anchors future learning about water-related phenomena (Gunckel et al., 2012). However, water-related phenomena are challenging for students (Henriques, 2002), particularly process sequences that underlie system dynamics. Yet, little research has been conducted on elementary students' reasoning about hydrologic cycling and, as a result, there is much to learn about how to optimally support early learners to use models to reason scientifically about the water cycle. This study is grounded in a learning performances framework (Forbes, Zangori, & Schwarz, 2014; Schwarz et al., 2009) that highlights mechanism and sequence as core elements of model-based explanations. Our questions are:

1. Do embedded curricular scaffolds impact students' model-based explanations for the water cycle?
2. If so, how do 3<sup>rd</sup>-grade students formulate model-based explanations for the water cycle when provided embedded curricular scaffolds?

## Background and Theoretical Framework

The hydrologic cycle is a particularly challenging area for students because many underlying processes that comprise this complex geosystem, such as phase change and groundwater flow, do not lend themselves to unaided observation (Gunckel et al., 2012; Henriques, 2002). Early learners struggle to postulate unseen mechanisms for observable phenomena. Both evaporation and subsurface water flow are 'hidden' processes that even older students have difficulties conceptualizing (Gunckel et al., 2012; Henriques, 2002). Rich, learner-centered science learning environments should therefore be designed around multiple scaffolds, both curriculum-embedded and provided by the teacher through instruction, that work synergistically to address cognitive and practice-oriented learning outcomes (Sherin, Reiser, & Edelson 2004). Curricular scaffolds, here defined as visual and written prompts embedded within curriculum materials (McNeill & Krajcik, 2009), are an

important mode of providing cognitive supports to students. However, little research has been conducted to explore how to optimally scaffold early learners' use of models to reason about water systems.

To support both the design AND empirical study of model-centric elementary science learning environments, we have developed a comprehensive, domain-specific learning performance framework to account for students' model-based explanation-construction and conceptual understanding about *water in motion* (i.e. 'big ideas') and the scientific practice of modeling (Forbes et al., 2014; Schwarz et al., 2009). A core component of the framework is process sequences. Sequences represent the connections and the continuity between components of the process that comprise a complex system (Machamer et al., 2000). For example, when scientists attempt to understand or explain complex systems through modeling, the components of the system are connected with arrows (e.g., condensation → precipitation → evaporation). The arrows represent the activity for *how* and *why*, for example, the condensation component 'became' the precipitation component and so on. It is within the arrows that the mechanism – the underlying unobservable cause – is articulated. It is only in the understanding of what the arrows represent that the mechanism is understood (Bechtel & Abrahamsen, 2005; Machamer et al., 2000). Sequences are apparent in geosystems which are defined by overlapping and integrated processes creating dynamic complex systems. These processes are a function of sequential cause and effect, both observable and unobservable, in which one phenomenon impacts another. In order to understand dynamic systems, including the water cycle, early learners must be provided opportunities to both identify the sequences within this system of occurrences and postulate mechanisms that connect them to provide a foundation for a more sophisticated understanding of systems (i.e., systems thinking) that they will develop in later grades (Gunckel et al., 2012; Schwarz et al., 2009).

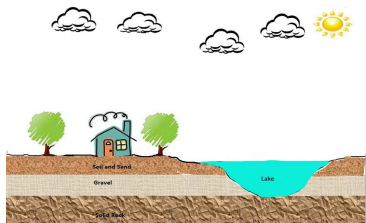
## Research Design and Methodological Approach

This concurrent mixed methods study is situated within a broader design-based research program conducted as part of a 3-year, NSF-funded project designed to a) explore and promote 3<sup>rd</sup>-grade students' formulation of model-based explanations for hydrologic cycling through curriculum materials enhancement and instruction, and b) empirically investigate associated instructional and student learning outcomes. Six 3<sup>rd</sup>-grade classrooms were purposefully selected (Patton, 2001) based on teachers' teaching experience, student demographics, and their use of an existing, commercially-available, kit-based curriculum module about water.

## Design

To afford student opportunities to formulate model-based explanations, two supplemental lessons were integrated into the curriculum module, one each at the beginning and end. Each lesson afforded students the opportunity to complete a modeling task that involved constructing a 2-D diagrammatic process model of the water cycle and responding to a series of prompts designed to elicit students' mechanism-based explanations for answers to the following question: '*where does the rain go when it reaches the ground?*'. Two different versions of the modeling task were employed. Students in three classrooms completed modeling tasks that included no written or visual prompts while students in the other three classrooms completed tasks with both verbal and visual prompts (Table 1). The modeling tasks were otherwise identical.

Table 1: Elements of scaffolded and unscaffolded student modeling tasks

	Unscaffolded	Scaffolded
Student Instructions	Use the box on the next page to draw a model of what you think happens to rain after it reaches the ground.	Use the box on the next page to draw a model of what you think happens to rain after it reaches the ground. <ul style="list-style-type: none"> <li>• Include what you think are the very <u>most important things</u> that happen to rain when it reaches the ground</li> <li>• Include what you think happens <u>on top of</u> and <u>under</u> the ground when it rains</li> <li>• Show <u>why</u> these things happen to rain when it reaches the ground</li> </ul> If helpful, use <u>words</u> and/or <u>numbers</u> to label parts of your model
Model Template	(Empty box)	

## Data Collection and Analysis

All pre- and postunit student modeling artifacts were collected ( $n=120$  scaffolded;  $n=112$  unscaffolded) and scored using a rubric developed from an empirically-tested learning performances framework for elementary students' sensemaking about the hydrologic cycle (Forbes et al., 2014; Schwarz et al., 2009). We examined and scored the students' modeling tasks for the level of sophistication in their representations of sequences (e.g. water in the sky  $\rightarrow$  falls to the ground) for the big idea of *water in motion*. The scoring rubric is shown in Table 2. Scoring levels were identified and validated through empirical development of the learning performance framework (see Forbes et al., 2014). The unit of analysis for scoring was the students' models and written responses to task prompts. The individual scores for students' pre- and postunit modeling tasks were imported into SAS for statistical analysis using double-factor repeated measures mixed model ANOVA. The dependent variable was the students' scores on the postunit modeling task and the independent variable was the scaffolded and unscaffolded modeling groups, controlling for student scores on preunit modeling task.

Table 2: Sequence scoring rubric

Level	Sequence representation
0	No sequence represented
1	Only describes 1 change (water in the sky $\rightarrow$ falls to the ground)
2	Describes 2 or more changes but the sequence only goes in one direction
3	Describes 2 or more changes and the sequence goes in two directions

Five students from each classroom were also selected to participate in reflective grounded interviews about their pre- and postunit water cycle models and written responses ( $n=60$ ). All student interviews were imported into ATLAS.ti and analyzed qualitatively using classical content analysis (Patton, 2001) for *a priori* code of sequence and mechanism. Qualitative analysis involved an iterative process of data coding, displaying and verification (Miles & Huberman, 1994) to identify themes within the interviews that provided insight into the students' articulation of mechanisms generated from their modeled water cycle sequences.

## Empirical Results

In research question 1, we examined the impact of embedded curricular scaffolds on students' representation of water cycle sequences and found that embedded curricular visual and written prompts supported students' representation of the direction and quantity of process sequences underlying the water cycle in their postunit models,  $F(1, 90) = 0.05$ ,  $p = 0.01$ , as shown in Figure 1.

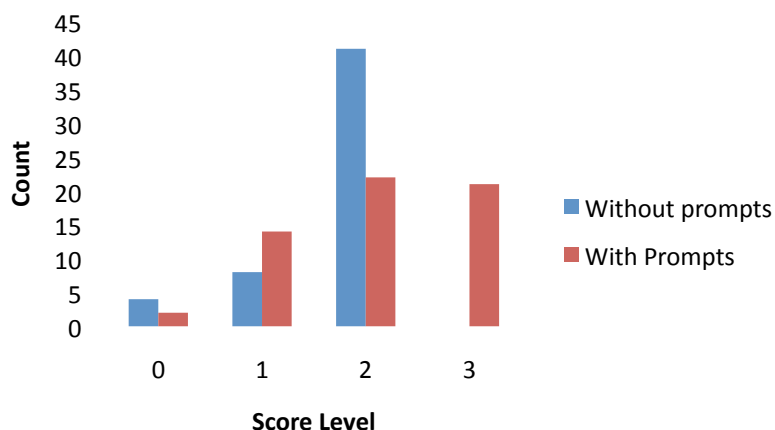


Figure 1. Process sequences in students' scaffolded ( $n=60$ ) and unscaffolded ( $n=55$ ) water cycle models

As shown in Figure 1, the most substantial difference between the two conditions was the prevalence of level '3' scores in the scaffolded group as compared to the unscaffolded group, in which there were no level '3' scores. More students from the scaffolded group were able to incorporate two or more process sequences into their models and illustrate multidirectionality of these process sequences in their explanations.

In research question 2, we qualitatively analyzed students' modeling tasks and interviews to explore differences in students' model-based explanations between the two conditions. We found two dominant themes. First, students in the scaffolded modeling group more frequently represented 'hidden' sequences of groundwater and water movement underground prior to returning to the sky (Figure 2). The students in the scaffolded group used both words and arrows to show sequences of rain moving through the underground layers. They frequently

articulated that “water get trapet [trapped]” (A.CM1) in the gravel layer and was unable to move any further underground. They drew and traced with their finger sequences of water moving vertically until it reached the gravel layer then moving horizontally into the lake (Figure 2). As Jackie stated, since “[rain] can’t go under the solid rock...it goes back into the lake” (P1:2713:2714). While the unscaffolded group also drew sequences of rain reaching the ground, their representations did not go further into the ground than just under the surface. They articulated that vertical water movement stops at ground surface because once rain reaches the ground, it does not have “anywhere else to go” (P1: 2904:2907) under the ground. We found that both groups included evaporation in their sequences (Figure 2); however, only the scaffolded group connected evaporation to their underground sequences creating a continuous loop and thereby representing the water cycle. The unscaffolded group most frequently only considered evaporation occurring from puddles and did not connect this sequence to their representations of water falling to the ground. While evaporation in both groups was drawn as arrows moving from bodies of water back to the sky, the scaffolded group most frequently drew arrows of water returning to clouds while the unscaffolded group drew arrows of water returning to the sun (Figure 2).

Second, even though the scaffolded group more frequently represented arrows connecting and indicating ‘hidden’ sequences underground, they were unable to articulate the mechanism - the *how* and *why* – for how water moves underground and returns to the sky. When we asked students in the scaffolded group why water flows vertically through the gravel layer, they responded with a description of what occurs rather than *how* or *why* it occurs. For example Nancy stated “...it [rain] comes from the sky...into the grass, and through the soil, sand and gravel, and...it makes the lake bigger...and the thing [evaporation] is taking the water from the lake” (P1:2836:2841). In this manner, Nancy has described her model to us, but not generated an explanation for the process sequences. However the unscaffolded group used their models to begin to attribute mechanisms for *how* and *why* water moves both in their representations of water falling to the ground and then water returning to the sky. They discussed that water reaches the ground because plant matter “acts like a magnet” for pulling water from the sky (N.CM2) and the “sun is so hot” it ‘takes’ (P1:2981) or ‘soaks’ (P1:423) water up from the ground. Overall, the unscaffolded group more frequently generated model-based explanations models for process sequences while the scaffolded group typically did not.

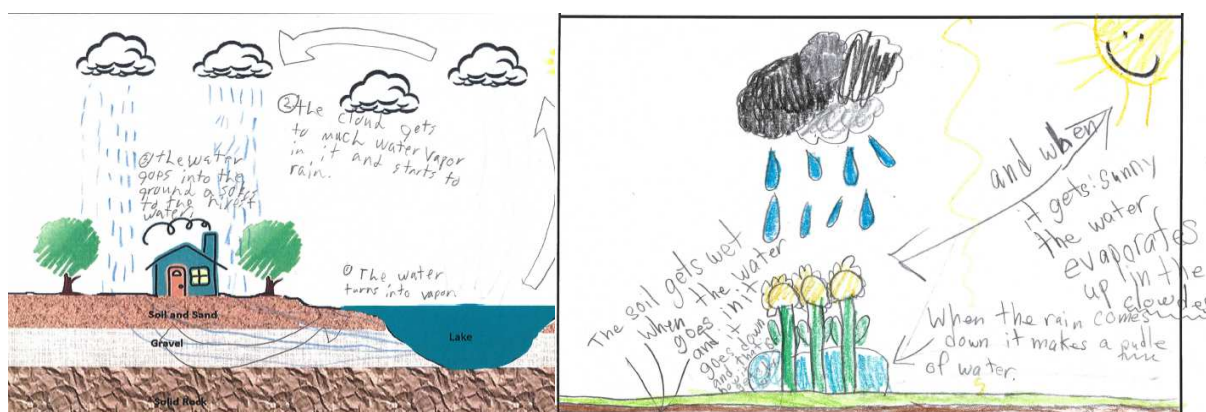


Figure 2. Students sequence in embedded scaffold (S3.AM2) and unscaffolded (T.NM2) postunit models

## Discussion and Relevance to the Conference Theme

This work foregrounds elementary students’ learning within a discipline-specific (i.e. hydrologic cycle) epistemic practice (i.e. modeling) and therefore exemplifies the ICLS 2014 conference theme of ‘learning and becoming in practice’. Scientific modeling is a core scientific practice (NRC, 2012) that remains underemphasized in K-12 science, particularly in the elementary grades. Too often, when models are used in science classrooms, they are provided as static illustrations rather than to engage students in model development, use, and refinement as an active, sustained practice. As a result, little research exists to guide efforts to engage students in epistemically-rich, model-centric elementary science learning environments that foster and promote modeling as a *way of learning* (Abell & Roth, 1995; Windschitl et al., 2008). Here, we engaged students in co-development of modeling practices and content knowledge to support their formulation of model-based explanations (Forbes et al., 2014; Lehrer & Schauble, 2010; Manz, 2012; Schwarz et al., 2009).

The water cycle is a complex geosystem fundamental to understanding biotic and geospheric phenomena and, as such, is central in K-12 science standards (Gunckel et al., 2012; Henriques, 2002; NRC, 2012). However, students often struggle with the epistemic and cognitive demands placed upon them by the dynamic processes that comprise complex systems such as the hydrologic cycle where major components are largely ‘hidden’ from view. In order to support students in considering hidden process sequences, we provided visual and written prompts (McNeill & Krajcik, 2009) to explore the ways in which students engaged with these prompts to conceptualize water cycle sequences, and reason about groundwater. Study findings indicate that

visual and written prompts embedded in curricular tasks supported students to consider some important ‘hidden’ components of water in motion that the unscaffolded group typically did not include in their models. This may imply that embedded scaffolds provide students with additional representational space to add elements they would not otherwise consider (Sherin et al., 2004). However, results also indicate that the students who were prompted to model underground water processes seemed unable to articulate conceptual understanding about the phenomenon and did not generate explanations for sequences they represented within the visual prompts. We hypothesize that even though the invisible components were present, the phenomena may become meaningless to the learner if they cannot generate an explanation. In these instances, models became illustrations to describe rather than representations for use in sensemaking (Bechtel & Abrahamsen, 2005; Braaten & Windschitl, 2011). In contrast, the unscaffold group did not represent water underground, but did articulate model-based explanations for the sequences they included in their models. Even though the explanations from this group were based on naïve mechanisms of evaporation, their reasoning indicates that they were able to generate scientifically accepted explanations from their representations (Machamer et al., 2000). Taken together, these results suggest that engaging elementary students in generating model-based explanations about the water cycle may require multi-modal representations and varied scaffolds to support students in conceptualizing hidden components and how they may function within a system to afford mechanistic outcomes (Sherin et al., 2004). However, caution must be followed using embedded visual prompts within the modeling task as they may inhibit student opportunities for sensemaking (e.g., Abell & Roth, 1995).

## References

- Abell, S. & 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.
- Bechtel, W. & Abrahamsen, A. (2005). Explanation: A mechanist alternative. *Studies in History and Philosophy of Biological and Biomedical Science*, 36, 421-441.
- Braaten, M. & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education*, 95(4), 639-669. doi: 10.1002/sce.20449
- Forbes, C.T., Schwarz, C., & Zangori, L. (in press). Development of an empirically-based learning performances framework for 3rd-grade students’ model-based explanations about hydrologic cycling. In Proceedings of the Eleventh International Conference of the Learning Sciences – ICLS 2014. Boulder, CO: International Society of the Learning Sciences.
- 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. doi:10.1002/tea.21024
- Henriques, L. (2002). Children’s ideas about weather: A review of the literature. *School Science and Mathematics*, 102(5), 202-215. doi: 10.1111/j.1949-8594.2002.tb18143.x
- Lehrer, R. & Schauble, L. (2010). What kind of explanation is a model? In M. K Stein & L. Kucan (Eds.) *Instructional explanations in the disciplines*, 9-22, New York, NY: Springer.
- Machamer, P., Darden, L. & Craver, C. (2000). Thinking about mechanisms. *Philosophy of Science*, 67(1), 1-25.
- Manz, E. (2012) Understanding the codevelopment of modeling practice and ecological knowledge. *Science Education*, 96(6), 1071-1105. doi: 10.1002/sce.21030
- McNeill, K. L. & Krajcik, J. (2009). Synergy between teacher practices and curricular scaffolds to support students in using domain specific and domain general knowledge in writing arguments to explain phenomena. *The Journal of the Learning Sciences*, 18(3), 416-460.
- Miles, M.B. & Huberman, A.M. (1994). *Qualitative data analysis*. Newbury Park, CA: Sage.
- NRC, (2012). *A framework for K-12 science education: Practices, cross-cutting concepts, and core ideas*. Washington, DC: National Academies Press
- Patton, M. Q. (2001). *Qualitative research and evaluation methods*. Thousand Oaks, CA: Sage.
- Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., Schwartz, 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.
- Sherin, B. Reiser, B. J., Edelson, D. (2004). Scaffolding analysis: Extending the scaffolding metaphor to learning artifacts. *The Journal of Learning Sciences*, 13(3), 387-421. doi: 10.1207/s15327809jls1303\_5
- Windschitl, M., Thompson, J. & Braaten, M. (2008). How novice science teachers appropriate epistemic discourses around model-based inquiry for use in classrooms. *Cognition and Instruction*, 26(3), 310-378. doi: 10.1080/07370000802177193

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