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Development of an Empirically-based Learning Performances Framework for 3rd-grade Students' Model-based Explanations about Water

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Title:
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Abstract:
To develop scientific literacy, elementary students should engage in articulation, negotiation, and revision of model-based explanations about the water cycle (NRC, 2012). However, scientific modeling remains underemphasized in elementary science learning environments and little past research has explored early learners' engagement in domain-specific modeling practices. We are engaged in research and development to investigate 3rd-grade students' model-based reasoning about water. Here, we report on the development of an empirically-tested learning performances framework that integrates science content (i.e., 'big ideas') and scientific practices (i.e., modeling). This learning performances framework a) grounds the iterative development of curriculum and assessment and b) lays the groundwork for future development of a learning progression for K-12 students' learning about water.

Development of an Empirically Grounded Learning Performances Framework for 3rd-grade Students' Model-based Explanations about Water

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Rationale

- The water cycle is a foundational topic highlighted throughout the K-12 science curriculum (AAAS, 2007; ESLI, 2009; NRC, 2013)
- Early learners often struggle to understand hydrologic phenomena (e.g., Bar, 1989; Henriques, 2002)
- Scientific modeling a scientific practice to support students' conceptual understanding (NRC, 2013)
  - Elementary science rarely involves scientific modeling
  - Little past research on elementary students' model-based reasoning

Project Overview

- Modeling Hydrologic Systems in Elementary Science (MoHSES)
- 3-year exploratory DRK-12
- Goals
  - To promote 3rd-grade students' model-based reasoning about water through curriculum materials enhancement and instruction
  - To engage in exploratory research to investigate elementary students' model-based reasoning about water and how elementary teachers scaffold students' model-based reasoning

Early Learners and Science

- "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" (NRC, 2007, pg. 44)
- Elementary students can effectively engage in modeling (Abell & Roth, 1995; Lehrer & Schauble, 2006; Manz, 2012; Schwarz et al., 2009)
- Scaffolding is critical (Hapgood, Magnusson, & Palinscar, 2004; Hardy, Jonen, Möller, & Stern, 2006; Herrenkohl & Cornelius, 2013; Metz, 2004; McNeill, 2011)

Theoretical and Empirical Foundations

- Scientific modeling (Abell & Roth, 1995; Author, 2009; Lehrer & Schauble, 2012; Manz, 2012; Passmore, Cartier, & Stewart, 2009; Windschitl, Thompson, & Braaten, 2008)
- Mechanistic perspective on scientific explanation (Braaten & Windschitl, 2011; Chinn & Malhotra, 2002; NRC, 2013; Windschitl, Thompson, & Braaten, 2008)
- Learning progressions (Alonzo & Steedle, 2008; Lee & Liu, 2010; Mohan, Chen, & Anderson, 2009; Stevens, Delgado, & Krajcik, 2010; Wilson, 2005)
- Heuristics for curriculum design (Krajcik, McNeill, & Reiser, 2007; Shin, Stevens, & Krajcik, 2010)

Year 1 Empirical Findings

- Research questions
  1. How do 3rd-grade students formulate model-based explanations about the water cycle?
  2. How do 3rd-grade teachers support their students' model-based reasoning about water?
- Data
  - Pre/post-unit student modeling artifacts (n=120; 112)
  - Pre/post-unit student interviews (n=30)
  - Teacher interviews (n=5/teacher)
  - Videorecorded observations (n=5/teacher)

Design Heuristics and Process

- Design-based research
- Construct-Centered Design and Construct Modeling
  (Shin et al., 2010; Wilson, 2005)
  - Step 1: Articulating a Theoretically-Grounded Learning Performances Framework
  - Step 2: The Curricular Context: Developing the Student Modeling Task
  - Step 3: The Outcome Space: Defining Levels of Construct Maps
  - Step 4: Using Construct Maps to Evaluate Students' Water Cycle Models

Step 1 – Defining the Content

- Big idea: Water is matter that, when heated and cooled, changes form and circulates through the Earth's geosphere, biosphere, and atmosphere
- Three target concepts
  1. Water exists in different forms below, at, and above the Earth's surface (Concept 1)
  2. Water on Earth is in motion and cycles at a global scale (Concept 2)
  3. The cyclical movement of water on Earth shapes and impacts the geosphere (Concept 3)

Step 1 – Epistemic Dimensions

- *Components* - which elements, both visible and non-visible, students include in their models
- *Sequences* - temporal relations between system sub-processes
- *Explanatory process* - mechanisms that explain process sequences
- *Principle* - a generalization about the phenomena that relates to abstracted components of the model
- *Mapping* - how the representation or components in the representation relates to the physical phenomenon

(Schwarz et al., 2009)

Step 1 – Learning Performances Framework

	(1) Forms of water	(2) Water in motion	(3) Water/geosphere interactions
Components	Student identifies two or more examples of VISIBLE AND NON-VISIBLE examples of forms, phases, and/or states of water	Student identifies two or more examples of VISIBLE AND NON-VISIBLE examples of non-geospheric water movement	Student identifies two or more examples of VISIBLE AND NON-VISIBLE interactions between water and the geosphere.
Sequence	Student describes at least one bi-directional example of changes in forms, phases, and/or states of water	Student describes at least one example of non-geosphereic water movement that exhibits bi-directionality	Student describes at least one example of bi-directional interactions between water and the geosphere
Explanatory Process	Student articulates both how and why temperature effects changes in water forms, phases, and/or states	Student articulates both how and why gravity and temperature effect water movement	Student articulates effect of water's movement and how it shapes the geosphere such as breaking up existing Earth materials and why it shapes the geosphere such as depositing Earth materials due to gravity in new locations which can lead to other, new landforms.
Mapping	Student identifies and provides an evidence-based rationale for one model component that represents a form, phase, or state of water in the water cycle	Student identifies and provides an evidence-based rationale for one model component that represents an example of water movement	Student identifies and provides an evidence-based rationale for one model component that represents an interaction between water and the geosphere
Principle	Student identifies all elements of the scientific principle that accounts for forms, phases, and/or states of water	Student identifies all elements of the scientific principle that accounts for water movement	Student identifies all elements of the scientific principle that accounts for interactions between water and the geosphere

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Step 2 – Curricular Context

- 6 3rd-grade classrooms
- FOSS Water module
- Supplemental lessons
- Student modeling task
  - Pre-/post-unit
  - 'Where does the rain go when it reaches the ground?'
  - 2-D diagrammatic models
  - Written responses to 4 prompts

Step 2 – Modeling Task

Where does the rain go when it reaches the ground?

Model Template	Instructions
(Empty Box)	Use the box on the next page to draw a model of what you think happens to rain after it reaches the ground • Include what you think are the very most important things that happen to rain when it reaches the ground • Include what you think happens on top of and under the ground when it rains • Show why these things happen to rain when it reaches the ground • If helpful, use words and/or number to label parts of your model.

Step 2 – Modeling Task

Look at your model to help you answer these questions.

1. What does your model show happening to rain as it reaches the ground?
2. Why do you think this happens to rain when it reaches ground?
3. What have you seen that makes you think this happens to rain when it reaches the ground?
4. How would your model help you convince others that this is what happens to rain when it reaches the ground?

Step 3 – Defining Learning Performance Levels

- Student modeling tasks (n_{pre}=112, n_{post}=107)
- Clinical interviews with students (n=60)
  - 5/classroom
  - Pre- and post-unit models
  - Selected in consultation with teachers to represent continuum of achievement and engagement
- Coded in ATLAS.ti for 15 codes (learning performances framework)
- Coded data organized into 'levels' for each of 15 learning performances

Step 3 – An Example

- Concept 3 - the cyclical movement of water on Earth shapes and impacts the geosphere

Level	Learning performance level
(3)	Student identifies two or more examples of VISIBLE AND NON-VISIBLE interactions between water and the geosphere.
(2)	Student identifies two or more examples of VISIBLE interactions between water and the geosphere.
(1)	Student identifies one example of VISIBLE interactions between water and the geosphere.
(0)	No evidence

Step 3 – An Example

- Level 1 – one visible interaction
- Most students articulated at least one visible example of interactions between water and Earth materials
- Streams and rivers, floods, soil penetration, and runoff
  - "water goes in [to cracks in the ground] and creates a cave"
  - "it starts going down, down, down the mountain and then it will reach the ground"
  - "[when] it fell out of the lake and onto the land, a bunch of water…there will be a flood"

Step 3 – An Example

- Level 2 – more than one visible interaction
- Fewer students identified more than one visible interaction
- Water flows “Doooowwwwnnnnn…[a hill]…and it moves and it hits a pond” and “soaks into…underground”.
- Evidence of relative de-emphasis on geospheric components of hydrologic cycling

Step 3 – An Example

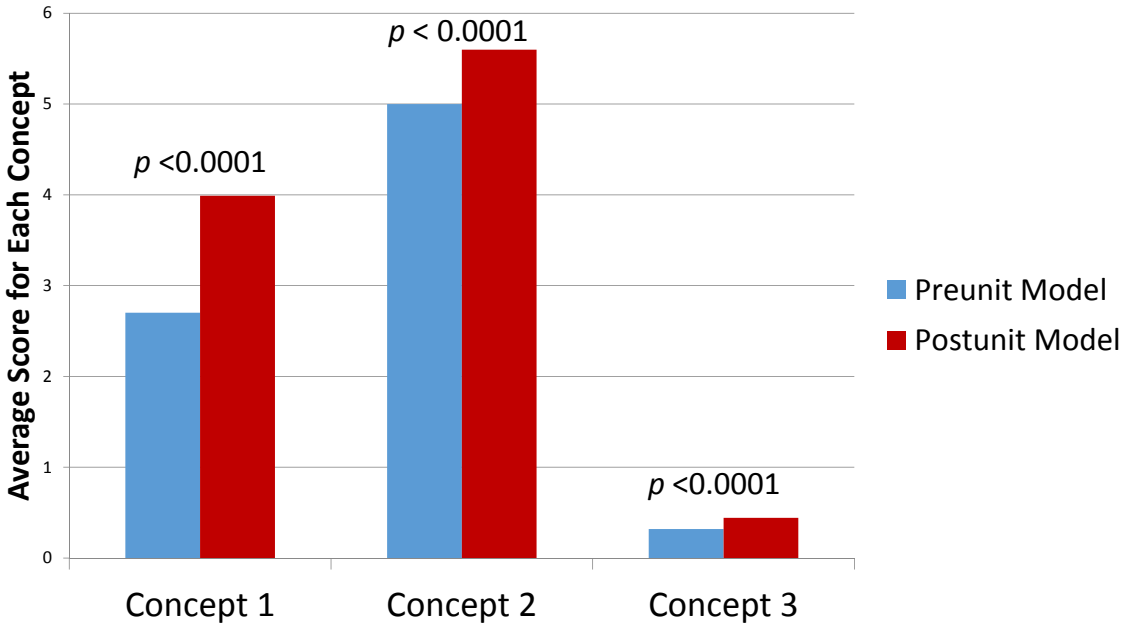
- Level 3 – more than one interaction, at least one 'invisible'

I –So you've shown you have water in these layers - the soil and sand and the gravel.
S – uh huh
I – but you didn't draw any in the rock did you? Did you?
S – No, because it's solid rock
I – Ok. And so water doesn't go into there?
S – uh uh
I – Why not, do you think?
S – because the rock's so hard…packed together, and the water can't go through.
I – because it's packed together?
S - uh huh
I – So what do you mean by that? That's it's so packed together? What, what's so different about the solid rock than the gravel or the soil and sand?
S – Because they're, because the sand is thinner and the rock has space in it so the water can go through
I – ok so the water can go through these because there's space in between them?
S – uh huh

Step 4 – Analysis of Models

- Scored using LP-based rubric
- Quantitative analysis - 3-way double-factor repeated-measures mixed model ANOVA
- Qualitative Analysis - *A priori* coding for all three concepts (*forms of water*, *water in motion*, and *water/geosphere interactions*) and 5 dimensions (components, sequence, explanatory process, mapping, and scientific principle)

Step 4 – Evaluating Students' Water Cycle Models



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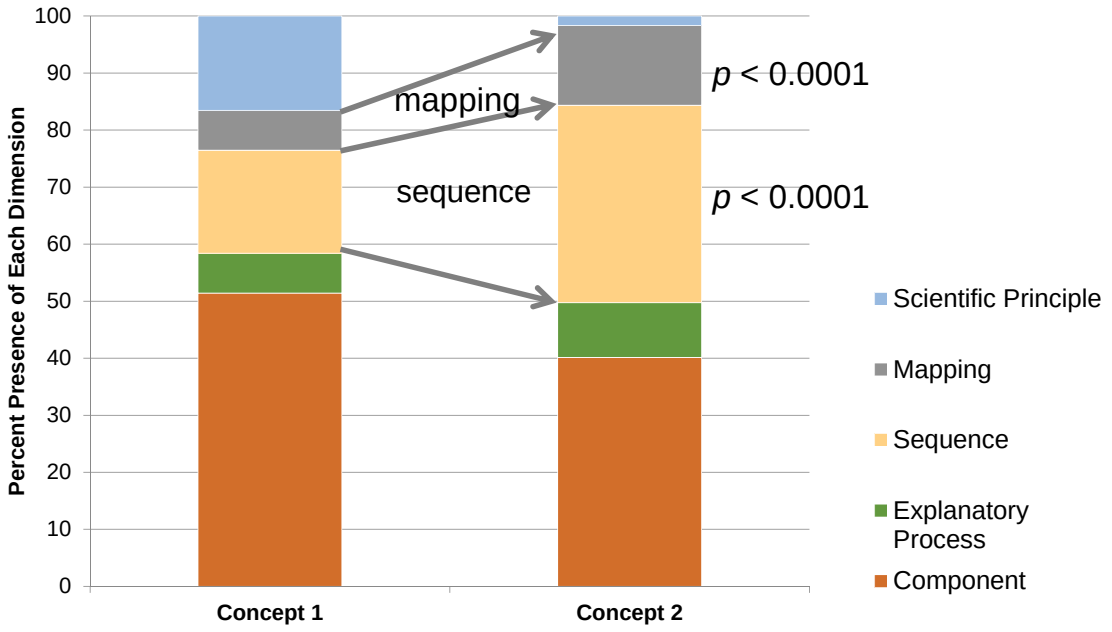
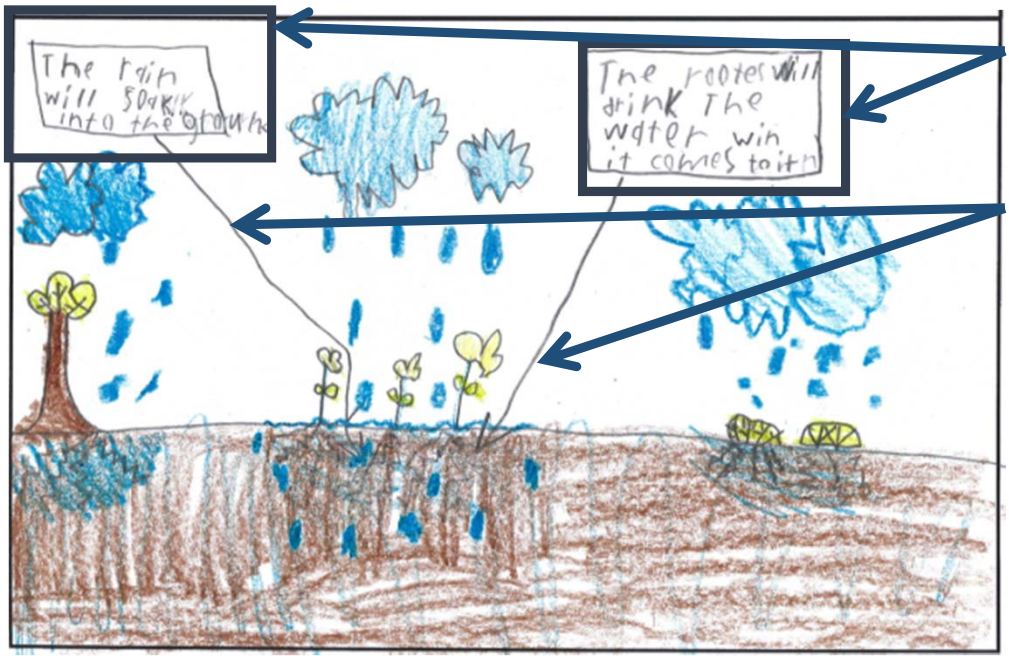
Step 4 - Trends in Students' Models

- Emphasis on atmospheric and hydrologic dimensions of the water cycle over geospheric
  - Liquid water most commonly represented, but also water vapor as clouds
  - Water movement most commonly rain
  - Some representation of surface flow and standing water
- Representational elements
  - Mostly sketches and arrows
  - Less labeling and use of text

Step 4 – Evaluating Dimension Differences Between Concepts



Step 4 – Sequences and Mapping for Concept 2, Water in Motion



Mapping elements

Sequence elements

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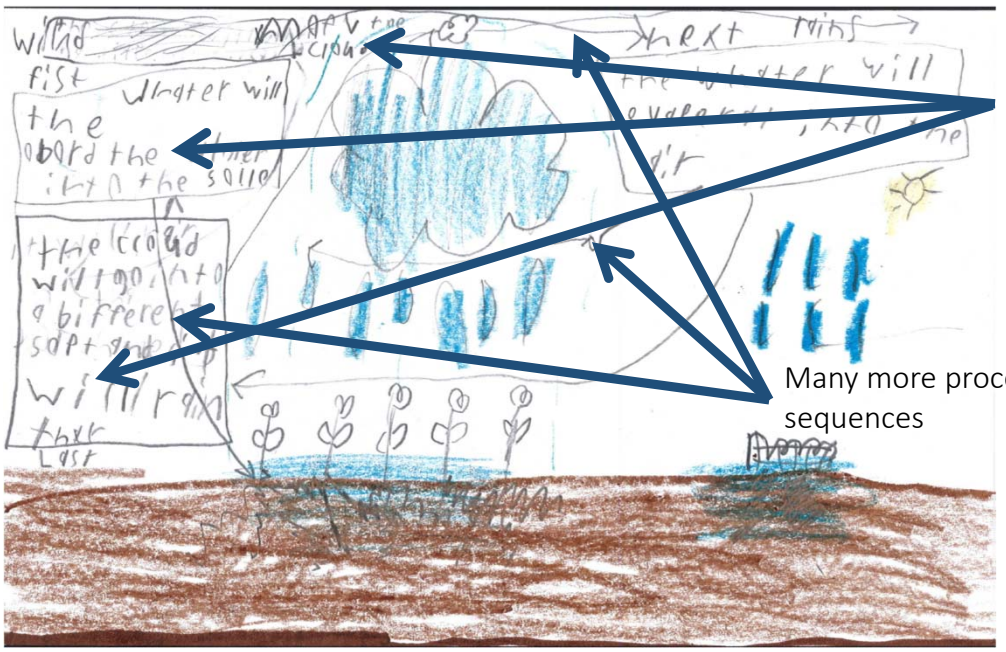
Step 4 – Sequences and Mapping for Concept 2, Water in Motion



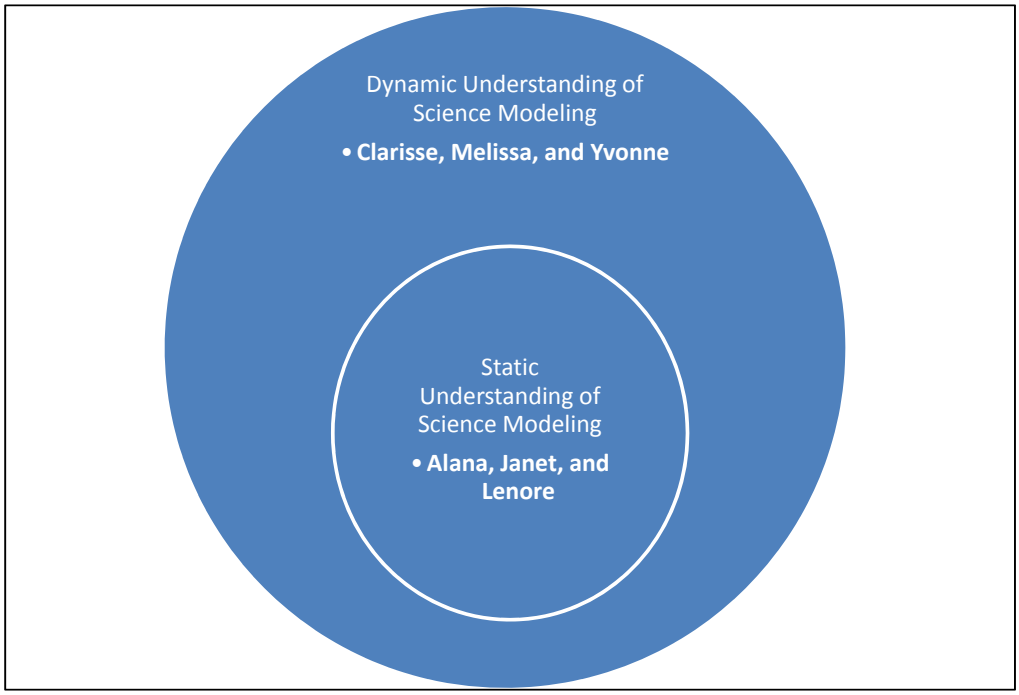
Student Findings Summary

- Provide evidence of students' ideas about the water cycle
  - Increased sophistication of conceptual representation
  - No change in epistemic dimensions represented
  - Unobservable components of the water cycle such as water vapor and subsurface groundwater
  - General de-emphasis on water-Earth materials
- Empirically-grounded learning performances framework for students' model-based explanations for water-related phenomena

Year 1 Findings: Teachers

- Teachers' conceptions and practices
- Data
  - Teacher interviews (n=5/teacher)
  - Videorecorded observations (n=5/teacher)
  - Miscellaneous instructional artifacts
- Same coding approach (modeling practices and epistemic dimensions)

Findings: Static & Dynamic Groups



Findings: Teacher Groups

- Static
  - Conceptions: Focus on modeling practices, a static activity with fill in the blank type activities
  - Scaffolding: models as an evaluation tool
- Dynamic
  - Conceptions: Some awareness of epistemic commitments in addition to practices, a dynamic activity focused on larger conceptual understanding
  - Scaffolding: supporting students' use of models to formulate explanations

Examples of Conceptions

- "…I feel 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)" ~*Static*

- *"*[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)." ~Dynamic

Examples of Classroom Practices

- Static
  - Using models as formative assessment - "[Model discussion] would be beneficial for them, but mostly for me, so that I could see where they are at…" (AP2:30)
  - One-shot model creation
  - Whole-group sharing of model components
- Dynamic
  - Comparing student models
  - Using models to interpret phenomena
  - Revising models

Coda: Related Research

- 3rd-6th-grade teachers' (n=27) use of formative assessment to teach Earth science
- Data
  - Content knowledge assessment
  - Instructional logs (online mini surveys; n=73)
  - Interviews, observations, artifacts with subset of 3rd and 5th-grade teachers (n=6)
- Includes 3 teachers from MoHSES project

Coda: Related Research

- Findings
  - No observable relationship between teachers' Earth science content knowledge and use of formative assessment
  - Reliance on low-level vocabulary 'markers' in analysis of students' work
  - Instructional strategies/approaches decoupled from evidence of students' understanding
- Curriculum materials not strongly emphasizing student sense-making

Teacher Findings Summary

- Teachers see models as important tools for assessing student progress and representing students' 'mental models'
- May or may not view them as reasoning aids for students and support epistemic domains of modeling practice
- Observed classroom practices generally align with their ideas and orientations
- Rely heavily on curricular resources

Overall Implications

- Curricular resources and instructional approaches aligned with empirical evidence of student understanding
  - Supporting model-based explanation-construction
  - Emphasizing less-easily-observed water cycle components
  - Leveraging sequences and mapping as part of explanations
- Preservice and inservice PD that targets KNOWN gaps in teachers' conceptions and practices
  - Helping teachers see value in models for students
  - Instruction that supports modeling practices and epistemic dimensions

Project Next Steps

- More substantial curricular and instructional intervention in Year 2
- Analyzing Year 2 data
  - Comparing students' explanations in Year 2 to Year 1
  - Focusing on other epistemic dimensions and practices
- Year 3
  - Constructing 3-year longitudinal case studies of 6 teachers
  - Developing student assessment aligned with LPs
  - Quasi-experimental study of treatment and non-treatment classrooms

For More Information

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