Teacher Responses to Assessments of Understanding of Water in Socio-Ecological Systems: A Learning Progressions Approach

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Abstract

An understanding of how water and substances in water move through socio-ecological systems is critical for environmentally-literate citizens capable of participating in evidence-based decision-making about environmental issues. This study used a learning progressions framework to assess elementary through high school teachers' understandings about water. 61 teachers participating in a summer professional development program were assessed using items previously developed and validated to assess student understanding of the same domain. Teacher responses were coded using previously developed indicators of levels of achievement. Teacher results were compared to results from high school students. Results show that more teachers performed at Levels 3 and 4 than high school students. However, more teachers performed at Level 3 (school science narratives) than Level 4 (model-based reasoning). Like students, teachers who performed at Level 3 encountered difficulties applying principles such as gravity and permeability, when tracing water and substances in water through socio-ecological systems. Also like students, teachers had difficulty reasoning about substances in water at the atomic-molecular scale. These results suggest that a Discourse of school science narratives predominates in schools. These results have implications for the changes to school communities that may be necessary to support the development of model-based reasoning in schools.

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We live in a world in which human actions increasingly affect the natural systems on which all life depends. For example, climate change and changes in human land use patterns are producing an unprecedented crisis in the supply of high-quality fresh water world-wide (Jones, Dahm, Grimm, & Williams, 2009). Addressing and mitigating this crisis requires both individual and collective public response. As individual consumers, many of our citizens will have to accept the necessity of making changes in their lifestyles that will conserve water or maintain water quality. Collectively we face difficult choices about land use and the allocation of our water resources that will not be made by experts alone. A goal of school science should therefore be to prepare students to become environmentally-literate citizens capable of using scientific understandings and practices to participate in evidence- based decision making about environmental issues, such as protecting our supply of high-quality fresh water. (Gunckel, Covitt, Dionise, Dudek, & Anderson, 2009; Mohan, Chen, & Anderson, 2009).

Our research focuses on understanding student reasoning about how water and substances in water are distributed in socio-ecological systems[1] and supporting students in developing the scientific practices necessary to participate in individual and collective decisions about water (Covitt, Gunckel, & Anderson, 2009; Gunckel, Covitt, Dionise, et al., 2009). We take a learning progressions approach to describe how students' ideas and practices change as they progress through school. Learning progressions are defined in the National Research Council's *Taking Science to School* (2007, p. 219) as "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time." Learning progressions are anchored at one end by the ideas and ways of reasoning that students bring with them to school. At the other end, learning progressions are anchored by expectations of what we would like students to know and be able to do as scientifically literate citizens. Levels of achievement describe qualitative differences in student performances between the lower and upper anchors. The focus on using grounded research to describe students' ideas and ways of thinking about topics is one key characteristic that differentiates learning progression frameworks from scope and sequence science standards documents developed in the past (Duncan & Hmelo-Silver, 2009). Thus, a central goal for learning progressions is that they will help science educators use knowledge of students' ideas to inform instructional planning and curricula (Alonzo & Steedle, 2009; National Research Council, 2007, Wiser, Smith, Doubler & Asbell-Clarke, 2009).

Our previous research has shown that by high school, most students do not use scientific models and principle-based reasoning to trace water and substances in water through socio-ecological systems at multiple scales (Covitt, et al., 2009; Gunckel, Covitt, & Anderson, 2009; Gunckel, Covitt, Dionise, et al., 2009). This result has led us to investigate teacher understandings about water in socio-ecological systems. Deep, interconnected content knowledge is essential for teachers to be able to support students in developing scientific knowledge and practices (Abell, 2007; National Research Council, 2007; Windschitl, 2009). Teachers with stronger knowledge of scientific concepts are better able to engage in effective

[1] We use the term "socio-ecological" to reflect the understanding that ecological systems must be considered as intrinsically connected to the human social systems that interact with ecological systems (Long Term Ecological Research Planning Committee, 2007) .

teaching strategies to support student learning, and know how to support student thinking (Gess-Newsome & Lederman, 1995; Roehrig & Luft, 2004). Strong content knowledge is also is necessary for teachers to assess student ideas, measure progress, and build on student ideas to support more sophisticated scientific understandings (Driel, Verloop, & Vos, 1998; Grossman, Schoenfeld, & Lee, 2005). If learning progressions are going to be productive tools helping teachers support student learning, then teachers themselves must perform at the upper anchor of the learning progression. Therefore, we wanted to know:

1. At what level of achievement in a learning progression about water in socio-ecological systems do teachers perform?
2. How do teachers' performances in a learning progression compare to high school students' performances?

Research on Children's and Teachers' Understandings of Water Systems

Research on children's understandings about water has focused on identifying common naïve conceptions about phase change, with some work on students' ideas about watersheds, groundwater, and pollution. There has also been recent work on systems thinking and the effects of instruction on children's ideas about water. There has been little reported work on teachers' and other adults' ideas. Little reported research has addressed ideas about how water moves through human-engineered systems or the difference between solutions and suspensions.

Children do not tend to develop connected thinking about water in hydrologic systems. Children view water in locations as disconnected from water in other locations. They do not often think about water in dynamic, cyclical systems (Ben-Zvi-Assaraf & Orion, 2005a, 2005b). Furthermore, they tend to view the water cycle as a textbook representation and do not connect the textbook version of the water cycle to their understanding of water in their own geographic location (J. Dove, 1997; J. E. Dove, Everett, & Preece, 1999; Endreny, 2009; Shepardson, Wee, Priddy, Schellenberger, & Harbor, 2009).

Children often have difficulty describing water and processes in hidden or invisible parts of the water cycle (Ben-Zvi-Assaraf & Orion, 2005a, 2005b; Covitt, et al., 2009). For example, when probed about groundwater, children conceive of groundwater as located in underground sewers, lakes, streams, or layers (Ben-Zvi-Assaraf & Orion, 2005a, 2005b; Covitt, et al., 2009; Dickerson, Callahan, Van Sickel, & Hay, 2005; Dickerson & Dawkins, 2004; Dickerson, Penick, Dawkins, & Van Sickel, 2007). They hold inaccuracies in conceptions of the size and scale of aquifers, and view groundwater as a dead-end in the hydrologic cycle (Ben-Zvi-Assaraf & Orion, 2005a, 2005b; Dickerson, et al., 2005; Dickerson & Dawkins, 2004).

When probed about water in the atmosphere, younger children may recognize that water that evaporates goes someplace else (Lofgren & Hellden, 2008), or they may explain that water changes into something else, such as smoke or cotton (Bar, 1989; Osbourne & Cosgrove, 1983; Piaget, 1930; Taiwo, Ray, Motswiri, & Masene, 1999). Older students may mention that heat is involved, and later may describe evaporation as involving molecules (Lofgren & Hellden, 2008). However, especially at younger ages, children do not often recognize water as an invisible gas in the air (Bar, 1989; Bar & Travis, 1991; Osbourne & Cosgrove, 1983). Similarly, children have difficulty tracing water vapor back to liquid water. Students often do not recognize that the water that condenses on a glass or in a cloud comes from the invisible water vapor in the air. Older children recognize that the water must come from somewhere, explaining the appearance of water on a cold glass as coming from inside the water glass or as the glass "sweating" (Bar & Travis, 1991; Ewing & Mills, 1994; Osbourne & Cosgrove, 1983). Some work on elementary preservice teachers' ideas about water show that many preservice teachers also hold naïve ideas about how clouds, rain, fog and snow form (Stoddart, Connell, Stofflett, & Peck, 1993).

Children also have a variety of conceptions about watersheds. They may think of watersheds as human structures such as sheds or towers, or they may have more developed ideas about river systems, but rarely view watersheds as connected through the processes of evaporation, condensation, precipitation, and infiltration to groundwater, atmospheric, and biotic systems (Endreny, 2009; Shepardson, Wee, Priddy, Schellenberger, & Harbor, 2007; Shepardson, et al., 2009). Children often view rivers as existing in rural and non-urban environments only (J. E. Dove, et al., 1999).

Young children think about water pollution as stuff that people throw on the ground. By 8th-grade they consider water pollution to be chemicals, and by 11th-grade they may understand pollution as having more than one source (Brody, 1991). Research with teachers shows that many teachers use informal conceptions of the term "chemicals", defining chemicals as artificial, poisonous and dangerous substances, rather than as all substances that have mass (Salloum & Boujaoude, 2008).

Although children's initial ideas about water are often naïve and unconnected, work by Endreny(2009) and Ben-Zvi-Assaraf & Orion (2005a, 2005b) show that children develop more connected, sophisticated, and systems-oriented ideas about water through instruction. Successful instructional approaches include inquiry-oriented, place-based, and outdoor experiences, and first-hand experiences with phenomena. Therefore, it is important to assess teachers' understanding of water and substances in water if we are going to support them in providing the types and content of instruction that help students develop more sophisticated, scientific views of water.

A Learning Progression Framework for Water in Socio-ecological Systems

Our work on a learning progression for water in socio-ecological systems builds on and connects to the literature on children's ideas about water. This section describes our view of what students should know about water in socio-ecological systems by the time they graduate from high school and a framework for how student's ideas about water progress through their school years.

Figure 1, adapted from the Loop Diagram from the Long Term Ecological Research Network (Long Term Ecological Research Planning Committee, 2007) illustrates our view of the knowledge and practices of environmentally literate citizens with respect to water and substances in water in socio-ecological systems. The diagram highlights that environmental systems provide ecosystem services valued in human social and economic systems. The arrows inside the Environmental Systems box represent the processes that move water and substances in water through connected natural and engineered systems. Environmentally literate citizens engage in the practices of inquiry, explaining and predicting, and making decisions in ways that consider the effects of their actions on the distribution and quality of fresh water. In the research described below, we concentrate on high school student and teacher understanding of the surface, atmosphere, and soil/groundwater system that is evidenced by their explanations and predictions of how water and other substances that are carried by water move through connected natural and human engineered systems.

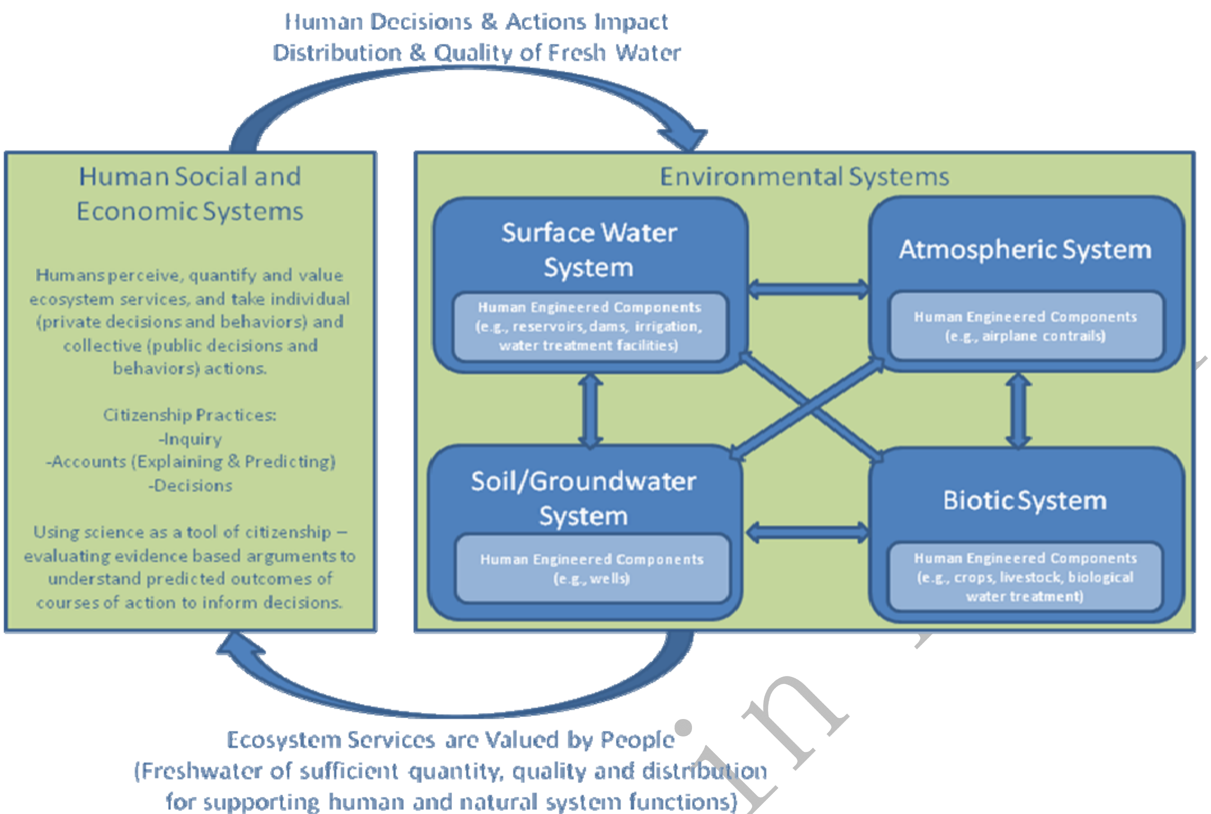


Figure 1: Domain of the Water Systems Learning Progression

Learning progressions describe successively more sophisticated patterns in student reasoning about a domain (Corcoran, Mosher, & Rogat, 2009; National Research Council, 2007). In a learning progression, increasing levels of achievement describe changes in student performances across a wide age range, usually 6-8 years. The Water Systems Learning Progression describes changes in student thinking about water and substances in socio-ecological systems across elementary through high school grades. It is anchored on the upper end by the scientific, principal-based reasoning about water in socio-ecological systems that is necessary to explain how water and substances in water move through systems and predict the outcomes of changes in systems. The lower anchor of the learning progression describes the ways of thinking about water and substances in water that students bring to learning about water systems in school science. In between are levels of achievement that mark distinct pattern of progress from less to more sophisticated ideas. Changes in student thinking are tracked along progress variables. The Moving Water progress variable tracks student thinking about the structures of the systems through which water moves and the processes that move water. The Substances in Water progress variable tracks student thinking about substances that mix with water and the processes that mix, move, and unmix substances with water. Both progress variables track student thinking from macroscopic to atomic molecular and landscape scales.

Progress along the Water Systems Learning Progression marks changes in student thinking about the world (Gunckel, Mohan, Covitt, & Anderson, In press). Progress cannot be thought about in terms of simply adding more concepts to students' conceptual networks. Knowledge and practices are embedded in Discourses, ways of thinking, talking, and acting that are characteristic of communities (Cobb & Hodge, 2002; Gee, 1991; Wenger, 1998). Therefore, progress from the lower anchor to the upper anchor represents changes in how students reason about events and phenomena. Students come to school with a primary Discourse that views the world in ways that are significantly different from the model-based, scientific Discourse of scientific and environmentally literate communities. Progress along the learning progression is not intended to represent developmental stages in thinking. Rather, it shows a process of learning new Discourses, and gaining access to new communities that engage in scientific, model-based reasoning (Gunckel, et al., In press).

Table 1 shows the Water Systems Learning Progression Framework (Gunckel, Covitt, Dionise, et al., 2009; Gunckel, et al., In press). Level 1 is the lower anchor that represents the primary Discourse that students bring to learning about water. Although students come from diverse communities, our research has shown that there is a pattern in student thinking about phenomena that is rooted in vernacular language and that this pattern extends across languages (Pinker, 2007; Talmy, 1988). Students participating in primary Discourses take a force-dynamic view of the world, where they see water as part of the background landscape. These students focus on visible forms of water and do not recognize how water in one location is connected to water in another location. Level 1 students also categorize water into different types, such as "dirty water" or "clean water." At Level 2, students' still rely heavily on the force-dynamic thinking of their primary Discourse. However, they also recognize that water can move places and that water can change quality. They often invoke actors or enablers to do things to water. For example, Level 2 students talk about how machines can clean polluted water or how the sun dries up the water in a puddle. At Level 3, force-dynamic thinking is less-prevalent. Level 3 represents the Discourse of school science narratives. Students often repeat stories about how water and substances move from one place to another. They can name and sometimes explain processes at a macroscopic level. However, because they do not consider how principles such as gravity, permeability, or conservation of matter govern the movement of water and substances in water, Level 3 students often have difficulty tracing water and substances through invisible or hidden portions of socio-ecological systems. They view water quality as substances mixed with water, although they often have difficulty explaining how the substances mix or unmix. Level 4 represents the qualitative model-based reasoning of the scientific Discourse. This Discourse is our goal for all high school students to achieve. Students at Level 4 can trace water and substances in water along multiple pathways and at multiple scales (from atomic-molecular to landscape scale).

Table 1: Water Systems Learning Progression Framework

Levels of Achievement	Progress Variables	
	Moving Water	Substances in Water
4: Qualitative model-based accounts	Can trace water through connected systems along multiple pathways and at multiple scales. Applies principles that govern movement of water (e.g. gravity, pressure, permeability, conservation of matter).	Can identify and trace substances mixing, moving, and unmixing with water along multiple pathways and at multiple scales. Applies principles (e.g. conservation of matter, solubility) to reasoning about substances in water.
3: "School science" narratives	Tells school science narratives about how water moves through the water cycle. Names processes but has difficulty describing processes at atomic-molecular scales or tracing water across landscape-scale systems. Does not use principles in reasoning about water movements. Does not apply school narratives to local situations.	Tells school science narratives about substances mixing, moving, and unmixing. Names processes but has difficulty describing processes at the atomic-molecular scale. Does not use principles to govern reasoning about substances. Does not apply school narratives to local situations.
2: Force-dynamic narratives with hidden mechanisms	Recognizes that water can move from one place to another and recognizes that there are hidden mechanisms that move water. Uses force-dynamic thinking that invokes actors or enablers to move water.	Recognizes that water quality can change. Usually thinks of water quality in terms of bad stuff mixed with water. Invokes actors or enablers to change water quality (e.g. clean the water).
1: Force-dynamic narratives	Views water as part of the background landscape with natural tendencies (e.g. flows). Does not view water in one location as connected to water in another location.	Views water quality in terms of types of water (e.g. dirty water or clean water).

Procedure

This research is part of a larger project to develop a learning progression for water in socio-ecological systems. Learning progressions research uses an iterative design process to develop, test, and refine a framework using student assessment data. The research reported in this paper is the result of one cycle of design that specifically added data from teachers to expand and refine the Water Systems Learning Progression framework.

The teachers who participated in this cycle of development were participating in an environmental literacy professional development program for elementary through high school teachers at two Long Term Ecological Research Stations (LTER) located in two states in The USA; one in the upper Midwest and the other in the Rocky Mountains. Both LTERs were participating in a larger project designed to increase teacher understanding of the water cycle, carbon cycle, and biodiversity. Each LTER designed and conducted their own professional development program, situated in their local area. A total of 61 teachers were enrolled in the program across the two sites (LTER #1 n=34, LTER #2 n = 27). The teachers spanned the elementary, middle school, and high school grade bands.

Two assessments were developed from a pool of 20 items designed to probe teacher understanding of processes that move water and substances through atmospheric, surface water, groundwater, and human-engineered systems. Of these 20 items, 14 items had been previously developed and used on assessments of student learning during earlier cycles of the development of the Water Systems Learning Progression (Gunckel, Covitt, & Anderson, 2009; Gunckel, Covitt, Dionise, et al., 2009). The assessments analyzed in this paper were administered prior to the workshop. At one LTER site, the same assessments were administered after the workshop. However, for this paper, only assessments administered prior to the workshop were analyzed in order to determine the level of achievement that the teachers brought to the professional development program. Teachers at both LTERs randomly received either Form A (n=33) or Form B (n=28) of the assessment.

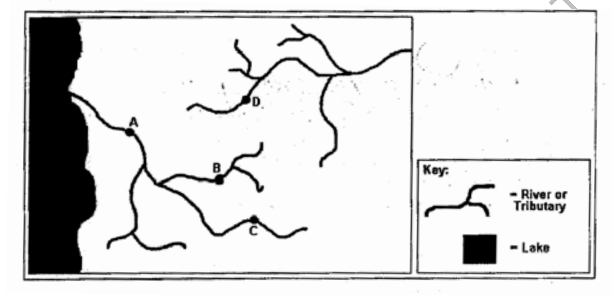
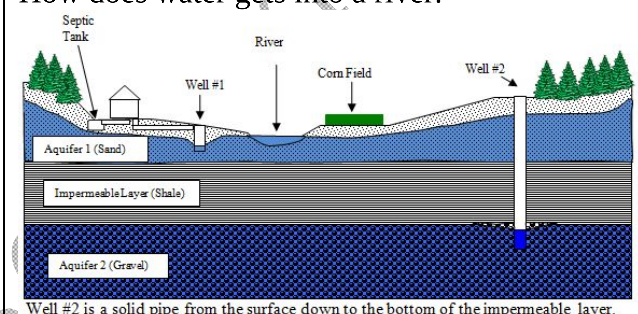
Earlier cycles of research have shown that reliability of analysis of item responses increased when items were grouped and multiple responses from an individual were analyzed together. Clusters of items were developed, with each cluster including two to six items. Each cluster included items that aligned with one progress variable and probed both natural and human-engineered aspects of at least one system of the framework for water in socio-ecological systems. Each cluster also had an exemplar worksheet with indicators for each level of achievement and example responses for the items in the cluster (Mohan, et al., 2009). These exemplar worksheets had been developed during previous cycles of this learning progression research and had been validated using earlier student assessment data.

Eight items on the teacher assessment forms aligned with items in four of these clusters: Aquifers, Rivers, Puddles, and Mixing/Unmixing (see Table 2). Because the items were distributed across forms of the assessment, each cluster included responses from 24-33 teachers. For each teacher, responses to items in each cluster were then analyzed for indicators of levels of achievement in the Water Systems Learning Progression, using the exemplar worksheets for each cluster. We had a total of three researchers coding responses. For each cluster, responses were divided between two of the three coders. 10% of the items overlapped between coders to determine interrater reliabilities (66-90%). For each cluster, the percentage of teachers at each level of achievement was then calculated. The frequency distributions were compared with the frequency distribution of responses across levels of achievement for each cluster for a sample of 30 high school students. We compared teacher results to those of high school students because we argue that since Level 4 represents what we think all students should achieve by the end of high school, then all teachers should achieve Level 4 as well.

Qualitative comparisons of teacher and student responses were conducted to identify patterns in teacher and student thinking. We specifically looked for patterns in how teachers and students demonstrated awareness of structure and components of hydrologic systems, viewed connections between natural and engineered aspects of socio-ecological systems, made connections between abstract concepts and concrete examples, and used principles and scale to guide reasoning.

The limitation of this study is the relatively small number of teachers and high school student responses analyzed. In future work we will include more teachers so that we will also be able to compare teacher performance to the grade level that they teach.

Table 2: Item clusters for teacher data

Progress Variable	Cluster	Items
Moving Water	Puddles	• *Puddles* After it rains you notice puddles in the middle of the soccer field. After a few days you notice that the puddles are gone. Where did the water go? • *Bathtub* Can the water in the puddle end up in end up in your bathtub? If yes, how?
	Rivers	• *Water pollution* If a water pollutant is put into the river at town C, which towns (if any) would be affected by the pollution? Explain how the pollution would get to the towns you circled.  • *Water in River 1* How does water gets into a river. 
	Aquifers	• *Wells Affect Rivers* Could pumping from well #1 affect the water in the river? Could pumping from well #2 affect the water in the river? Explain your answers. • *Water into Wells* How does water get into well #1? Explain as many pathways as you can. Also draw the pathways on the cross section. Be sure to label the pathways. (See diagram for Water in River Item in Rivers Cluster)
Substances in Water	Mixing and Unmixing	• *Solution/Suspension Pictures* Draw a picture of a substance in suspension and a substance in solution. Show atoms and molecules if you can. • *Lake Water Treatment* Describe 3 ways to make lake water safe to drink

Findings

We report our results by cluster. In our results, we indicate prominent patterns in frequencies of responses for high school students and teachers. However, due to the small sample size, we do not report statistical significance levels for differences between frequencies. While frequencies are reported, the emphasis in the findings is placed on the qualitative characterization of student and teacher responses.

Puddles Cluster

Items in the Puddles Cluster probed students' and teachers' thinking about pathways through connected natural and engineered systems that water on the Earth's surface may follow. Items in the cluster asked where water in a puddle may go and if there are pathways that might connect the water in a puddle to water in a bathtub. Figure 2 shows the distribution of high school student and teacher responses across levels of achievement for the Puddles cluster. More teachers than students reached Levels 3 and 4 (83% of teachers and 53% of students). More teachers reached Level 3 (60%) than Level 4 (23%). Fewer than 10% of high school students provided Level 4 responses.

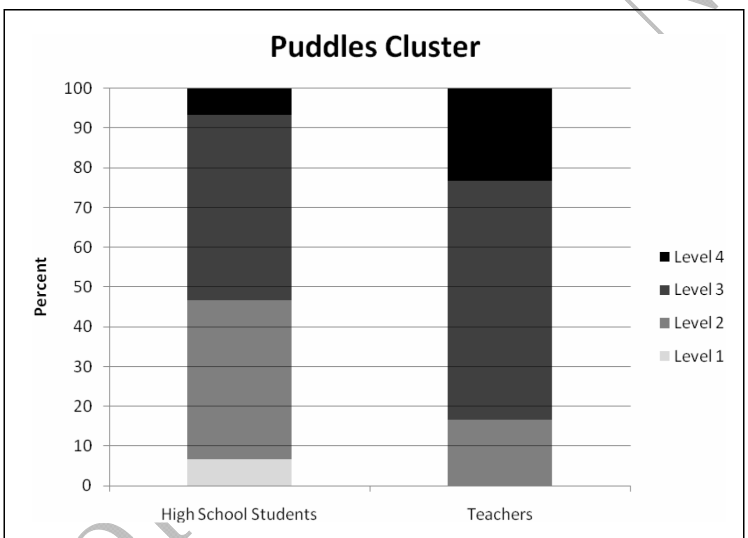


Figure 2. Puddles Cluster Level Frequencies for High School Students and Teachers

Teachers' Level 3 answers show some similar features to students' Level 3 answers. Teachers and students tell stories about where water goes. Students at Level 3 recognize that water exists in the air or underground. However, processes are often misidentified or missing, and details about connections between systems, especially engineered systems, are often missing. Students sometimes traced water from the puddle into the atmosphere through evaporation, but did not mention groundwater pathways until the Bathtub item prompted them to do so. Other students traced water only through the ground, and did not mention evaporation as a possible pathway. Teachers' stories, however, often traced water from the puddle into both the atmosphere and the groundwater without being prompted. Table 3 shows examples of high school and teacher Level 3 responses. Each row represents responses for both questions by the same student or teacher.

Table 3. Example High School Student and Teacher Responses to Puddles Cluster

	Puddles Question: *After it rains you notice puddles in the middle of the soccer field. After a few days you notice that the puddles are gone. Where did the water go?*	***Bathtub Question:*** *Can the water in the puddle end up in end up in your bathtub? If yes, how?*	***Level***
Student	It soaked into the ground.	It could because it goes into the ground and your water pumps gets ground water which you could use to fill up your bathtub.	3
Student	All the water from those puddles evaporated.	The mud evaporates, than it rains again, and goes threw [sic] the ground, into your well, and in your bathtub.	3
Student	It evaporated into the air.	It can seep through the ground and get into your water table and if you have a well you might use it.	3
Teacher	Percolated into ground and evaporated into air.	Yes. Percolated into watershed which ends up as water supply. Evaporate, clouds, rain, water supply.	3
Teacher	Evaporation, soak into ground.	Yes: groundwater could be used as a source of water for a city or if you have a well. Evaporated water could form clouds and rain on surface water that could also be used.	3
Teacher	evaporation/groundwater.	Yes: puddle to evaporation to condensation to precipitation to city's clean water aquifer.	3
Teacher	Evaporation into the air. Infiltration and percolation into gravel then to plant roots or groundwater table or soil horizon	Yes. Water pumped out of aquifer to city water system or to aquifer and a well.	4
Teacher	1. It evaporated. 2. It seeped into the ground. 3. The cow on the soccer field drank it.	Yes. Soccer field to runoff to drain to reservoir to water purification station to my house.	4
Teacher	Down through the soil layers, or if the soil was high in clay the water may have evaporated.	Yes: Groundwater flows into aquifers. My well pumps water out of an aquifer.	4

The higher percentage of teachers who provided Level 4 answers shows that some teachers were able to provide more pathways and more detail about the pathways along which water moves than students. For example, teachers providing Level 4 responses often recognized that water in a puddle could move into the biotic system (e.g., plant roots or a cow). Teachers providing responses at Level 4 also demonstrated greater awareness of components of human-engineered systems such as pumps. Many teachers were also able to identify principles such as permeability (e.g., "if the soil was high in clay the water may have evaporated') that govern the pathways that water would follow.

We note that Level 4 answers do not necessarily represent perfect responses to the item prompts. Many teachers' Level 4 answers do not provide great detail about the connections between natural and engineered systems. However, teachers' Level 4 answers do show that the teachers were using more principle-based reasoning about the multiple pathways that water could take through connected systems.

Rivers Cluster

Items in the Rivers Cluster probed student and teacher thinking about how water moves into rivers and where water in rivers flows. Items in this cluster also provided some insight into student and teacher thinking about connections between surface water and groundwater systems. Most of the items in this cluster included maps or cross-section diagrams. Figure 3 shows the distribution of high school student and teacher responses across levels of achievement for the Rivers Cluster.

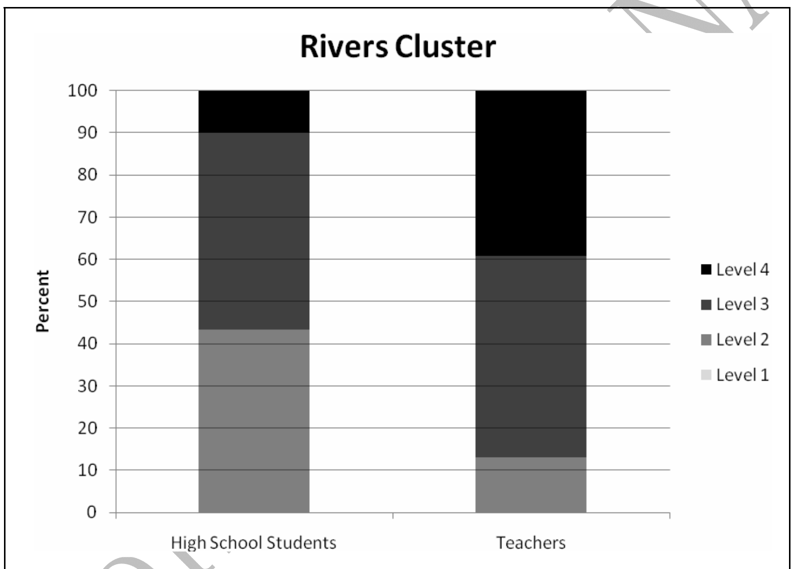


Figure 3. Rivers Cluster Level Frequencies for High School Students and Teachers

No high school students or teachers provided Level 1 responses to the Rivers Cluster questions. However, over 40% of high school students demonstrated only Level 2 understanding. Like the Puddles Cluster, more teachers than students reached Level 3 and Level 4 (87% of teachers and 57% of students) in their Rivers Cluster responses. More teachers reached Level 3 (48%) than Level 4 (39%).

Also, like the Puddles cluster, teacher responses at Level 3 show similarities to student answers. Teachers and students were asked a question about how water gets into a river that was accompanied by a cross section diagram (see Table 2). The diagram included a cornfield, a house with a septic tank, and a confined and unconfined aquifer. At Level 3, both students and teachers tell stories about how water gets into and flows in rivers, but do not use principles such as gravity or permeability to govern where water flows. Students and teachers included connections between rivers and groundwater in their stories. However, neither students nor teachers used the diagram as a tool for reasoning. Teachers at Level 3 did not consistently use the principles of gravity and permeability to govern where water in rivers can flow to. For example, two of the teacher responses in the examples above use the plural form "aquifers" to indicate how water gets into the river in the diagram. However, one of the aquifers in the diagram is a confined aquifer that is not hydrologically connected to the river. We infer that teachers were not reasoning from the diagram when providing their answers. Table 4 shows example high school and teacher responses to this item

Table 4. Example Level 3 High School Student and Teacher Responses to Water in River Item

	How does water get into a river?	***Level***
Student	1) through aquifer 1 2) after the person waters the corn field.	3
Student	water in the river comes from Aquifer 1 and runoff.	3
Student	ground water; Rain, and Runoff contributed to the water.	3
Teacher	water runs off from the watering of the corn field, down the hills from rain/snow.	3
Teacher	One way water gets into the river is by run off from the inclined planes on each side. Another way is from precipitation.	3
Teacher	Water gets into the river from rain, run off and the aquifers underground.	3
Teacher	Water enters the river via rain fall, run off from the land and aquifers.	3

The Water Pollution item probed thinking about where water in rivers goes, using the pollution as a tracer (See Table 2). Table 5 shows responses to this item. Interestingly, students did not consider groundwater pathways. However, a common factor among teachers' answers is that the teachers sent the water underground across watershed boundaries. These teachers did not recognize that lateral boundaries for unconfined aquifers generally follow the boundaries of the surface watershed above the aquifer, and similarly, that direction of groundwater flow will generally follow the direction of surface water flow.

Table 5. Example Level 3 Responses to Rivers Cluster Water Pollution Question

	If a water pollutant is put into the river at town C, which towns (if any) would be affected by the pollution? Explain how the pollution would get to the towns you circled.
Student	[Towns] A,B,C: Because the river in town C flows into the River by town A, making it polluted
Student	([Town] C: Because the water flows from C to the lake which is only on the way to A.
Teacher	[Towns]A,B,C: The pollution would get to the town by both the river current as well as seeping into the ground.
Teacher	[Towns]A,B: Water flows down stream from C, directly affecting town A since it is directly in its path. Town B be could be affected due to groundwater.
Teacher	[Towns] A, B, C, D. A-downstream. B-water table below basin. C-source. D- fish from the lake, etc.

At Level 4, teachers were able to apply principles of permeability and gravity to trace water into rivers (Water in Rivers Item) and trace where water in rivers goes (Watershed Pollution Item) using the maps and diagrams provided as reasoning tools (Table 6).

Table 6. Example Teacher Level 4 Responses to Rivers Cluster Items

How does water get into a river?
A: Rain, snow. B: downhill flow from septic. C: along the aquifer following the impermeable layer. D: runoff from irrigation of corn. E: runoff from domestic use wells.
If a water pollutant is put into the river at town C, which towns (if any) would be affected by the pollution? Explain how the pollution would get to the towns you circled.
A: The pollutant is most likely water soluble or transferrable by the water it will flow down stream. Town A is down stream.
[Towns] A, C: A& C are directly affected by being in the same line of stream flow. [Town] B & D are less likely to be affected unless there is tremendous groundwater seepage (unlikely). [Town]D even appears to be in a completely different watershed and unless there exists a very porous rock layer or cracking/cave network it should not get any pollution from [Town] D. A being downstream should get a good deal of pollution from [Town] C.

While the second response to the second question in Table 6 does include groundwater as a possible pathway for the pollution (similar to the Level 3 responses to this question), the Level 4 response recognizes that this pathway is not a very probable one, and the teacher provides a principle-based reason for why (i.e., unless there exists a very porous rock layer or cracking/cave network it should not get any pollution from [Town] D).

Aquifers Cluster

Items in the Aquifers Cluster probed student and teacher thinking about how water moves into and through groundwater systems, including connections to engineered systems such as wells. Most of the items in this cluster also included the cross-section diagram showing unconfined and confined aquifers and wells (See Table 2). Figure 4 shows the distribution of high school student and teacher responses across levels of achievement for the Aquifers Cluster.

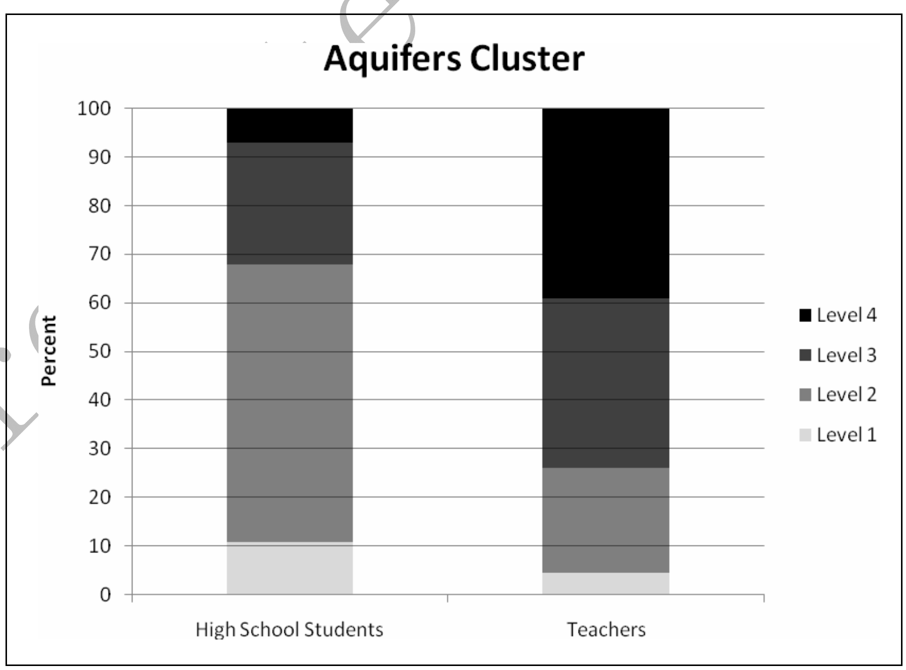


Figure 4. Aquifers Cluster Level Frequencies for High School Students and Teachers

In the Aquifers Cluster, 32% of students reached Levels 3 and 4, while 74% of teachers reached Levels 3 and 4. A similar number of teachers achieved Level 3 (35%) compared with Level 4 (39%), while very few high school students (7%) reached Level 4.

Most student and teacher responses at Level 3 described the diagrams associated with the items. However, the responses did not trace the water or provide reasons for the answers beyond describing what the diagram showed. Many students and teachers said that pumping water from a well (well 1) in an unconfined aquifer (aquifer 1) could affect a nearby river because the river and the well were both touching the same water or were both in the same water. Similarly, when asked if pumping from a well (well 2) in a confined aquifer (aquifer 2) would affect a nearby river, most students and teachers who claimed that it would not affect the river reasoned that the water in the confined aquifer did not touch or was too far away from the water in the river. In contrast,the teachers who provided Level 4 answers to the Aquifers Cluster used the principles of gravity and permeability to reason about which wells would affect the river. (See table 7)

Table 7. Example Level 3 Responses to Aquifers Cluster Wells Affect Rivers Question

	Could pumping from well #1 affect the water in the river? Could pumping from well #2 affect the water in the river? Explain your answers.	***Level***
Student	Pumping from well #1 affects the river water because the well runs into aquifer 1 which also connects with the river. However, pumping from well #2 doesn't affect the river because well #2 runs right through aquifer 1 all the way down to aquifer 2.	3
Student	The aquifer is at the same level as the river, it supplies well 1. Aquifer 2 is below the river.	3
Teacher	Well #1 is in aquifer 1, so the draw on the well could impact the river. Well #2 is in a deeper aquifer and would have little or no impact on the river.	3
Teacher	Well 1 taps into aquifer that is part of the river's water source. River level may change. Well 2 does not draw water from aquifer 1.	3
Teacher	If aquifer 1 is continually pumped out, more water from the river will seep (percolate?) into the aquifer from the river... Impermeable means can't be penetrated, so it [well 2] would not take water out of the river…	4
Teacher	Well 1 is in the first aquifer layer. The river is also in aquifer 1. So they are both affected by the aquifer (river). Well 2 would not be affecting the river because of the impermeable layer.	4

Substances Cluster

Items in this cluster addressed the substances in water progress variable. These items probed student and teacher thinking about mixtures of substances in water and how substances unmix from water. Teachers were asked to identify and draw pictures of substances in suspension and in solution in water and to describe how substances could be unmixed from water. Levels of achievement for teachers' responses to these two items were compared to levels of achievement for high school student responses to similar items addressing the same concepts. However, the exact wording of items in the cluster was different for teachers and students.

As with the three clusters associated with the moving water progress variable, more teachers achieved Levels 3 and 4 (94%) than students (17%). In fact, no students achieved Level 4 for this cluster. Most teachers (67%) achieved Level 3, and only 27% achieved Level 4.

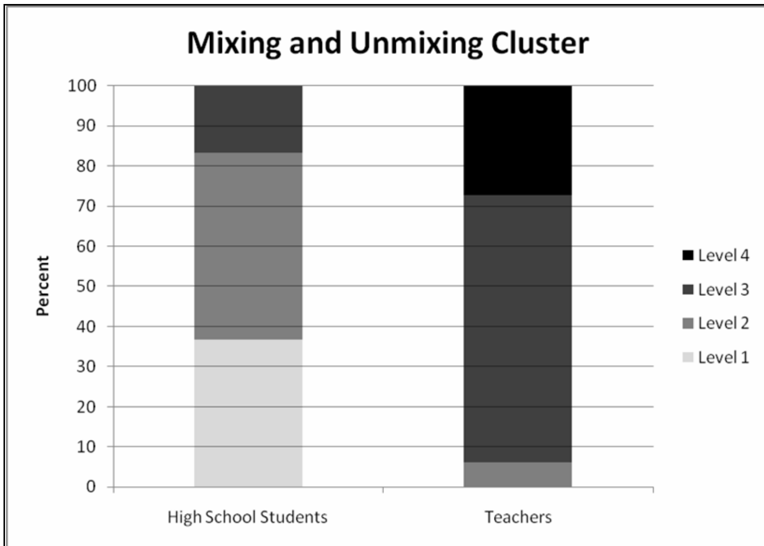


Figure 5. Mixing and Unmixing Cluster Level Frequencies for High School Students and Teachers

Level 3 responses to items in this cluster included pictures and stories that described water and substances in water at a macroscopic scale. For example, Level 3 teacher drawings of substances in suspension and solution often showed trash floating on top of the water as a substance in suspension and used small dots distributed throughout a cup of water to represent salt in solution. In contrast, Level 4 drawings identified substances such as silt in suspension and salt in solution. Level 4 drawings distinguished between macroscopic and atomic molecular scales. For suspension drawings, Level 4 responses showed suspended substances as particles floating in water (a macroscopic or possibly microscopic view). In contrast, in solution drawings, Level 4 responses zoomed in to atomic molecular scale. Water was shown in a molecular representation (usually spherical or ball and stick representation) and Na+ and Cl- ions were depicted as small, labelled spheres. Na+ and Cl- ions were often shown as being distributed among the water molecules. Some teachers showed that the negative pole of the water molecule was attracted to the positive sodium ion and the positive pole of the water molecule was attracted to the negative chloride ion.

Students and teachers were both asked how to make water drinkable. Teachers were asked to describe 3 ways to make lake water drinkable. Students were asked to describe methods to treat drinking water or waste water, and to explain what those methods do to treat the water. Students at Level 3 tended to name processes and provide descriptions at the macroscopic scale. The nature of substances in water were desribed in general or generic terms, such as describing “chemicals” instead of identifying specific chemicals, such as chlorine. Unlike high school students, Level 3 teacher responses tended to name rather than describe processes, even though they were prompted to give descriptions. In contrast, Level 4 teacher responses provided detailed descriptions of at least one process named. The chemical nature of substances in water were identified, and some descriptions identified changes of state.Table 8 shows example student and teacher responses to items in this cluster.

Table 8. Example High School Student and Teacher Responses to Water Treatment Questions

	Describe the different treatments that are used to make sure water is safe for people to drink (or waste water is safe). How does each kind of treatment you mention change the water? Talk about substances and molecules if you can.	***Level***
Student	Filters take solid materials out; heat boils the bad stuff out; chemicals kills bacteria.	3
Student	Filtering filters out trash, leaves, stick, rocks, etc.; heating kills bacteria and germs.	3
	Describe three ways to make lake water safe to drink.	
Teacher	1. filter. 2. boil. 3. chemically treat.	3
Teacher	1. boil it. 2. treat it with chemicals. 3. aeriate [sic] the lake.	3
Teacher	1. Boiling. 2. Chemicals. 3. filtration system	3
Teacher	Distillation is taking the water, boiling it until it becomes a gas, cooling it and collecting the drops. This leaves behind anything that was in the water. Chemical treatment to remove contaminants. Filtration.	4
Teacher	Depends on what is polluting it. If anything boil to kill microorganisms. Distill to remove fertilizers, salts, medicines. Chemically treat to kill microorganisms.	4

Summary of Findings

While we do not report significance levels for differences between frequencies, some similarities across the clusters (note that participants are different for different clusters) help to highlight several prominent patterns. These include that more teachers than students reach Levels 3 and 4, that very few teachers provide Level 1 responses, and that few high school students provide Level 4 responses. Also, the percent of teachers who provided Level 4 responses does not exceed 40% for any cluster.

Discussion

The results of this analysis show that teachers in general reach higher levels of achievement in the learning progression than do students. More teachers reach both Levels 3 and 4 than do students. However, it is somewhat troubling that more teachers do not reach Level 4. A conclusion that one might draw from these data is that teachers do not have as high an understanding about how water and substances move through socio-ecological systems as they should in order to support students in reaching high levels on the learning progression. Such an explanation, however, blames teachers for not having high subject matter knowledge. We argue that the issue is more complex than that teachers just do not have high subject matter knowledge about water. Rather, we argue that these results have more to say about the Discourses that are present in schools.

Level 3 on the learning progression describes school science narratives. School science narratives are stories about phenomena that repeat typical or prototypical explanations from the school science curriculum (Mohan, et al., 2009; Shepardson, et al., 2009). In the context of water, school science narratives are stories about water moving through the water cycle. School science narratives are typically limited to macroscopic descriptions of events. They require students to identify components of systems (e.g. rivers, aquifers, wells, etc), and processes (e.g. evaporation, infiltration), and to describe common pathways (e.g. evaporation into the air; infiltration into the ground). However, they do not require students to use principles to reason about how water and substances in water move through connected systems (Mohan, et al., 2009; National Research Council, 2007). School science narratives do not require students to reason about how principles such gravity, permeability, pressure, and the size of particles will govern how water and substances in water move through connected systems.

Discourses describe the ways in which members of a community view the world. Discourses shape the way that members of the community talk, reason, and act as members of a socially meaningful group (Gee, 1991). The results of this analysis suggest that in schools, school science narratives are the dominant Discourse in science classes. Teachers as well as students tell narratives rather than use principles to guide reasoning about events. Principle-based reasoning using models to account for matter moving through connected systems is not a feature of school-based reasoning, at least with respect to water in socio-ecological systems. Possible reasons for the prevalence of a Discourse of school science narratives include the predominance of prototypical, school science narratives in textbooks and other curriculum resources (Shepardson, et al., 2009), as well as the climate of testing and accountability that focuses on narrow, multiple choice tests that do not provide opportunities to assess model-based reasoning practices (National Research Council, 2006; Quellmalz & Haertel, 2004). Thus, both teachers and students participate in school communities where the Discourse of school science narratives and not the Discourse of model-based reasoning shapes their reasoning about phenomena.

Environmental science literacy requires principle-based reasoning. Environmentally literate citizens must be able to both explain phenomena and predict the outcomes of different courses of action. They must be able to evaluate options and make decisions based on evidence. For example, in a community that needs to replace an aging landfill, citizens have a number of options. Each option has financial and ecological consequences. Environmentally literate citizens need to be able to use the principles of gravity, permeability, solubility, and conservation of matter to reason about how water moves through landfills into underlying aquifers or nearby rivers and how substances mix, move and unmix with water in the landfills. Citizens play a variety of roles in the decision-making process about a new landfill, from workers, to policy makers, to voters. However, all should be able to use the qualitative model-based reasoning of a scientific Discourse to inform the decisions they make and support about the landfill. School science narratives do not support students or teachers in these important practices.

Therefore, if schools are going to play a role in developing environmental science literacy, then we need to change the Discourse in schools. Changing the Discourse from school science narratives to model-based reasoning will required changes in science standards, science curriculum materials, and science assessments. Professional development can also play a role, by supporting teachers in recognizing the differences between school science narratives and model-based reasoning. We suggest that professional development make the practices of these Discourses explicit to teachers by providing them with opportunities to examine examples of student reasoning at each level of achievement on the Water Systems Learning Progression. Professional development can also support teachers in developing their own model-based practices, using principles to reason about how water and substances move through systems. Based on the results from this research, we recommend that professional development focus on supporting teachers in thinking across systems and scales, especially at the atomic-molecular scale. We also recommend that professional development efforts support teachers in using the principles of permeability to trace water through subsurface systems.

Conclusion

The results of this research show that in general, teachers reached higher levels of achievement on the Water Systems Learning Progression than do high school students. However, more teachers performed at Level 3 (school science narratives) than at Level 4 (model-based reasoning). Given that Level 4 for the learning progression represents the expectation for high school graduates, teachers' performances are not as high as would be desired. Teachers still demonstrated difficulty using principles to reason about water and substances in water in socio-ecological systems. These results suggest that the dominant Discourse in schools is a Discourse of school science narratives and not a Discourse of model-based reasoning. In order to better support students in becoming environmentally-literate citizens, we must change the Discourses in schools so that model-based reasoning, not school science narratives, shape the way that students and teachers reason about phenomena. Changing the Discourse will require more than just professional development to increase teacher understanding of water systems. We must further examine the ways in which standards, curriculum materials, and standardized assessments shape the Discourses in school science classrooms.

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