Middle and High School Teachers' Accounts of Water in Environmental Systems

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Abstract

The *Framework for K-12 Science Education* emphasizes scientific practices such as constructing explanations and predictions of phenomena. One domain in which this practice is important is explaining how and why water and substances in water move through environmental systems. This study used a learning progression framework to examine middle and high school teachers' accounts (i.e., explanations and predictions) of water in environmental systems. We assessed 62 teachers participating in an environmental literacy professional development program prior to their participation in program activities using assessment items and analysis procedures previously developed and validated to explore student understanding of the same domain. Teacher accounts were also compared with accounts from 167 high school students and to expectations for explanations from the *Framework*. Findings suggest that teachers demonstrate more sophisticated explaining and predicting practices compared with high school students. However, many teachers fall short of providing the types of model-based explanations and predictions called for in the *Framework* for explaining how and why events happen. Supporting teachers in developing more scientific accounts of water in environmental systems will likely require shifts in the expectations of explanations in standards, curriculum materials, and assessments.

Keywords: Explanations, Learning Progressions, Practices, Crosscutting Concepts, Water Systems

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Recent publication of the *Framework for K-12 Science Education* (National Research Council, 2012) provides science educators with an updated vision for what students should understand about Earth systems. The Earth and Space Science core ideas in the *Framework* emphasize that human actions have significant impacts on functions of Earth systems and that the sustainability of human societies depends on our management of these systems. One system that is particularly vulnerable to human impacts, and which thus receives considerable attention in the *Framework,* is Earth's hydrologic system. Because "humans affect the quality, availability, and distribution of Earth's water," (National Research Council, 2012, p. 194) it is essential that students graduating from high school have sufficient understanding to make informed decisions about water systems and issues. Preparing students to meet this goal requires teachers who are also knowledgeable about water in environmental systems.

Developing understanding of Earth's hydrologic systems involves more than just understanding core disciplinary ideas about water. In addition to identifying important core scientific ideas, the *Framework* highlights two other key dimensions of science learning. These dimensions include *scientific practices* such as constructing explanations and predictions, and *crosscutting concepts* that have applicability across science disciplines, such as systems and system models, and cause and effect. Teachers and students should be able to use core disciplinary ideas and crosscutting concepts to explain and predict where and how water moves through environmental systems; what substances might be in water; and how those substances, mix, move, and separate from water. For example, in order to understand how a small city meets its water needs, citizens must be able to interpret maps that show watershed systems, understand how gravity pulls water flow downhill, consider how topography constrains the direction of water flow, and identify potential pollution sources that could contaminate the water.

Inclusion of practices and crosscutting concepts as dimensions in the *Framework* emphasizes that understanding science as a body of facts is insufficient preparation for participating in public discussions of socioscientific issues and for using science in one's daily life (National Research Council, 2012). The *Framework* advocates integrating science content with scientific practices and crosscutting concepts in science instruction to support students in developing the capacity to use science understanding in meaningful, real-world contexts. For example, citizens who are able to develop scientific explanations and predictions about water in environmental systems will be better prepared to use their understanding to inform decisions about water issues they confront in their lives. They will understand how and why changes may occur in their local water systems, and will be able to predict how personal and community actions will impact water resources in the future.

Given the vision for integrating core disciplinary knowledge and crosscutting concepts with scientific practices set forth in the *Framework*, the important role that teacher knowledge and practice can play in supporting student learning, and the vital importance of students developing the capacity to explain and predict where and how water and substances in water move through environmental systems, it is necessary to take stock of teacher explanations and predictions, which we call *accounts*, of water in environmental systems. In this article we use a learning progression framework, which incorporates important crosscutting concepts, to analyze teachers' accounts and compare them to accounts provided by high school students. This approach provides a metric for understanding teacher knowledge and practices relative to students' knowledge and practices, and relative to the scientific knowledge and practice goals set forth in the *Framework for K-12 Science Education.*

Previous Research on Teachers' Understanding of the Water Cycle

In order to support students in understanding and constructing scientific explanations and predictions about water in environmental systems, it is imperative that teachers understand relevant science content (Abell, 2007; National Research Council, 2007; Windschitl, 2009). Teachers with strong and interconnected knowledge of both disciplinary and crosscutting scientific concepts are more likely to identify and focus instruction on fundamentally important science concepts and to engage in effective teaching strategies to support student thinking and learning (Gess-Newsome & Lederman, 1995; Roehrig & Luft, 2004; Windschitl, 2009). Strong content understanding is also necessary for teachers to assess and build on student ideas, and to measure student progress (Driel, Verloop, & de Vos, 1998; Grossman, Schoenfeld, & Lee, 2005). Furthermore, teachers need to be able to use this understanding to develop and evaluate scientific explanations and predictions and to support students in learning these practices.

Only a few previous studies have explored teachers' and preservice teachers' understanding of the water cycle. These studies suggest that teachers' understanding of water systems may be weak. Stoddart, Connell, Stofflett, and Peck (1993) explored elementary preservice teachers' explanations of water cycle phenomena such as condensation, boiling, and clouds. They classified responses into three categories: naïve conceptions (i.e., no science understanding or terminology), scientifically naïve conceptions (i.e., incorrect use of science terminology), and scientific understanding (i.e., responses corresponding to scientific explanations for phenomena). Stoddart et al. found that 72% of the preservice teachers' responses fell into the first two categories. In another study that examined the impact of professional development on teachers' understandings of watersheds and water quality, Shepardson, Harbor, Cooper, and McDonald (2002) found that prior to their professional development activities, only 44% of teachers were able to define a watershed as an area that drains water and that 44% of the teachers believed that high quality water does not contain any pollutants. Both studies, however, found that teachers' understanding of relevant water content improved following instruction.

Explanations and Predictions for Water in Environmental Systems

The previous studies cited above focused on teachers' knowledge of the water cycle. The *Framework*, however, calls for fusing core disciplinary content and crosscutting concepts with practices. As defined in the *Framework*, the practice of constructing scientific explanations includes both describing phenomena and explaining of the causes and mechanisms that underlie phenomena (National Research Council, 2012). Scientific explanations and predictions also incorporate multiple crosscutting concepts, including systems and system models, cause and effect, and energy and matter.

Explaining and Predicting Practices

The focus on scientific practices in the *Framework* is grounded in recent work intended to identify and characterize important practices in science and to construct tools and heuristics to support students in engaging in these practices. The practice of constructing explanations has received particular attention (Berland & McNeill, 2010; Braaten & Windschitl, 2011; McNeill & Krajcik, 2008). The definition of a scientific explanation, especially as distinct from scientific argument, and its role in science education is not well-established (Berland & McNeill, 2012; Osborne, 2012; Osborne & Patterson, 2011). This ambiguity can be problematic for classroom teaching and assessment (Braaten & Windschitl, 2011; Osborne, 2012).

To address this situation, Braaten and Windschitl (2011) proposed a three part typology of explanations that address what, how, and why. The most basic what-type explanations are descriptions of what happens, including restating patterns in data. This form of explanation is common in science lessons. Teachers often ask students to repeat descriptive information about phenomena, and/or engage students in carrying out experiments and making observations without developing links to associated theories and models (Banilower, Smith, Weiss, & Pasley, 2006; Braaten & Windschitl, 2011; Horwood, 1988; National Research Council, 2007; Osborne & Dillon, 2008; Roth & Garnier, 2006). More sophisticated how-type explanations explain how events happen. The most sophisticated why-type explanations reference unobservable or theoretical aspects of models to provide causal mechanisms for observable events (Braaten & Windschitl, 2011; Harrison & Treagust, 2000; Osborne & Patterson, 2011). Constructing and using causal why-type explanations requires knowledge of scientific models and use of model-based principles to reason about phenomena and events (Lehrer & Schauble, 2006; Stewart, Passmore, Cartier, Rudolph, & Donovan, 2005; Windschitl, Thompson, & Braaten, 2008). Model-based explanations are necessary for understanding phenomena, predicting outcomes of events, evaluating arguments, and making science-based decisions (Authors, 2012a; Authors, 2012b; Coyle, 2005; Driver, Newton, & Osbourne, 2000; Windschitl et al., 2008).

The Water Systems Learning Progression

Efforts to bring coherence to the discussion of what counts as a scientific explanation have mostly generalized across content areas rather than examined the specific characteristics for explanations in target domains. However, the principles and models upon which scientific explanations are based are specific to particular domains. To define characteristics of scientific explanations and predictions for the domain of water in environmental systems, we use the water systems learning progression. This learning progression describes a hierarchy of accounts (i.e., explanations and predictions) from informal accounts common among young students to scientific model-based accounts that explain how water and substances move through environmental systems and predict outcomes of changes in systems[1] (Authors, 2012b). Each level within the hierarchy is called a level of achievement.

Elements of Accounts. Changes in accounts are tracked along elements of accounts that can be described at every level of achievement. The water systems learning progression includes five elements of accounts: systems and system structures, scientific principles, scale, representations, and dependency and human agency. Scientific accounts of how and why water and substances move along observed and predicted pathways requires attention to structure of systems and the scientific principles that constrain processes that move the water and substances. For this article, we focus on two elements of accounts: structures of systems and scientific principles[2]. These elements incorporate three crosscutting concepts from the *Framework*: Systems and system models, energy and matter, and cause and effect.

All accounts of water moving through environmental systems reference models of these systems (Ben-Zvi Assaraf & Orion, 2010; Schwarz et al., 2009). Scientific models of *systems* include details about the structure of systems involved, such as the stratigraphy of a groundwater system, the topography of a watershed, or the chemical nature of substances that mix and move with water through these systems (Authors, 2012b; Ben-Zvi Assaraf & Orion, 2005, 2010). These models define the boundaries of the systems in which phenomena are observed, explanations are applied, and predictions are made (National Research Council, 2012). Scientific explanations of water and substances in water moving through systems must also adhere to scientific principles (Authors, 2012b). These principles include the drivers that *cause* movement of water through systems and that mix, move, or separate substances from water as water moves through systems and the principles of conservation of *matter and energy* that constrain the movement of water. Drivers that cause water and substances to move include gravity, pressure, and thermal energy. Laws of conservation of matter and energy define the ways that factors such as permeability, topography, and relative humidity constrain movement of water within and among environmental systems.

Levels of Achievement. Table 1 provides an overview of the elements of accounts and related crosscutting concepts at each level of achievement. Progress to a higher level of achievement represents more than simply the addition of more concepts to conceptual networks; it also represents fundamental changes in explanations and predictions of events and phenomena. With increasing levels of achievement on the learning progression, changes in both knowledge and practices are apparent.

Table 1

Levels of Achievement in the Water Systems Learning Progression

		Elements of accounts	
Level of achievement	Type of account (explanations & predictions)	Structure & systems	Scientific principles:
Level 4: Qualitative model-based accounts	Scientific, model-based accounts of how and why events happen	Multiple, detailed connected systems	Driving forces & constraining factors
Level 3: School science accounts	Primarily descriptions of what happens	Connected systems, including visible and some hidden components	Puts events in order, names processes, uses "school rules"
Levels 1 & 2: Force-dynamic accounts	Force-dynamic perspectives of events	Visible, familiar components of systems	Force-dynamic reasoning

Accounts at the lower two levels of the learning progression trace water only through visible and familiar components of systems. Hidden or invisible systems or components of systems, such as the soil/groundwater system, are not well defined. These lower level accounts do not conserve water as it moves out of visible systems. For example, in these accounts water can disappear into the sky or into the ground. These lower level accounts rely on *force-dynamic reasoning* to explain where water moves (level 1) and how or why it moves there (level 2). In force-dynamic reasoning, events are explained as the outcome of the interplay between actors/agents with different powers (Pinker, 2007; Talmy, 1988). From this perspective, actors/agents, which can be humans or other entities, have needs and purposes. Water can fulfill these needs or help an actor/agent to fulfill its purposes. A force-dynamic account of water evaporating from a puddle, for example, may explain that the clouds pick up water or that the sun evaporates water. In these statements, the clouds and sun are actors that do something to the water. Force-dynamic reasoning can provide causal reasons for water movement in that actors fulfilling needs serve as the explanations for how and why water moves. However, these reasons are not grounded in scientific reasoning based on theoretical models such as kinetic molecular theory (Braaten & Windschitl, 2011) or a systems-based perspective of the world (Ben-Zvi Assaraf & Orion, 2005, 2010).

Level 3 on the learning progression represents the discourse of school science stories. These accounts trace water and substances through connected systems, often including components of systems where water may be hidden or invisible, such as the atmosphere. They frequently repeat stories about water moving from one place to another, often describing ordered events and named processes. For example, level 3 accounts may trace water evaporating from a puddle by noting that the water evaporates into the atmosphere, condenses into the clouds and then rains down as precipitation. In this example, several ordered steps along a pathway are described and the processes involved are named. Level 3 accounts frequently rely on rules learned in school to explain what is happening in a particular situation without referencing underlying theories upon which those rules might be based. For example, when asked to interpret the direction of water flow on a map, a level 3 account might explain that water always moves from rivers into lakes. While water often does move from rivers into lakes, this explanation omits reference to causal mechanisms such as gravity and topography to explain why the water flows in that direction. Unifying scientific models and principles are not used to explain how water moves or why. As a result, level 3 accounts are often insufficient for predicting the likelihood of various pathways for water through connected systems.

Level 4 represents qualitative scientific model-based reasoning. These accounts are grounded in scientific models to explain both how and why water and substances in water move through environmental systems. These accounts trace water and substances in water along multiple pathways, across visible and invisible boundaries, and through connected natural and human-engineered systems. Level 4 accounts provide causal explanations grounded in generalized models of water movement. As such, they adhere to scientific principles, such as the conservation of matter. Furthermore, they include driving forces that move water (e.g., gravity, pressure, thermal energy) and constraining factors that limit pathways (e.g., permeability, topography). For example, a level 4 account of water during a storm event would explain that the force of gravity would pull water downwards. The pathway that the water would take would depend on the permeability and slope of the surface on which the water precipitated.

In this work, we use the water systems learning progression to explore teachers' accounts of water and substances in water moving through environmental systems. Our research questions are

1. At what levels of achievement in the water systems learning progression are teachers' accounts of water in environmental systems?
2. How do teachers' accounts of water in environmental systems compare with high school students' accounts and scientific explaining and predicting practices?

Methods

To answer these questions, we used a mixed methods approach (e.g., Creswell & Plano Clark, 2011; Johnson & Onwuegbuzie, 2004). We used the water systems learning progression to identify the mean and distribution of the levels of achievement of teachers' water accounts. We then conducted a qualitative analysis of the accounts from different levels to explore how they utilized key crosscutting concepts to explain and predict water phenomena.

Study Sites

The teachers in this study were participants in an environmental literacy professional development program for middle and high school teachers at four Long Term Ecological Research stations (LTERs) located in four states in the U.S. (Pacific, Rocky Mountain, Midwest, Atlantic). All four LTERs were part of a large research project that involved developing curriculum materials for teaching about water in environmental systems. Each LTER designed and conducted its own professional development program, situated in the local hydrologic environment, for supporting teachers in learning to use the curriculum materials. The teachers self-selected to participate in the professional development programs at their nearby LTER site. Teachers included in this study were new to the program in the spring of 2011 and had not yet participated in the professional development sessions about water systems. These sites provided the ideal context for studying teachers' accounts of water in environmental systems because they attracted teachers interested in learning about water systems and motivated to improve their teaching about water-related topics. As a result, we were able to assess teachers who were likely to provide high-level accounts of water systems. This information would allow us to make inferences about the state of the knowledge and practices of top teachers currently teaching about water in schools.

Participants

Teachers. Participating secondary teachers taught a range of all science topics, including general science, life science and biology, physical science and chemistry and physics, Earth science, and environmental science. Some teachers also taught advanced placement science courses. Table 2 shows the distribution of middle and high school teachers across the LTERs. Fifty-two percent of the teachers reported having a masters' degree or higher, usually in a topic related to science or science teaching.

Table 2

Teacher Participants from LTERs

LTER	Middle school	High school	Total
Pacific	6	12	18
Rocky Mountain	11	13	24
Midwest	6	4	10
Mid-Atlantic	3	7	10
	26	36	62

Teachers were asked to self-report demographic information. Seventy-one percent of the teachers reported being Caucasian, 3% reported being Asian American, 3% reported being of mixed decent, 2% reported being African American, no teachers reported being Hispanic, and no teachers reported being Native American. Fifty-eight percent of the teachers in the study reported being female and 21% reported being male. The rest of the teachers elected not to report demographic information.

Teachers participating in the project came from a wide range of schools. Demographics of the schools ranged from large urban schools with 97% of students being African American and 73% of students receiving free and reduced lunch, to urban and small rural schools with approximately 50% of students being Hispanic and 50% of students receiving free and reduced lunch, to suburban and urban schools with greater than 75% Caucasian students and 22%-50% of students receiving free and reduced lunch. Thus, these teachers represented teachers from a complete cross-section of school sizes and demographics across the United States.

Students. To understand how teachers' accounts of water compare to high school students' accounts, we sampled and analyzed accounts from high school students of teachers who had participated in the LTER professional development prior to 2011. These teachers were not the same teachers whose accounts we analyzed for this study. The reason we did not compare teachers' performance with their own students' performance is that we had far more teachers who took the assessment than who administered the assessment to their own students. Furthermore, in this study we were not analyzing the potential effect of teacher performance on the student performance; the student accounts functioned only as a benchmark against which to compare teacher accounts.

Six teachers who had previously participated in the LTER professional development taught the learning activities in the LTER-developed curriculum materials to their students in the 2010-2011 school year. Four teachers were from the Mid-Atlantic LTER, 4 teachers were from the Rocky Mountain LTER, and 1 teacher was from the Pacific LTER. Their students took pre- and post-assessments water in environmental systems (described below). From each of these six classes, we sampled 30 post-assessments or as many post-assessments as were available. This sampling procedure provided a total sample of 167 student assessments. We chose to compare teachers' accounts to students' post-assessment accounts because the post-assessment accounts assured that we were comparing students who had all received similar learning experiences related to water in environmental systems. Furthermore, Level 4 on the water systems learning progression and the *K-12 Framework* set expectations for student achievement at the end of high school. Therefore, high school students' (average age 15.2 years) post-assessment accounts served as a measure of high school students' level of achievement post-water instruction.

The schools which the students attended represented a wide range of school demographics. These schools ranged from a small city school with a mostly Hispanic student population (82%) and 69% of students receiving free and reduced lunch, to a large urban-area school with a mostly African American student population (90%) and 48% of students receiving free and reduced lunch, to small city schools with mostly Caucasian students (75%) and 20% of students receiving free and reduced lunch.

Instruments

To investigate teacher and student explaining and predicting practices, we used the water systems learning progression assessment previously developed and validated to elicit accounts of water and substances in water moving through environmental systems (Authors, 2012b). Teachers and students took the same assessment, with students taking the assessment pre and post to participating in learning activities about water. The version of the assessment used in 2011-2012 prompted six different accounts of water and substances in water. In order to prompt accounts that included elements we were interested in analyzing, two to three assessment items were used to prompt each account, for a total of 15 items. We analyzed four accounts, for a total of 10 items, for this study. These accounts were chosen because they covered water and substances moving through the surface, soil/groundwater, biotic, and atmospheric systems. Table 3 shows the account topics and the water systems addressed by item prompts for each account.

Table 3

Accounts Prompted in the Assessment Instrument and Analyzed for this Study

Account	Topic	Number of items	Systems assessed
Soccer Field	Rain falling on a saturated soccer field and a nearby sandy playground.	3	Surface water, soil/groundwater, atmospheric
River Maps	Pollution moving through a watershed	2	Surface water
Trees	Role of trees in water systems	2	Surface, soil/groundwater, biotic, atmospheric
Fertilizer	Substances mixing with water and effects on water quality	3	Surface, soil/groundwater, substances in water

Analysis

We scored each response to each item for level of achievement on the learning progression using exemplar worksheets (Authors 2012b; Authors, 2012c; Authors, 2009). Exemplar worksheets identify indicators and example responses for each level of achievement for each item in a cluster. The exemplar worksheets used in this study had been developed during previous research on the learning progression and had been validated using earlier student and teacher assessment data (Authors, 2012b). We scored items by level of achievement 1-4. Sometimes, responses aligned with indicators from two adjacent levels (e.g., level 2 and level 3 or level 3 and level 4). In these instances, items were scored using half levels (e.g., level 2.5 or level 3.5).

For each account, two researchers independently scored one half of the responses to each item, with 10% of the responses scored by both researchers. A third researcher also scored 10% of the other two researchers' responses. For interrater reliability checks, we considered scores within one half levels as matching. Interrater reliability for all three researchers was at least 80%

on all four accounts. For responses where disagreements existed, all three researchers discussed and agreed on the final scores.

For each account, we calculated a mean score for each student and teacher for all items within the account. A mean score across all accounts was then calculated. We used a *t*-test with a Bonferroni correction to compare teachers' mean levels of achievement for each account and to compare overall level of performance between teachers and high school students. In addition, we also tested whether there were significant differences between middle and high school teachers' mean levels of achievement.

To further describe and elaborate on teachers' explaining and predicting practices across levels of achievement, we conducted a qualitative examination of accounts at each level of achievement. We examined features of accounts associated with the crosscutting concepts of systems and system models, cause and effect, and matter and energy. We used these features to describe how teachers' and students' accounts compared to the expectations for explaining and predicting practices in the *K-12 Framework*.

Results

On average, most teachers provided accounts at level 3 and above. The mean level of achievement for all teacher accounts was 3.13 (*SD* = 0.33). Based on *t*-tests with a Bonferroni correction (adjusted alpha = 0.01), there were no significant differences between middle school (*M*=3.2, *SD* = 0.32) and high school teachers' (*M*=3.1, *SD* = 0.32) accounts.

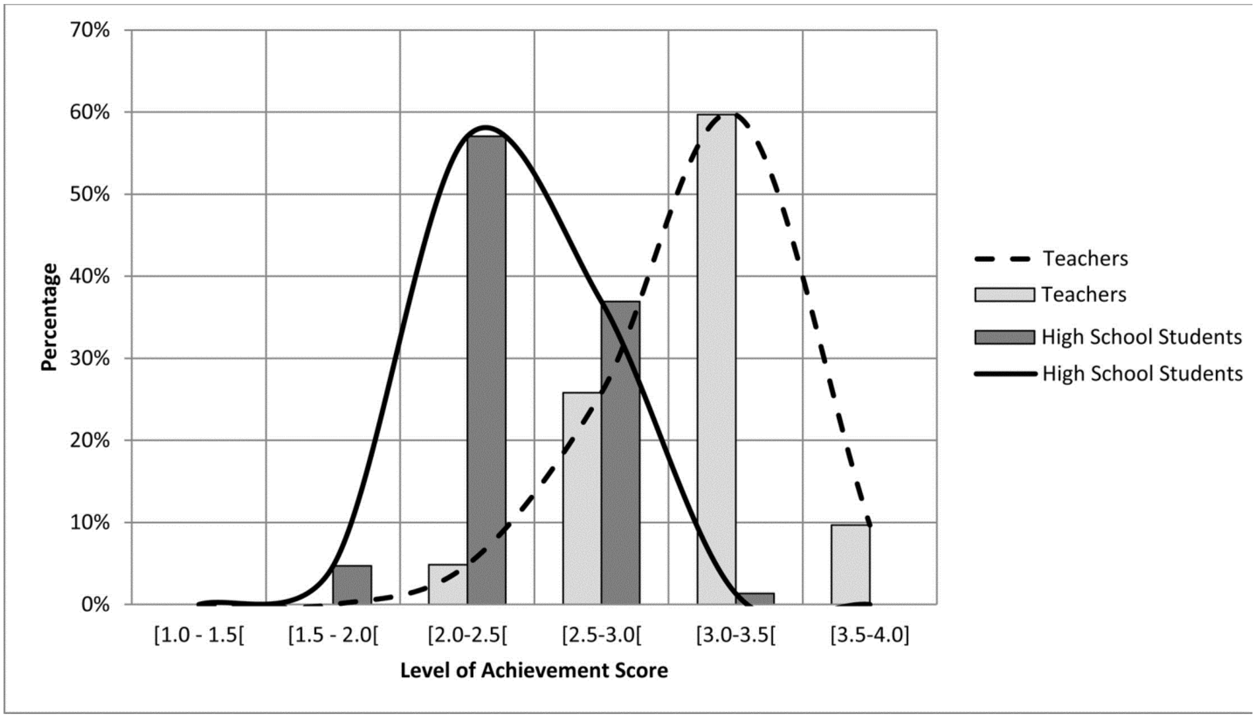

Figure 1: Comparative distribution of account means for teachers and high school students

Figure 1 shows the distribution of the mean level of achievement for accounts for teachers and high school students. This graph shows that most teachers provided accounts that were, on average, scored between level 3 and level 3.5, with the mean being 3.13 (SD = 0.33). These teachers' accounts included mostly level 3 features with a few level 4 characteristics. Only a small number of teachers provided accounts with average scores below level 2.5 or above level 3.5.

In comparison, the mean level of achievement for high school students' accounts was level 2.4 (SD = 0.29). Students provided mostly level 2 and level 3 accounts, with most student accounts having an average level of achievement of between levels 2 and 2.5. Few high school students provided level 1 accounts. Approximately 25% of students had an average level of achievement for all accounts above level 3. The *t*-test result shows that teachers' accounts scored significantly higher than those provided by high school students (*t* (209) = -15.66, $p < 0.01$).

To better illustrate the significance of these results, we compared examples of students' level 2 accounts with teachers' level 3 and level 4 accounts, focusing on the elements of accounts that align with the systems and models, cause and effect, and matter and energy crosscutting concepts. For this comparison, we used teachers' and students' soccer field and fertilizer accounts. The items used to prompt the soccer field accounts (Table 4) asked respondents to trace water through surface, soil/groundwater, biotic, and atmospheric systems. Fertilizer account items (Table 5) asked about substances in water and the effect of the substances on water quality. In these tables, the examples for each level of achievement are from the same respondent. Example teacher and student accounts for the river maps and tree account items are available in Online Resource 1 (River Maps Accounts) and Online Resource 2 (Trees Accounts).

Table 4

Soccer Field Account Example Responses at Levels of Achievement 2, 3, and 4

	Soccer field account items Your soccer game gets canceled at half time due to a massive down pouring of rain. As you run for cover, you notice that there are large puddles forming on the grass covered playing field, but no puddles forming in the sand covered playground just a few steps away.		
	Soccer field item #1: Where could the water landing on the sandy playground be going?	Soccer field item #2: How does the water on the sandy playground get to where it is going?	Soccer field item #3: The next week you come back to the soccer field and you notice there is no water on the grassy field. Where is that water now?
Level 4 (Teacher account)	It is percolating down into the ground.	Gravity pulls the water down through spaces in between the grains of sand.	The water on the field evaporated or percolated more slowly than the water on the sand because of the smaller size of the soil particles in the field compared to the corse [sic] sand that allows water to pass between more quickly.
Level 3 (Teacher account)	The water in the sandy playground is infiltrating through the sand and entering the water table.	Water travels through the air spaces located between the sand grains, following the path of least resistance.	The water on the grassy field also infiltrated into the groundwater supply or evaporated from the puddle to enter the atmosphere.
Level 2 (Student account)	It would be sinking into the ground because the sand is not strong enough to hold the water for it to form a puddle.	Like I said above, the sand is not strong enough to hold the water for it to form a puddle. So it just sinks into the ground through the sand.	It had evaporated into the ground or it got dried up from the sun.

Table 5

Fertilizer Account Items and Example Responses at Each Level of Achievement

	Fertilizer account items [aerial photo of soccer field next to a river]		
	Fertilizer item #1: If the playing fields were treated with fertilizer, do you think that some of the fertilizer could get into the river? If you think yes, describe how fertilizer could get into the river. If you think no, describe why fertilizer would not get into the river.	Fertilizer item #2: What is in the fertilizer that could get in the river? (In other words, what is fertilizer made of?)	Fertilizer item #3: If some fertilizer got into the river water, how would the fertilizer affect the river water and living things in the river?
Level 4 (Teacher account)	Fertilizer is water soluble so that whatever is not absorbed by the plants before rainfall will start to penetrate into the soil and will reach the ground water and then end up in the river.	Fertilizers are composed of nitrates and phosphates, mostly. There are also trace minerals and potassium.	Eutrophication. This is the process of phosphates and nitrates enter the water supply causing increase in the growth of Algae, when the algae dies it sinks to the bottom where bacteria and water fungi decompose the algae in this process the bacteria and fungas [sic] use up the dissolved oxygen that is in the water, this can cause an anoxic condition that could cause the fish to die, or migrate out of the area.
Level 3 (Teacher account)	When the fields are watered, or during a rainstorm, the fertilizer would run off the field with the water runoff. Chances are the fields are built to prevent flooding, encouraging the extra water run-off to travel downward to the river.	Nitrogen, phosphorus, and other elements that help plants live. I have seen little white balls of something in many fertilizer mixes. (scored at level 3.5)	The fertilizer can change the pH of the water and also add nitrogen and phosphorus to the water. This would affect the organisms that live there because they are adapted to survive in a specific pH and chemical levels. If those levels change, the organisms may need to change to adapt or die. New organisms that survive better in those conditions may begin to live in the river.
Level 2 (Student account)	Yes, beacuse [sic] when they lay the fertilizer the wind could pick up and it can carry the fertilizer in the direction of the water.	manuer. [sic]	Better, because it could help fertilize the vegetation around the water and [be]cause its[sic] the same as fish fecies [sic] in the water so it wont [sic] do anything bad.

Structure and Systems: Systems and System Models

Teachers' accounts suggest that the system models that teachers use to explain and predict pathways along which water and substances in water move are more detailed than students' models. For example, in Table 4 for the soccer field accounts, the both level 3 and level 4 teacher accounts trace water into the soil/groundwater system and describe the hidden and microscopic features of these systems, including sand grains and pore spaces. The student level 2 account, on the other hand, focuses mainly on the observable phenomenon of the surface water and does not describe features of the underground system or accurately name processes that connect surface systems to either atmospheric or soil/groundwater systems. Similarly, in Table 5 showing the fertilizer accounts, the teacher level 3 and level 4 accounts include more details about invisible and hidden components of systems. The level 4 teacher account references groundwater movement, whereas the student level 2 account focuses only on surface processes. Furthermore, the teachers describe fertilizer in terms of elemental composition rather than macroscopic identities (e.g., manure). Overall, the teachers' accounts reference more sophisticated models that include hidden or invisible components when tracing water and substances in water than accounts from most high school students.

Comparison of the teachers' accounts suggests that there are few differences between teacher level 3 and level 4 accounts along the structure and systems account element. Teachers' level 3 and level 4 accounts include detailed descriptions of the structure of the systems involved, such as pore spaces, water tables, and chemical components of fertilizer. Therefore, the systems and system models cross-cutting concept is not the concept which distinguishes between teachers' level 3 and level 4 explanations and predictions.

Scientific Principles: Cause and Effect and Energy and Matter

Although having detailed descriptions of models and systems to support explanations and predictions is important for providing scientific accounts of phenomena, what distinguishes a scientific account from a good descriptive account is whether accounts explain how and why events happen and whether these causal explanations adhere to scientific principles (Braaten & Windschitl, 2011).

Students' predominant level 2 accounts attempt to explain how or why events happen. For the soccer field account (Table 4), the example student account explains that water sinks into sand because sand is not strong enough to hold up the water. In the fertilizer account (Table 5), the student level 2 response explains that wind picks up fertilizer to account for how fertilizer might get into water. These responses rely on force-dynamic reasoning, which does not adhere to scientific principles. In the soccer field account, the student explains why rain does not collect in puddles on the sandy playground by the sand's lack of power to stop the water. In the fertilizer account, the wind is an actor that picks up fertilizer to move it. It is interesting to note that in the level 2 account, it is wind, not water, that is the transport mechanism for fertilizer and the fertilizer only mixes with water when it reaches the river. Furthermore, in the fertilizer example, the student explains the effect of the fertilizer on water quality in terms of whether the fertilizer is bad or good, again attributing powers to the fertilizer. While these force-dynamic accounts attempt to explain how and why events happen or the effects of events, they do not adhere to scientific principles to explain cause and effect or matter cycling.

Teachers' accounts do not rely on force-dynamic reasoning. However, only level 4 accounts use scientific principles to explain how and why water and substances in water move through systems. For example, for the soccer field accounts, although both the level 3 and level 4 accounts describe that the water infiltrates into the sand, only the level 4 account references gravity as a driving force that causes the water to infiltrate. Furthermore, the level 4 account explains how permeability constrains the rate at which water infiltrates, thus explaining why rain might form a puddle on compacted soil and not on loose sand. The level 3 account relies instead on a school rule, that water follows a path of least resistance, to explain how and why the water infiltrates. The level 3 account does not identify the driver that pulls water along this path or the constraining factor, permeability, which defines the resistance along a potential pathway. As a result, the level 3 account offers several possible pathways, but offers no reasoning for why one pathway may be more likely than another. The level 4 account references drivers and constraints, which are unseen, model-based constructs, to explain how and why water moves through sand faster than it moves through a grassy field.

Similarly, for the fertilizer accounts, both the level 3 and level 4 accounts describe how fertilizer will move with water into the river, with the level 4 response making specific reference to the solubility of fertilizer in water. However, only the level 4 account uses scientific principles to explain the effect that fertilizer has on water quality, noting that decomposition requires oxygen, creating anoxic conditions for fish and other aquatic life. This particular account would be stronger if it further explained what happens to the dissolved oxygen in the process. Nevertheless, like the level 4 account soccer field account, the level 4 fertilizer account references unseen theoretical aspects of scientific models to explain how and why substances affect water quality. The level 3 fertilizer account also describes potential chemical effects of fertilizer in water. However, the account does not include a mechanism for these effects or account for the fertilizer ions in the process.

Teachers’ accounts of water and substances represent a significant intellectual shift from students’ force-dynamic accounts. Teachers’ accounts describe systems and system models in more detail than students’ accounts, including identifying hidden and invisible aspects of systems. However, teachers’ predominantly level 3 accounts fall short of the requirements for scientific accounts that address the causes of observed phenomena to explain how and why water moves through systems or the effects of substances in water on water quality. Teachers' level 4 accounts include not just descriptions of system models, but also reference unseen theoretical aspects of models, such a driving forces and constraining factors, to explain cause and effect and trace matter through cycles. Overall, although teachers' accounts are significantly more sophisticated than students' accounts of water, teachers' explaining and predicting practices for water in environmental systems fall short of providing scientific explanations and predictions that account for how and why events happen.

Discussion & Implications

One conclusion from the analysis of teachers' accounts of water in environmental systems is that teachers lack the knowledge and practices to support students in reaching higher levels on the water systems learning progression. However, the practices in which one engages are situated in and shaped by the norms and expectations of the community in which one participates (Cobb & Hodge, 2002; Gee, 2005; Wenger, 1998). A more nuanced conclusion is that teachers' explaining practices reflect the explaining practices prevalent in the school science discourse.

In the current age of accountability, the norms and expectations in schools are highly influenced by state standards and assessments (Anderson, 2012). These standards emphasize descriptive explanations. For example, for the topic of water in environmental systems, a typical science standard reads, "Students know and understand that continental water resources are replenished and purified through the hydrologic cycle" (Colorado State Board of Education, 2007). An example state science assessment item asks

> The role of glaciers in the water cycle is to
> A. filter salt water
> B. store fresh water
> C. move liquid water

D. precipitate solid water
(Maryland State Department of Education, 2012)

These standards and assessment items require detailed descriptions of components of water systems (e.g. rivers, aquifers), identification of processes (e.g. runoff, evaporation, infiltration) and descriptions of common pathways (e.g. evaporation into the air; infiltration into the ground). They do not, however, emphasize principles of cause and effect or matter cycling nor do they require explanation of how and why water moves through systems.

The descriptive nature of teachers' accounts of water and substances in water reflect the descriptive nature of state science standards and assessment items to which teachers are held accountable. Teachers' accounts further shape the norms for explanations they request and expect from their students. In this respect, teachers are well-prepared to support their students in achieving expectations set by state standard documents and assessments.

However, the *Framework* sets higher expectations for student explaining and predicting practices than repeating descriptive school science stories. The *Framework* emphasizes using knowledge of core disciplinary ideas and crosscutting concepts to construct scientific explanations that address how and why events happen. To meet these goals, accounts of water in environmental systems need to include the driving forces that move water and consider the factors that constrain where and how water moves within systems.

These types of accounts are necessary to explain and predict how people's actions affect the quality and availability of water. For example, in a community that needs to manage an aging landfill, citizens have a number of options. Each option has financial and ecological consequences. Citizens play a variety of roles in the decision-making process about a landfill, from workers, to policy makers, to voters. People in all of these roles need to be able to reason about how gravity, permeability, and solubility affect how water could move substances through an aging landfill into an underlying aquifer or nearby river. The types of explaining and predicting practices about water in environmental systems supported by the *Framework* are necessary for citizens to able to use science to make decisions in situations such as these (Authors, 2012b).

Yet, teachers' accounts do not consistently refer to underlying driving forces that move water or factors that constrain water pathways to explain how or why water and substances move through systems. Although teachers' accounts show evidence of features of level 4, these features were not prominent across all accounts. As a result, teachers may not be prepared to fully support students in developing the types of model-based accounts of water in environmental systems that meet the goals for the *Framework* and are necessary for understanding important environmental issues related to water.

Changing teachers' level 3 accounting practices may not be simply a matter of introducing teachers to driving forces and constraining factors. The prevalence of school science stories shapes the expectations of teachers and may constrain the types of accounts that teachers readily provide. Therefore, teachers' accounts of water in environmental systems will likely not change to use models and theories purposefully without an accompanying change in the norms and practices of the communities in which teachers participate. The *Framework* provides the first step towards changing the expectations of what counts as an acceptable explanation of core disciplinary concepts in schools. Supporting teachers in developing more scientific accounts of water will require multi-pronged efforts to shift the expectations for scientific explanations and predictions in standards, curriculum, and assessments.

Conclusion

The findings from this study provide an updated picture of middle and high school teachers' understanding of water and substances in water moving through environmental systems. This study shows that teachers are well situated to provide descriptive accounts and support students in developing school science accounts of water and substances in water. Yet, teachers' descriptive explanations fall short of expectations for scientific explanations that address how and why events happen. As a result, teachers are not yet prepared to ask students for and support students in developing model-based scientific accounts of water in environmental systems.

In this study we focused specifically on secondary teachers' accounts of water in environmental systems. Moving forward with the expectations for scientific explanations that incorporate crosscutting and core disciplinary concepts set forth by the *Framework for K-12 Science Education* will require changing the norms and expectations currently shaping explaining and predicting practices in schools at all grade bands. In order to support students in becoming literate about Earth's hydrologic systems and to participate in democratic discussion of water-related issues, state standards and assessments, curriculum, and instructional models will need to change to support teachers and students in learning to use scientific principles to provide scientific level 4 accounts of water in environmental systems.

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Footnotes

1. Environmental systems refer to connected surface, atmospheric, soil/groundwater, and biotic systems, including the human-engineered components of these systems.
2. Please see Authors (2012b) for more detail on the scale, representations, and dependency and human agency elements of accounts.

Online Resource 1

River Map Account Items and Example Responses at Each Level of Achievement

	River Maps [map showing two tributaries (tributaries B & C) flowing together into a mainstem river A and then into a lake. Another watershed is also shown with tributary F flowing north into river E.]	
	River Maps Item #1: Can pollution in the river water at point B [one tributary] get to point C [other tributary]? Explain why or why not.	River Maps Item #2: Describe the direction water is flowing away from point F. How do you know the water is flowing this direction?
Level 4 (Teacher account)	No. Creek B is a tributary to River A. C also is a tributary to A, thus water would have to flow uphill against gravity to move from B to C without some unnatural disturbance	Tributaries flow to rivers so where there are more branches flow to where there are less branches. Also A flows to the lake which means C is the 'high point' so D would be the 'high point' for the other system flowing down to E, so F would need to be flowing down towards E [which] is North from point F.
Level 3 (Teacher account)	No. Both rivers start at those points (B and C) and flow to A, which then flows into the larger body of water.	Water is flowing from point F to point E. Water flows from smaller tributaries to larger streams and rivers and then to a larger source such as a lake or the ocean.
Level 2 (Student account)	Yes. Because the rivers are connected and the lake pulls the water towards it.	It is flowing south west. Because the water travels towards the lake.

Online Resource 2

Trees Account Items and Example Responses at Each Level of Achievement

	Trees Like many rivers, the Sturgeon River in northern Michigan has lots of large trees growing along its banks.	
	Trees Item #1: What would happen to the amount of water in the river if all of the trees died or were cut down? Be sure to give reasons for your answer.	Trees Item #2: A large tree can use 200 gallons of water a day. Where do the 200 gallons of water go?
Level 4 (Teacher account)	It would decrease because more sunlight on the river would lead to more evaporation. However, the trees would not be using the river water and losing much of that water to transpiration.	To the atmosphere - transpiration (but the amount depends on the conditions: light, humidity, wind, temperature, etc)
Level 3 (Teacher account)	More water would enter the river because there would be nothing to stop the runoff into the river. The trees stop the flow of water and allow more to soak into the ground for use by the trees and other plants.	The water goes into the roots of the tree. It gets there by absorbing through the cells in the root hairs of the root.
Level 2 (Student account)	The amount of water in the river would decrease because the trees would need it to grow bigger.	The water would go to the roots of the tree to help it grow.