DEVELOPING A LEARNING PROGRESSION FOR STUDENTS' UNDERSTANDING OF WATER IN ENVIRONMENTAL SYSTEMS

Abstract

This paper presents research on a learning progression for water in socio-ecological systems. This work conceptualizes learning as the process of mastering a new Discourse. Students enter school with their primary Discourses, or ways of understanding the world that are rooted in their family and community experiences and practices. Science education seeks to help students develop a different, science-based Discourse that is characterized by viewing the material world in terms of connected systems in which processes are constrained by principles such as conservation of matter and energy. With respect to water, students who have acquired a scientific Discourse will be able trace and characterize what happens to water and other substances as they move through connected human and natural systems. The authors draw on analysis of elementary through high school student assessments to describe characteristics or levels of students' ways of thinking that span from primary, informal Discourses to secondary, scientific Discourse. Results show that many students come to school thinking about water with distinct ideas that differ from scientific conceptions of water in environmental systems. These students' thinking may be characterized as force-dynamic in nature. As force-dynamic thinkers, students view the world as a stage where actors have abilities to make things happen. Water is a part of the background landscape of the stage as well as being an "enabler" or necessity of life for the actors, including humans, plants, and animals. In contrast, many of the older students in the study provided responses that displayed aspects of scientific Discourse, or model-based reasoning. Model-based reasoning about water is characterized by understanding of connected human and natural systems where processes constrained by principles move water and substances along multiple pathways. Through continuing work on this learning progression, the authors aim to inform a science curriculum that will help students develop model-based understanding about water in connected natural and human engineered systems.

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Introduction

Protecting freshwater supplies is fundamental for sustaining life and societies on Earth. An important goal of science education should be to prepare our children to become environmentally literate citizens who can participate in the collective decision-making processes necessary to maintain and protect adequate fresh water quality and quantity for people and the natural ecosystems on which humans depend. The connected nature of natural and human systems means that citizens must recognize and account for the multiple pathways through which water and substances mixed with water are distributed. Such understanding requires that citizens understand the structures through which water and substances move, the processes responsible for moving water and substances through those structures, and the processes affecting water quality (which generally involve mixing and unmixing water with other substances).

The current K-12 curriculum does not support students in building a coherent understanding of the structures and processes associated with water quality, movement and distribution. Students may learn about the water cycle as a single circular representation presented in elementary school, then study phase changes of water in physical science in middle school and possibly study suspensions and solutions in high school chemistry. In order to develop a more coherent curriculum, we must understand more about student thinking and learning about the structures and processes that move water and substances through socio-ecological systems.

This paper presents research on a learning progression for water in socio-ecological systems. Learning progressions describe student thinking about a topic over broad spans of time, gradually reflecting more sophisticated and connected understandings about complex ideas (National Research Council, 2007). Learning progressions are anchored on one end by descriptions of the world view of young learners and on the other end by the target understandings that students should be able to use by the end of high school. Levels of achievement describe successively more sophisticated ideas in between the two anchors (Mohan, Chen, & Anderson, in press). This paper describes our framework for a water learning progression and characterizes trends in students' thinking as they develop successively more sophisticated ideas about water in socio-ecological systems.

Learning Progression Framework

Our work conceptualizes learning as the process of mastering a new Discourse (Gee, 1989, 1991). Discourses are the ways of talking, thinking, and acting that identify a socially meaningful group. Embedded within Discourses are the practices in which members of a group engage and the knowledge necessary to engage in those practices. Tracking students' progress as they learn new Discourses requires tracing changes in student knowledge as students engage in new practices. In this section, we first describe the Discourse framework for what changes in student thinking along a learning progression, and then we describe components of a learning progression.

Discourses, Practices, & Knowledge

Discourses. Each person brings to learning the knowledge and practices that link them to the primary Discourse of their home community. The primary Discourse includes the social and cultural practices and ways of knowing that people develop to make sense of their experiences in the world. In our framework, students' primary Discourses anchor the lower end of our learning progression. The process of learning involves acquiring or mastering the ways of talking, thinking, and acting of other, or secondary, Discourses. The target secondary Discourse of our learning progression is the Discourse of environmentally-literate citizens capable of reasoning scientifically as they participate in the many roles of democratic citizenship (Covitt, Gunckel, & Anderson, 2009; Mohan, et al., in press). Such roles include voters, volunteers, consumers, teachers, advocates, and workers who encounter and deal with issues related to sustainable use of the environment.

Practices. Embedded within Discourses are the practices that people engage in as they participate in local communities of practice (Cobb & Hodge, 2002, 2003; Wenger, 1998). The Discourse of environmentally-literate citizens includes the practices of scientific model-based reasoning necessary to identify and explain issues and situations and predict the consequences of potential courses of action. These practices include:

1. Investigating Practices – Citizens must be able to learn about and understand the specifics of environmental issues and situations. They must identify and understand pertinent evidence and then analyze and evaluate the quality of evidence and arguments presented by multiple stakeholders.
2. Explaining Practices – Citizens must combine scientific and social-scientific models and theories (i.e.., general knowledge) with specific facts of the case (i.e., local knowledge) to explain what is happening in the socio-ecological systems in which they live, and how these systems are affected by human actions.
3. Predicting Practices – When making informed decisions, citizens must use their understanding of socio-ecological systems to make predictions about the potential consequences of possible courses of action.

Knowledge. Each of these practices requires that citizens understand and use knowledge. Such knowledge ranges from understanding general principles, such as conservation of matter, to specific knowledge of local situations. Figure 1, adapted from the Loop Diagram from the Long Term Ecological Research Network (2007), shows the domain of general knowledge necessary for environmentally-literate citizens to engage in the practices listed above. The boxes show the natural environmental systems and human social and economic systems that comprise a global, connected socio-ecological system. Within each box are the structures through which water and substances move, and the processes responsible for moving the water and altering the composition of the water. The arrows represent connections between the human social/economic systems and the natural environmental systems. Fundamental to our framework is the recognition that the systems in neither box exist in isolation. Human social and economic systems depend on natural systems for freshwater; the processes that take place within the human social and economic systems have significant impacts on the quality and distribution of water in natural environmental systems. Thus, throughout this paper, we refer to connected human and natural systems as socio-ecological systems.

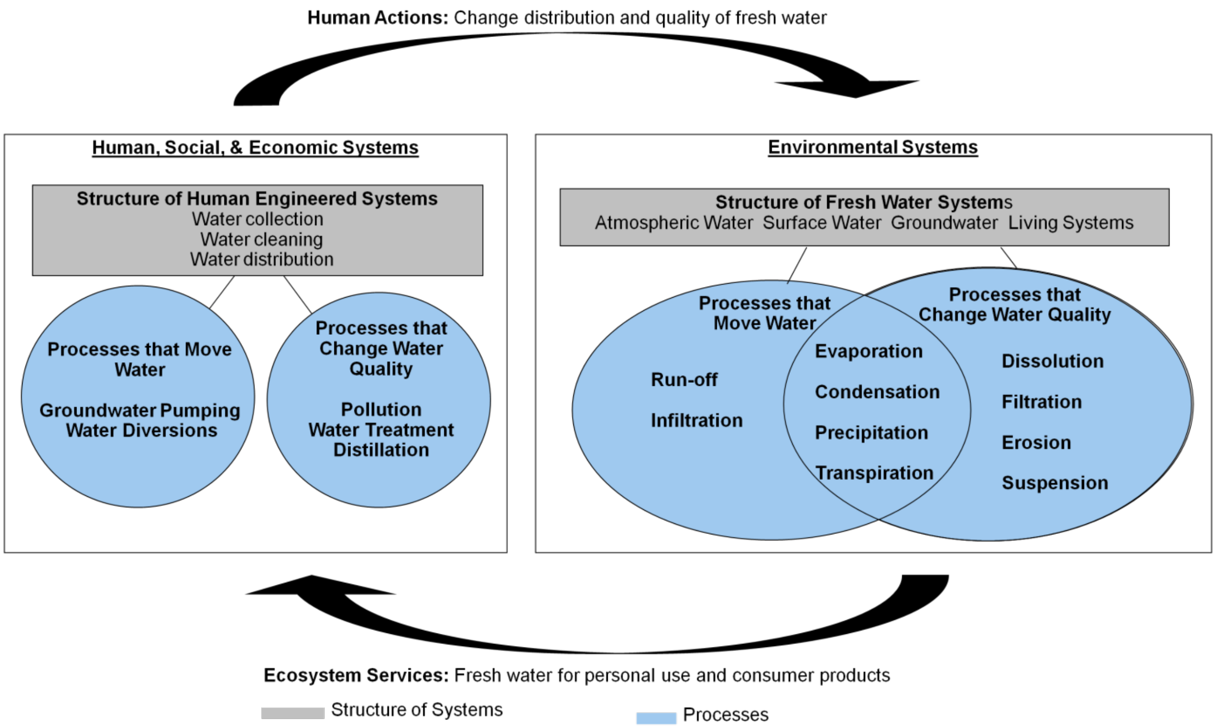


Figure 1: Loop diagram for water in socio-ecological systems

Levels of Achievement and Progress Variables

Progress in student thinking is categorized in levels of achievement that reflect patterns in students' knowledge and practices. In efforts to develop a water in socio-ecological systems learning progression, we have identified and characterized four levels of achievement that describe changes from students' primary Discourses to the knowledge and practices of the secondary Discourse of understanding water in socio-ecological systems.

Progress across levels of achievement is tracked by identifying domains of knowledge and practices that are present in student responses at all levels. These domains of knowledge and practice are called progress variables. In the water systems learning progression, the progress variables include student understanding of systems and scale, movement of water, and movement of substances. These progress variables and the descriptions of the levels of achievement are developed partly by theory and partly from the empirical evidence in student responses to assessments, as described below in the Methods Section (Briggs, Alonzo, Schwab, & Wilson, 2004; Wilson, 2005, Draney & Wilson, 2007).

Prior Research on Understanding Water

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. We take this work as a starting point for our learning progression. There are, however, some prominent gaps in research concerning students' ideas about water. For example, little research has addressed students' ideas about how water moves through human-engineered systems or students' ideas about the difference between solutions and suspensions.

Moving Water

There has been some research conducted on students' understandings of water systems. Dove, Everett & Preece (1999) looked at children's drawings of rivers. They found that children conceive of rivers in rural and not urban environments, that they draw where the rivers end but not where they begin, and that the rivers usually flow south. Shepardson, Wee, Piddy, Shellenberger, & Harbor (2007) examined children's ideas about watersheds. They identified four common conceptions of watersheds: a watershed as a human-built facility (e.g., a "shed" or "tower"), a watershed as a natural feature for the storage of water (e.g., a lake), a watershed depicted as a natural system including some hydrologic processes such as precipitation and evaporation, and a watershed depicted as a river or system of rivers including a more developed view of the hydrologic cycle (precipitation, evaporation, runoff, infiltration).

Some research has also been conducted to explore children's ideas about groundwater. Meyer (1987) identified some common naive conceptions about groundwater and linked them to American vernacular ways of talking about underground water (e.g., underground rivers). More recently, Dickerson and colleagues (Dickerson, Adcock, & Dawkins, 2007; Dickerson, Callahan, Van Sickel, & Hay, 2005; Dickerson & Dawkins, 2004) have documented numerous alternative conceptions about groundwater, including drawings that show groundwater as underground lakes, sewers, or layers; inaccuracies in the size of pore spaces or the scale of aquifers; and groundwater as a dead-end not connected to other hydrologic processes.

Some of the earliest work on children's understandings of processes that move water was done by Piaget (1930), who identified stages of children's development of ideas about clouds and rain. Piaget and many other researchers have documented common ideas about evaporation, cloud formation, and rain. For example, younger children tend to think about clouds as bags of water or sponges with drops of water in them (Bar, 1989). Younger students 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, students do not often recognize water as an invisible gas in the air (Bar, 1989; Bar & Travis, 1991; Osbourne & Cosgrove, 1983). Similarly, students 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).

Substances in Water

There also has been some work conducted to explore children's understanding of substances in water. Research related to water quality has examined children's understandings of pollution and sources of pollution. Brody (1991) found that by 4th-grade, children think of pollution as stuff that people throw on the ground. By 8th-grade, children's definitions of pollution include chemicals. By 11th-grade, children begin to understand that pollution can have more than one source, its effects are based on concentration, and that air, land, water, and living systems are interconnected. The finding that middle level children define pollution in terms of chemicals is an interesting one. Related research has shown that many students as well as adult teachers hold informal conceptions about chemicals, often defining chemicals as artificial, poisonous and dangerous substances, rather than defining chemicals as all substances that have mass (Salloum & Boujaoude, 2008).

In 2000, Suvedi, Krueger, & Shrestha looked closely at Michigan residents' knowledge about the relationship between land use practices and groundwater quality. They found that while most residents understood that land-use practices affected groundwater quality, most perceived that land use practices around their own homes were at low risk for adversely affecting groundwater quality.

The research cited above has focused on identifying students' ideas about specific aspects of water and systems. However, rather than thinking about how to change students' individual conceptions about the different aspects of water and systems, the learning progressions approach considers students' ideas as part of a coherent and robust way of looking at the world. Children's views are rooted in their primary Discourses and help them make sense of their world and experiences. Children's views of the world and ways of reasoning about their experiences, however, differ in important ways from the scientific, model-based approaches to reasoning about materials in systems that represent the secondary Discourse of the upper anchor of the framework. The goal of this research is to better characterize children's primary Discourse about water in socio-ecological systems and understand how children learn a new secondary Discourse that relies on model-based reasoning about water in connected systems.

Research Goals

This research is part of ongoing work to develop a learning progression for K-12 students' understanding of water and materials in water that move through socio-ecological systems (Covitt, et al., 2009). The goals of the research presented in this paper were to better characterize elements of students primary Discourse(s) related to understanding water and to hypothesize levels of achievement that students progress through as they develop more sophisticated understandings of water in socio-ecological systems. Our research questions were:

1. How do students think about water in socio-ecological systems?
2. What are coherent levels of achievement that describe student progress in learning the secondary Discourse?

Methods

The development of this learning progression has involved four years of iterative design research (Barab & Squire, 2004; Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003; Design-Based Research Collective, 2003). We began by identifying the knowledge and practices necessary to understand and reason about water and other substances moving through complex socio-ecological systems. As our research progressed, this framework developed into a description of the secondary Discourse of environmentally literate citizens.

We designed short-answer assessments for 2nd-12th grade students to elicit their understandings about water in environmental systems. We also conducted extended interviews with a sample of students to better understand their ideas. We selected a sample of student responses for each question and ranked responses from least sophisticated to most sophisticated. We grouped the student answers to identify similar features in the responses. This process allowed us to identify features that were changing from less to more sophisticated answers. We were then able to compare these changes across related questions to propose progress variables and initial levels of achievement.

In each iteration of development, we designed new assessment questions that tested our framework and probed new areas of student thinking. Each round of analysis resulted in refinement of the framework.

Participants

The results we present here represent data collected with grades 2-12 students in one Midwestern and one Mountain West state. The data were collected between 2006 and 2008. Table 1 shows the distribution of student tests that were used to provide responses for analyses.

Table 1: Distribution of student tests used for analyses

Grade Level	Number of Teachers	Number of Tests
Elementary	4	46
Middle School	5	61
High School	5	86

Many of the teachers who administered the tests were teaching their students about water, though most did not use specific curriculum materials provided by our project. Some of the teachers administered the tests once, either before or after their unit of study about water. Other teachers administered the tests twice, as a pre and post-test around their water instruction. Because our analyses focused on articulating students' different understandings, rather than measuring change in their understanding, we used results from both pre and post-tests in our analyses, without distinction. Our primary goal in sampling was to identify a range of student responses representing multiple levels of understanding for each assessment item.

Data Sources

Data came from assessment questions developed by us over the past four years. Each year we expand our assessment question bank by adding new questions and modifying others. Because we have too many questions to administer to students on one test instrument, we have recently begun to design two instruments for each grade band (i.e.., two elementary tests, two middle school tests and two high school tests). Some questions overlap across tests – both across the two tests at each grade level band, and across the assessments at the different grade level bands.

Some assessment questions were only asked of elementary students or only of middle and high school students because it was important to ask about phenomena with which students have some experience. Overall, the assessment questions explore how students make sense of water concepts and use their understanding in the context of connected natural and human-engineered systems. Most questions required a short, written answer and provided space for students to respond by writing a few sentences. In addition, several questions required students either to draw a picture or choose among options and provide an explanation for their choice. On the tests, there were some questions that stood alone and some that were connected. An example of a set of connected questions would be providing a cross-section diagram showing a river with land surrounding it and the position of groundwater underneath, and asking students a series of questions related to the diagram.

For the results presented here, we have sampled data from multiple tests administered by teachers to their students. In our iterative process, we have continually refined our frameworks and have conducted initial examinations of student responses to identify questions that yielded particularly fruitful responses with respect to the framework. Through this process, we identified a set of 19 questions to analyze in depth this year. Tables 2 and 3 summarize the questions we identified and show how they fit into the conceptual domains of our framework. The wording of the questions is shortened. A few questions are included in more than one analysis cluster. In these cases, different, relevant aspects of the responses were analyzed for each cluster.

Table 2: Questions addressing structure and processes of moving water

Cluster	**Questions**
Water Cycle	Where does water in a puddle on a soccer field go?
	Could any water from the puddle end up in your bathtub? Explain.
	Where does water in your shower come from before it gets to your showerhead and where does it go after it goes down the drain?
Surface Water	Draw the watershed boundaries for the rivers in the diagram.
	If a water pollutant is put into the river at Town C, which towns (if any) would be affected by the pollution?
Groundwater	Draw a picture of what it looks like underground where there’s water.
	Can a landfill cause water pollution in a well? Explain.
	If a well is built near a river, could it affect amount of water flowing into river? Explain.
	How does water get into a river?
	(Given diagram) Could pumping water from labeled wells (one into unconfined aquifer, one into confined) affect the water in the river? Explain.

Table 3: Questions addressing structure and processes of substances mixing with, moving with, and separating from water

Cluster	**Questions**
Stuff in Water (Structure)	What are examples of water pollution?
	Why can’t we drink ocean water?
	What happens to salt when it dissolves in water?
Stuff Moving with Water (Process)	Can a landfill cause water pollution in a well? Explain.
	(Given diagram) Do you think person living in house has good water to drink? Explain.
	(Given list of materials such as trash, fish, salt, algae, etc., check which could get into a well with water entering well.)
Stuff Mixing or Unmixing with Water (Process)	How would you make ocean water drinkable?
	Describe treatments used to make wastewater safe. How does each treatment change the water?
	Can polluted lake water turn into polluted rain? Explain.
	If you live by the ocean, will your rain be salty? Explain.

Data Analysis

Preparation for data analysis began by creating an Excel file workbook for each of the questions above. Workbooks include columns for student initials, grade level, teacher name, test file, page number, student response, rating code and rationale. Next, sampled student responses were entered into the workbooks.

Once responses were entered, analyses began. The researchers divided up the question clusters to analyze. For a given cluster, a researcher began by ordering the student responses from least to most sophisticated. The researcher then grouped the student answers to identify similar features in the responses. This process allowed the researcher to identify features that were changing across less to more sophisticated answers. The researcher was then able to compare these changes across related questions to refine progress variables and levels of achievement.

The researchers met every two weeks during data analysis to discuss their codings and develop the progress variables and levels of achievement. Through these meetings, the researchers developed consensus on the levels of achievement represented by different characteristics of student responses. The researchers synthesized their results to refine the overarching progress variables and levels of achievement.

Results

We present these results in three sections. First, we describe the levels of achievement and the progress variables that we used to trace progress in student thinking. Next, we present an analysis of the question clusters, using examples of student responses to illustrate characteristics of each level of achievement and trends in progress variables for each cluster. We end with a summary of the trends in the progress variables across the levels of achievement.

Progress Variables and Levels of Achievement

Across all of the questions, we traced progress in student thinking by examining the following aspects of student responses. The following progress variables match the structure and processes components of our loop diagram framework.

1. Systems & Scale (Structure) – Focuses on whether or not students consider hidden or invisible parts of systems (e.g., groundwater) and the scale at which students describe and reason about water, materials in water, and structures of systems (from atomic-molecular scale through landscape scale).
2. Movement of Water (Process) – Focuses on how students identify and describe processes that move water through connected systems. Considers whether or not students recognize and apply constraints on processes such as conservation of matter, gravitational control of water flow, and permeability of materials.
3. Movement of Substances (Process) – Focuses on how students identify and describe processes that mix and move substances with water through connected systems. Considers students' conceptions of water quality and changes in water quality, including reasoning about how substances may be separated from water. Also focuses on whether or not students recognize and apply constraints on processes, including conservation of matter, gravity, and permeability of materials.

Looking across question clusters, we are able to describe the following levels in student thinking. These descriptions focus on student attention to systems and scale, processes moving water, and processes mixing and moving substances.

Level 1 Force-dynamic thinking: Water as part of the background landscape. Level 1 thinking is characterized by force-dynamic reasoning. These students view water as part of the background landscape. They recognize water in visible, discrete locations, such as rivers, lakes, or bathtubs. They also identify discrete types of water, such as “dirty water” or “salty water.” In addition, they conceive of changes in water as a result of actions by actors without any stated mechanism and/or as materials being added to water to change the water into a different type of water.

Level 2 Force-dynamic thinking: Enablers & antagonists. Students at level 2 also use force-dynamic thinking, but they now view water as having natural tendencies that enable it to move and change. Students at Level 2 recognize that water can move from one place to another and that water can exist in places that they cannot see. However, the nature of those invisible places is not explicit and students often consider water in these places as gone or unavailable. In addition, students at Level 2 often invoke actors or agents that enable or restrict movements of water or changes in water quality.

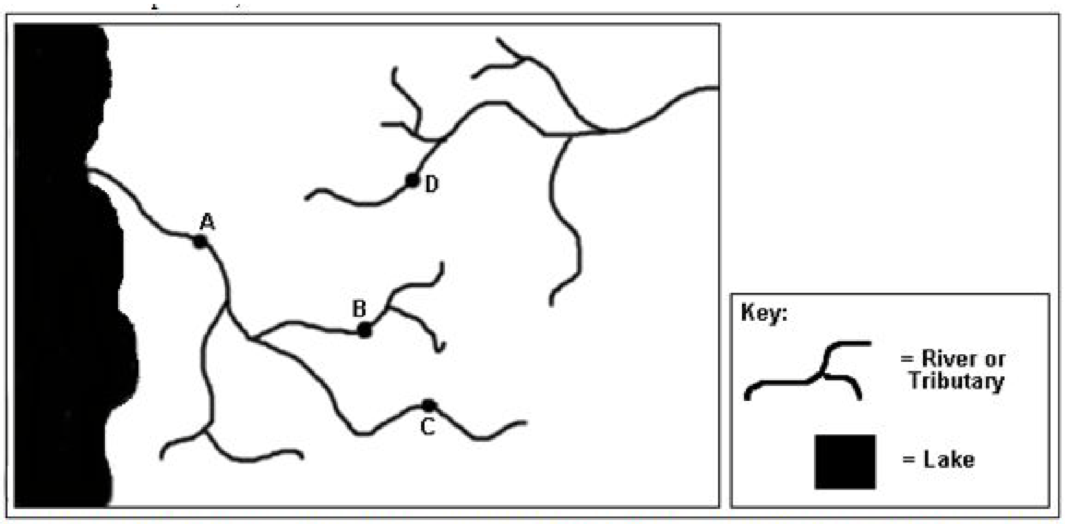
Level 3 Beginning model-based reasoning. At Level 3, students view water as part of a connected system. Students recognize that water moves across invisible boundaries and understand that natural and engineered systems are connected. Furthermore, students at Level 3 understand that other materials can move with water and that these materials can be removed from the water by natural processes. However, students at Level 3 demonstrate errors in their thinking about the movement of water and materials, indicating that aspects of their models for water in environmental systems are incomplete. Furthermore, they tend to describe materials in water and processes that move water and other materials at a macroscopic level.

Level 4 Qualitative model-based reasoning. By Level 4, students have complete or nearly complete qualitative models of water in socio-ecological systems. They can trace water and materials along multiple pathways across visible and invisible boundaries. They can describe substances in water with their chemical identities. Furthermore, they can describe the processes that move water and materials at both atomic-molecular and landscape scales and can apply scientific principles to reason through complex water situations (e.g., landfills polluting groundwater).

Analysis of Question Clusters

In this section we present analysis of six question clusters. Each cluster includes questions that probe specific structures and processes in our overall loop-diagram framework for water in socio-ecological systems. For each cluster, we describe the questions, identify trends in progress, and describe characteristics of thinking for each level of achievement, with examples from student responses. The first three clusters (Surface Water, Groundwater, and Water Cycle) focus on water moving within and through connected systems. The second three clusters (Stuff in Water, Stuff Moving with Water, and Stuff Mixing/Unmixing with Water) focus on materials in and moving with water through connected systems. There is some overlap among the two groups of clusters because in order to trace materials in water through systems, students must also be able to trace water through these systems.

Surface Water Cluster – This cluster included two related questions that probed student understanding of the structure of watersheds and the role of topographic control of the movement of water in surface water systems. The questions provided a map showing two separate river systems with four towns located on the rivers. Students were first asked to draw the boundaries of the watersheds for each river and then were asked which towns would be affected by pollution introduced into one of the rivers near a town at the headwaters of the river. Figure 2 shows the map and the questions.



If a water pollutant is put into the river at town C, which towns (if any) would be affected by the pollution?

(Circle as many letters as apply) A B C D

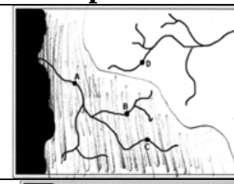
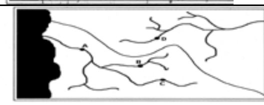
Figure 2: Map for surface water cluster.

Table 4 shows examples of student answers and key characteristics of student answers at each level. Students at Level 1 recognize that rivers and lakes have water in them. They recognize that adding a pollutant to the water will make the water in the river polluted, but they consider all of the water in the river the same, so that if a pollutant is added at a location, all of the water in the rivers connected to that location will become polluted. Students do not provide a mechanism for how the water will become polluted.

By Level 2, students recognize that rivers are part of systems. Furthermore, they recognize that water in the system flows from one place to another. Students at Level 2 reason that water will flow from one town to the next, carrying pollutants with it. However, they do not infer topographic features from maps and do not yet recognize how landscape-scale topographic features control water flow.

At Level 3, students begin to recognize a relationship between topography, watersheds, and water flow. However, their responses indicate that they often misinterpret map representations and therefore do not always correctly identify watershed divides or the direction of water flow. By Level 4, however, these issues are no longer problematic and students can correctly draw watershed divides on maps given limited topographic data, can use this information to correctly identify which towns would be affected by the pollution and provide an explanation for why some towns are affected and others are not.

Table 4 Surface Water Cluster

Question	**Level**	**Key Characteristics**	**Example**
Watershed Boundaries – On the map below, draw in the watershed boundaries	4	Correctly identifies watershed boundaries.	
	3	Identifies areas with respect to topography, but makes mistakes where topographic clues are fewer.	
	2	Random marks on map	
	1	No marks on map	
Watershed 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	4	Correctly identifies towns that will be affected and explains that rivers flow downhill.	A would be affected because the river always flows down, usually towards a lake, and A is on the path towards the lake. B wouldn' because that water is moving towards the central river and poluutants can't move through water moving in the opposite direction
	3	Recognizes topographic/ gravitational control, but incorrectly interprets direction of flow from map.	None because the water flows downstream
	2	Considers water that flows from the affected town to all other towns as connected by the same system of rivers.	(A,B,C,D) - A B and C would be poulluted by river flow D would be by rain
	1	All towns affected are nearby or connected to the initial town.	(A,B,C) - They are connected to town C's River.

Groundwater Cluster. Questions in this cluster probed students' understanding of the structure of groundwater systems and the movement of water through those systems (Table 5). Students were asked to draw pictures of water underground. Another question asked students to interpret a cross-sectional drawing of a groundwater system with confined and unconfined aquifers (Figure 3). Students were also asked to describe how water gets into a river. One question in this cluster asked students about the potential for a landfill to pollute a well. This question overlapped with questions in the Stuff Moving with Water cluster described later in this section.

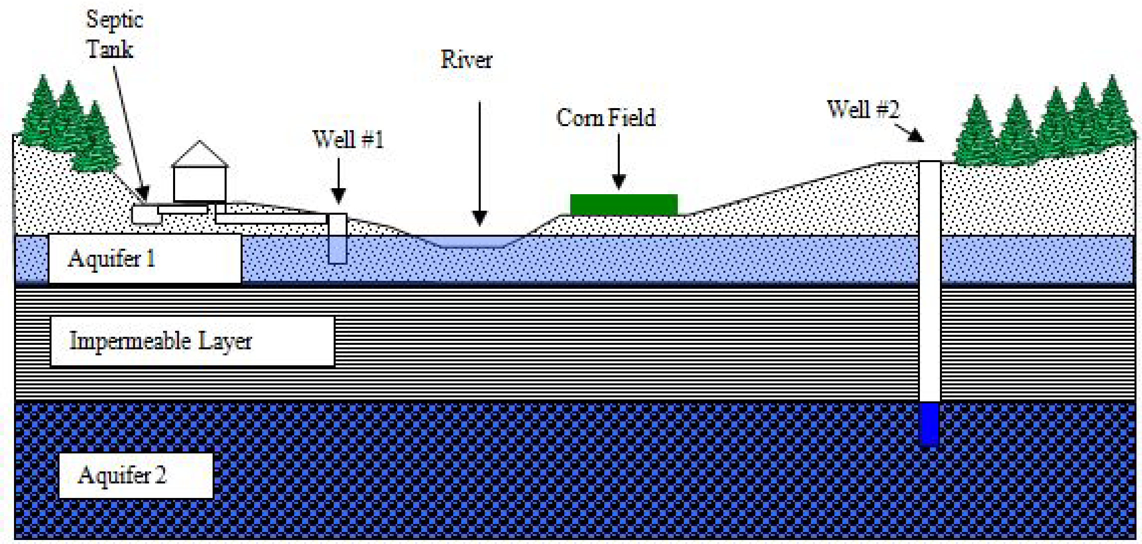


Figure 3: Cross-section diagram for Groundwater and Stuff Moving with Water Clusters.

Students at Level 1 do not easily describe water in underground systems. When pressed about wells, rivers, and aquifers, their drawings and stories often contain examples replicating human made systems such as pipes and tanks which hold and transport water underground.

At Level 2, students rely on surface features to explain groundwater systems. Their drawings are beginning to show and identify layers of dirt, soil, and smaller particles, but the water resembles underground lakes or rivers. Students recognize that water can move through some underground layers, but the nature of the connection between groundwater and surface water systems is not explicit for them. For example, when asked how water gets into a river, level 2 students often list unconventional means such as from glaciers or a tsunami. When asked if pumping from a well could affect the flow of water in a river, students rely on the proximity of the well to the river as a criterion for their response.

By Level 3, students recognize that water exists underground in pore spaces between dirt and rocks. However, they do not have a differentiated understanding of the role specific underground features, like aquifers and aquitards (confining layers) in constraining the movement of water underground. For example, students may draw water in a sand layer, but not in a gravel layer immediately below the sand. Such students are not considering that gravity will draw the water down into the gravel since there is no confining layer between the sand and gravel.

Level 4 students can identify and reason about water flow in confined and unconfined aquifers. They can also trace water across groundwater/surface water boundaries.

Table 5: Groundwater Cluster

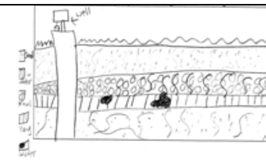
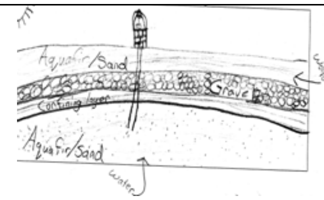
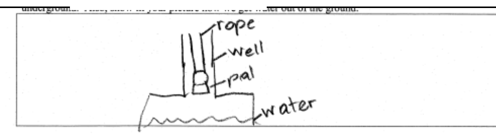
Question	Level	Key Characteristics	Example
Groundwater Pictures – Draw a picture of what you think it looks like underground where there's water.	4	Shows water exists in all porous spaces in the ground and shows layers, including impermeable layers. Drawing represents particle size of materials.	
	3	Shows layer detail, including composition of layers. Identifies water in pore spaces in sand and gravel. May include errors on location of water (such as in unconfined sand but not unconfined gravel).	
	2	Shows water is in underground river or lake.	
	1	Shows water is in pipes or tanks underground.	
Pumping – 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.	4	Recognizes aquifers and connections to river and wells. Understands and states the importance of impermeable layer.	No examples at this level
	3	Identifies unconfined and confined aquifers and the role of the impermeable layer in the diagram. Does not describe the nature of the materials in the aquifers vs. the impermeable layers.	Yes/no Pumping well #1 would effect the river because as the well goes down that were the river is coming from so it goes down too. Pumping well #2 wouldn't affect the river because theyre separated by the impermeable layer.
	2	Recognizes possible connections but relies on the proximity of the well to the river to decide the effect of the well on the river.	Pumping from #1 dries the ground by the river so more water can soak in. Pumping from #2 is too far away from it to effect it
	1	Considers rivers and wells as not connected.	No because it can't get to the well

Table 5 Continued

Question	Level	Key Characteristics	Example
Well Affect River- If a well is built near a river, could it affect the amount of water flowing into the river? If you think it could, explain how.	4	Recognizes that groundwater is the source of water for both the well and the river.	No examples at this level
	3	Understands well draws water from underground – unclear as to how the river is connected to water system underground.	When you take water out of the well, it has to refill, so it takes water from the river
	2	Conceptualizes rivers flowing into wells from the top of the well.	I think a well can because, the flow of the river could lead right to the well
	1	Sees no connection between groundwater and surface water.	No.
Water in River - How does water get into a river?	4	Describes more than one pathway and recognizes the connection to groundwater systems.	Water gets into a river through rain and groundwater
	3	Recognizes surface pathways.	through streams, tributaries, and run off
	2	Describes actors or agents who fill rivers.	tiolets when people flush and the sink when people run the water
	1	Lists places they know where water exits.	Water gets into a river from other palces.

Water Cycle Cluster. This cluster included three questions that probed students' understanding of water moving through socio-ecological systems. The questions asked students to explain what happens to water in a puddle, whether or not that water could get into a bathtub, and to describe where water from the shower comes from and goes to (Table 6).

Students at Level 1 recognize water in discrete locations, such as puddles or in bathtubs. However, they do not trace the water from one location to the next. They may identify that something happened to the water (e.g., it evaporates), but their answers suggest that water that is no longer visible simply disappears. As such, they consider water from a dried puddle or water that goes down the drain as simply gone.

At Level 2, students recognize that water can move from one place to another, such as moving into the air or into the ground. However, once moved, the water is no longer available. That is, water that has moved into the ground will not move to any other place and is effectively removed from the system. Students at Level 2 often invoke actors or special conditions that must be met to move the water from one place to the next. For example, a Level 2 student might say that water from a puddle will get into a bathtub if there is a connection between the puddle and the bathtub. Furthermore, Level 2 students may identify processes that move water (e.g., evaporation) but do not describe the processes. Sometimes, students at Level 2 identify water in natural systems and water in engineered systems as two separate, unconnected systems.

By Level 3, students can trace water through several steps, across visible and invisible boundaries and across natural-engineered connections. However, there are common errors in the model students use to trace matter. For example, students can trace water from the natural to the engineered system, but then the water within the engineered system is not returned to the natural system, indicating problems with conservation of matter. Level 3 students talk about water at the macroscopic level, but recognize water in invisible states (e.g., water vapor). Level 3 students can describe the processes responsible for moving water, although it is not always clear if they understand the constraints on processes.

At Level 4, students can trace water across visible and invisible boundaries, across connected natural and engineered systems along multiple pathways and at multiple scales. Students recognize constraints on processes, including conservation of matter.

Table 6: Water Cycle Cluster

Question	**Level**	**Key Characteristics**	**Example**
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?	4	Traces water to atmosphere and groundwater. Provides a mechanism and describes at atomic scale.	Into the ground and into the air. The moleculs are soaked into the ground like a sponge. Then in evaporation the molecules are heated and forced around to move more, and eventually become gas.
	3	Traces water into the air and/or the ground, but provides descriptions at macroscopic scale only or has some other critical error.	It evaporated into the air where it will condence into clouds and eventualy fall again
	2	Tells where the water went and that something happened to the water. No indication that recognizes that water in new location is still available.	The water goes and sinks under ground
	1	Suggest that water disappears.	The water got dried up by the sun

Table 6 Continued

Question	Level	Key Characteristics	Example
Bathtub- Could the water (from the puddles) get in your bathtub? Explain your answer. Water System - When you take a shower, water comes out of the showerhead and then goes down the drain. But where does it come from and where does it go?	4	Provides a complete and correct description of how the puddle is connected to the bathtub and provides more than 1 pathway.	Yes because of the water cycle. When it rains water falls to earth. The heat of the sun turns the standing water into a water vapor or gas that evaporates into the clouds (which are made up of water molecules). The coulds are carried by the wind, and when it rains again, some of the water seeps into the ground (called runoff) and we get our water supply from wells situated beneath the ground; we also get our water from lakes which are full of rainwater.
	3	Recognizes a connection, and provides a mechanism, but there is a problem with the mechanism or details missing.	Because the water rains and can go into rivers, streams, ect. Leading it into water pipes
	2	Recognizes a connection if special conditions are met.	Yes, If your bath tub was under ground and you had a leak in the downstairs bathroom.
	1	Sees no connection between puddle and bathtub.	No
Water System - When you take a shower, water comes out of the showerhead and then goes down the drain. But where does it come from and where does it go? Include as many steps as you can think of.	4	Identifies reasonable pathways through visible and invisible parts of system and through natural and engineered parts of system. Invisible processes may be identified. Water follows a natural-engineered-natural pathway.	(*Before Shower*) treatment plant, river, rain, sky, river, treatment plant. *(After Drain)* sewers, sewage plant, river, treatment plant, showers, sewers
	3	Describes a flow through visible and invisible locations. Order, particularly for links between human and natural parts of systems, is problematic and may include recycling within the engineered system.	(*Before Shower*) It was at the water treatment plant being cleaned. In a river or stream, in the sky (evaporated), rained into another water source, evaporated, rained into a water source *(After Drain)* to the treatment plant, into a big tank to be cleaned, gets cleaned, gets put into a tank, to someone's house, down a drain.

Table 6 Continued

Question	Level	Key Characteristics	Example
	2	Shows some sense of flow/connection. Locates water in invisible places (air, underground, treatment plant), but nature of that location is problematic. May include unreasonable or unlikely connections.	*Before Shower*) It might have came from a lake, In the sewer, in the clouds, in a river, in a lake, in a ocean *(After Drain)*The sewer, the lake, the water treatment plant, in your water pipe, in your shower again, in the sewer
	1	Lists locations of water.	(*Before Shower*)  *(After Drain)* [blank]

Stuff in Water Cluster. The questions in this cluster probed students' understanding of the nature of materials in water. These questions asked students to explain why ocean water is undrinkable, what water pollution is, and what happens to salt in water. (Table 7)

At Level 1, students think about water quality as types of water (e.g., dirty water, drinking water, ocean water, etc.). They recognize that stuff (e.g. trash) can be added to water, but when this happens, the water becomes a different type of water rather than a mixture of distinct substances. Level 1 students do not recognize invisible substances (e.g., dissolved salt) in water and focus only on macroscopic, visible materials such as trash or dirt. Furthermore, when Level 1 students describe what happens to substances that dissolve in water, they suggest that the substance disappears (e.g., salt). Level 1 students invoke actors or agents, such as people or machines, to change water.

At Level 2, students recognize materials in water as mixtures, but conceptualize the materials that mix with water as objects (e.g., garbage, pop cans, food, etc.) rather than substances or may mention generic categories of substances that they consider harmful (e.g., chemicals, oil). Students still invoke actors who make water polluted (e.g., people). Students sometimes think of materials that dissolve in water as disappearing if there is no visible evidence that the material is still present, but they will also note that the materials are still present if they see a physical change (e.g., turns water foggy) as a result of adding materials to water.

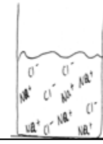
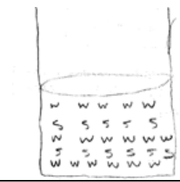
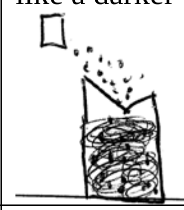
Level 3 students begin to apply principles of physical change to describe mixtures of materials with water. Students understand that materials mixed with water can form solutions or suspensions. Student responses suggest that they are aware that processes happen at an atomic-molecular level (e.g., "molecules mix"), but they do not yet describe processes at that scale. In addition, Level 3 students recognize that water quality is determined by relative concentrations of materials in water.

By Level 4, students can describe the properties and processes involved with substances mixing with water at smaller than macroscopic scale (e.g., cellular level for salt water dehydration, atomic-molecular level for salt in water). Principles of conservation of matter for both physical and chemical changes are followed. Substances are given their chemical identities, and these identities are connected to descriptions of how other substances mix with water.

Table 7: Stuff in Water Cluster

Question	**Level**	**Key Characteristics**	**Example**
Ocean Water - Why can't we use clean ocean water for drinking water without treating it?	4	Provides description of process by which drinking too much salt water harms body at cellular level.	Too much salt makes your body loses water because of diffusion & you will become dehydrated. If you keep drinking you will go crazy & die in 3 days.
	3	Indicates that concentration (amount) of salt in water is problematic or gives school science term for impact (e.g., dehydration).	We cannot use ocean water without treating it because the ocean water has high levels of salt
	2	Identifies that salt makes the water bad or people sick.	Because, if we don't treat it then we all will get sick, from salt water
	1	Does not recognize salt in water as problem. Focuses on other macroscopic materials in water that make water "bad" and/or on human or animal behaviors.	Because there is dirt & fish in the water the fish will urinate
Water Pollution What are some examples of water pollution?	4	This question did not elicit level four responses from the sampled students.	
	3	Identifies substances that mix with water.	Fertilizer, salt, bacteria
	2	Describes water pollution as objects in water or as unspecific substances (e.g., chemicals).	Trash in the lake, river, or ocean. 2. Dead animals. 3. Rotten food. 4. Oil dumped into the lake, river or ocean
	1	Focuses on actors putting objects in water or on water classified by type.	Some examples are things such as throwing garbage in a lake, or dumping oil or toxins in oceans

Table 7 Continued

Question	**Level**	**Key Characteristics**	**Example**
Salt in Water - What happens to salt when it dissolves in water?	4	Describes process wherein salt breaks into its ions of Na^+ and Cl^- and the ions interact with water molecules.	When salt is dissolved into water the salt breaks up into it's ions of NA^+ and CL^- 
	3	Conserves water and salt. Draws a picture at macroscopic level that shows that salt is invisible but still present. May suggest interaction between salt and water.	The molecules combine/react with each other and sticking to each other 
	2	May suggest that when salt and water mix, that salt disappears (goes away) or salt changes color of water. May suggest salt and water stay separate.	When salt dissolves in water it turns the water a different color like a darker color 
	1	Describes salt and water as actors. In example, more powerful actor prevails.	The salt dissolves, in water because of the chemicals that makes salt so hard, the water over powers the salt by making it disappear 

Stuff mixing with water. This cluster included four questions that probe students' understanding of how materials mix and unmix from water and the nature of that mixture. Questions asked students how ocean water could be made drinkable, how a sewage treatment plant works, whether or not polluted lake water can become polluted rain, and whether rain near the ocean is salty (Table 8).

Some students at Level 1 think about water quality as types of water. As a result, the idea of materials mixing or unmixing from water is not something they consider. Students at Level 1 view water in discrete locations unconnected to other locations and therefore do not view water as moving from one place to another. Some students recognize that things happen to change water. These students invoke actors or agents, such as people or machines who do unspecified things to water to clean the water.

Unlike Level 1 students, students at Level 2 consider materials mixing or unmixing with water. Students describe simple, macroscopic-scale actions responsible for mixing or unmixing water with other materials (e.g., filtering). Usually, students ascribe these actions to actors, such as people, or agents, such as clouds. Students may try to trace water and other substances across system boundaries, but have difficulty, particularly when boundaries are between visible and invisible systems (e.g., surface water to atmospheric water).

By Level 3, students recognize processes responsible for mixing and unmixing substances with water. Students describe these processes using macroscopic descriptions. Students make a distinction between processes responsible for unmixing materials in suspension versus materials in solution. However, students make common errors that indicate that their knowledge of processes and contexts, such as the processes used in sewage treatment plants, are still at a novice level.

At Level 4, students use principles of conservation of mass and chemical and physical changes to describe how substances in suspension and solution mix and unmix with water. They describe processes at the atomic-molecular scale and the chemical nature of substances are identified and described. Students are able to use general knowledge to trace matter and materials through specific mixing and unmixing processes.

Table 8: Stuff Mixing with Water Cluster

Question	**Level**	**Key Characteristics**	**Example**
Ocean Water II If you had to make ocean water drinkable, how would you go about doing it?	4	Describes separation of water and salt at an atomic-molecular scale.	No responses reached this level
	3	Describes processes that follow principles for removing salt. Descriptions are at a macroscopic scale.	To make ocean water drinkable you would have to distill the water because when you distill it the salt is what is left behind
	2	Describes actors or agents who use simple mechanisms to clean water.	I would use a filter to let the water go through to clean it
	1	Classifies water by types or describes humans changing water without mechanism.	I would not be very happy because I would have to drink uncleaned water
Sewage Treatment Plant Describe the different treatments that are used to make sure waste water is safe.	4	Describes more than one actual treatment process at an atomic-molecular scale.	No responses reached this level
	3	Describes at least one process that can remove materials/substances from water at a macroscopic level. The process may or may not be actually used in a sewage treatment plant.	Boiling kills bacteria.

Table 8 Continued

Question	**Level**	**Key Characteristics**	**Example**
	2	Describes actors or agents who use simple mechanisms to act on macroscopic objects. May employ vernacular terms without understanding.	Filter. Takes the rocks and mud/dirt out of it. Distillation. It uses osmosis.
	1	Describes actors or agents doing things that change water without describing processes.	Filtering. It would go through a machine and make it cleaner
Polluted Lake to Rain – Do you think polluted lake water could turn into polluted rain? Explain why or why not.	4	Describes separation of water and pollution at an atomic-molecular scale.	No responses reached this level
	3	Describes at a macroscopic scale how pollution is left behind when water evaporates.	The water could not turn into polluted rain because when the water it is mixed with evaporates the chemicals that were in it will not so the rain that comes down after that won't be polluted
	2	Describes actors using simple mechanisms on macroscopic objects, or water disappearing when it changes state, or pollution evaporating with water.	The water gets filtered before precipitation
	1	Considers water is in discrete locations or humans change the water.	No, because there is no way water can go back into the sky.
Salty Rain – If you live by the ocean, will your rain be salty? Explain why or why not.	4	Describes separation of salt and water at an atomic-molecular scale.	No because as it evaporates back into the clouds, the salt molecules are too heavy to evaporate as part of the water molecules
	3	Describes at a macroscopic scale how salt is left behind when water evaporates.	No, because when water evaporates it only evaporated as water and leaves the salt behind
	2	Employs an informal, simple mechanism or traces salt with the rain.	No because it’s filtered by the sky Yes, the ocean evaps and goes into the sky and precipitates.
	1	Characterizes rain as a type of water. May rely on proximity as a cause.	No, because the rain taste the same

Stuff moving with water. Questions in this cluster probed students' reasoning about how materials move with water in socio-ecological systems (Table 9). Students were provided a cross-section diagram (Figure 3) and asked whether the house in the diagram had good water for drinking. Students were also asked what materials might go into the well with the well water. This cluster includes a question that overlaps with the groundwater question and asks students whether or not a landfill could pollute a well.

Students at Level 1 thinking about water identify types of water (e.g., city water, river water) and assign a quality to that water. Students at level 1 recognize visible water and visible objects. They consider visible water as isolated from other water and other types of water.

At Level 2, students recognize that water and substances can move from one place to another. They can trace water in visible systems (e.g., surface water) and across boundaries where connections are visible. Level 2 students recognize that water can have stuff in it at a macroscopic scale. They usually think of water with stuff in it as bad water and water without stuff in it as good water. They also recognize that things can happen to water. If stuff is removed from water, the water quality improves or if stuff is added to water the water quality becomes bad. The nature of these processes is not explicit.

By Level 3, students can trace water and substances across invisible boundaries, but descriptions are usually at a macroscopic scale. They can describe processes at a macroscopic scale or in general terms (e.g., sediments filter stuff out of water). Although they do not specify a distinction between materials that are suspended and materials that are in solution, they do have general notions that some materials are larger or smaller in size than other materials and therefore move or are removed from liquid water (e.g., filtered) as water moves through connected systems.

Level 4 students trace water and materials along multiple pathways, through invisible parts of systems, and processes are described at an atomic-molecular scale. Level 4 students recognize the difference between suspensions and solutions and can identify which materials are in suspension or solution.

Table 9: Stuff Moving with Water Cluster

Question	Level	Key Characteristics	Example
Landfill Question- Can a landfill (garbage dump) cause water pollution in a well? Explain your answer.	4	Traces water and substances underground. Describes solutions/dissolution, possibly at an atomic-molecular scale. Recognizes water as transport mechanism.	When it rains it soaks into the landfill and collect pollutants which will go through the ground. (close to a 4)
	3	Traces water and substances into underground invisible system. Suggests water and pollutants mix but does not specify nature of mixing.	Yes. A landfil can cause water pollution into a well because the chemicals would get into the ground water and end up into your home.
	2	Recognizes that water and substances can move from one place to another. Recognizes connections if certain conditions are met. Often relies on surface (visible) connections.	Yes. It can cause pollution because if it rains or the wind blows it can move to bodies of water
	1	Sees landfills and well water as unconnected or mentions that garbage/trash can make water polluted (bad). May include actors and may rely on proximity.	Yes. Because if you dump garbage in a well you are polluting.
Well water quality- Do you think the person living in the house has good water to drink? Explain why or why not.	4	Traces water and substances into well along more than one pathway. Describes what happens to materials in water in aquifer at atomic-scale.	No responses reached this level
	3	Traces water and substances into well.	No. The well is to close to the septic tank. The sewage could seep out and go into aquifer 1 where the well water comes up.
	2	Describes actors or agents that make water good. May be tracing water into well from surface.	No because particles of dirt from the river bed are present in the water because they are picked up by the current; unless the water is treated however
	1	Considers type of water as indication of quality.	No because their water probably tasts rusty and it will definetely will not taste fresh it will be nasty water.

Table 9 Continued

Question	Level	Key Characteristics	Example
Stuff into Well - Could the following things get into well #1 water by coming into the well with the water?	4	Correctly identifies materials in solution are the only materials that can go into the well.	yes - fertilizer, salt, bacteria. No mud/dirt, fish, trash, algae, rocks, leaves
	3	Leaves out most materials that are in suspension	yes - fertilizer, mud/dirt, salt, bactera. No - fish, trash, algae, rocks, leaves
	2	Leaves out most macroscopic-scale materials (e.g., rocks, fish, leaves), but may also leave out materials in solution or suspension.	yes - mud/dirt, algae, rocks, bacteria. No- fertilizer, fish, trash, leaves, salt.
	1	Says everything goes into the well	Yes - fertilizer, mud/dirt, fish, trash, algae, rocks, leaves, salt, bacteria

Trends in Progress

Table 10 summarizes the trends in progress from Level 1 to Level 4. As students progress from Level 1 to Level 4, they move from describing only macroscopic features of systems to being able to describe systems and processes at multiples scales. In addition, they move from recognizing water in visible locations and forms only to being able to accurately describe the movement of water and substances in invisible parts of systems. At Level 1, students view water as existing in discrete, unconnected locations, but by Level 4 they can trace water along multiple pathways through connected systems. Furthermore, they apply constraints such as the law of conservation of matter and gravity to their reasoning about the movement of water. In terms of substances moving with water, students at Level 1 consider water quality as different types of water and invoke actors or agents to change water from one type to another. However, by Level 4, students recognize that substances mix with water, can identify the nature of those substances and the processes with which they mix and unmix with water, and can trace and conserve substances through and across systems. Furthermore, Level 4 students can apply constraints on mixing and unmixing processes (such as permeability of materials) when tracing substances with water through socio-ecological systems.

Table 10: Summary of trends in progress across levels

Aspect of Student Responses	**Level 1**	**Level 4**
Systems & Scale (Structure)	• Macroscopic scale only • Hidden aspects invisible	• Atomic-molecular to landscape scales • Conceptualizes water in invisible places
Movement of Water (Process)	• Water exists in discrete, unconnected locations. • Water can disappear	• Traces and conserves water along multiple pathways through connected systems • Recognizes and reasons with other constraints on processes (e.g., gravity and permeability of materials)
Movement of Substances (Process)	• Water exists as different types. • Actors or agents can change water into a different type (e.g., dirty to clean)	• Recognizes that substances mix with water • Provides chemical identities of substances in water • Conserves substances through systems and across connections. • Recognizes and reasons with other constraints on processes (e.g., permeability)

Discussion

The results of this analysis show that students come to school using ideas about water that are rooted in their primary Discourse (Gee, 1989, 1991). While all students have different primary Discourses, we note some common themes that we characterize as force-dynamic thinking (Pinker, 2007; Talmy, 1988). As force-dynamic thinkers, students view the world as a stage where actors have abilities to make things happen. Water is both a part of the background landscape of the stage and something that the actors need to survive. It forms the backdrop and is something that actors and agents can use or change. Although students who use force-dynamic thinking recognize that water moves, they do not consider it necessary to think about where the moving water came from or where it goes in order to make sense of moving water. To them, moving is a natural tendency of the water. Force-dynamic thinkers identify different types of water, such as pure water, murky water, or polluted water. Actors or agents with abilities, such as people or machines, can change water from one type of water to another, usually for some purpose (e.g., to clean the water). Rather than focusing on the processes or mechanisms that change water, force-dynamic accounts tend to focus on identifying the actors whose abilities make the change possible. Together, these ideas describe a view that is useful to young students to help them make sense of their world.

Force-dynamic thinking, however, is different in important ways from model-based reasoning that characterizes Level 4 thinking (National Research Council, 2007). Model-based reasoning about water in environmental systems is a secondary Discourse that students must learn. Model-based reasoning is characterized by the understanding of water in connected systems at multiple scales. Processes constrained by principles move water and substances through these systems along multiple pathways. Practices of this Discourse include using models and principles to reason about systems and processes. As such, model-based thinkers can apply key principles, such as the law of conservation of matter, to data about particular situations to trace water and substances through connected systems.

The transition from force-dynamic thinking characteristic of Level 1 to model-based reasoning characteristic of Level 4 reflects a process of learning a new Discourse. This process includes learning both the knowledge about structures of systems and the processes that move water and substances through systems. It also includes learning the practices that characterize model-based thinking. We can trace changes in student thinking about structures and processes as students become aware of and consider invisible or hidden parts of systems and describe the movement of water and substances through connected systems at multiple scales. However, we also notice that learning the knowledge and practices of a new Discourse is not a replacement process. That is, model-based reasoning does not replace force-dynamic thinking. Rather, students at higher levels of thinking develop another way of viewing the world that is useful and powerful for understanding environmental issues. Force-dynamic thinking does not go away, and students may still rely on force-dynamic thinking if the situation does not demand model-based reasoning. Students at lower levels have only one way to view the world, but students at higher levels have multiple models that they can use to understand the world around them.

We are continuing our work on the learning progression for water in environmental systems. What we present here is the result of three cycles of iterative assessment and analysis. Current and future assessment and analysis cycles will focus on analyzing data from individual students across multiple questions to develop a more comprehensive picture of student thinking at each level and more detailed descriptions of trends in progress. We would like to learn, for example, if students achieve the same level for all parts of our framework at about the same time, or if there are areas of understanding water in socio-ecological systems that are easier to learn and others that are more challenging. For example, do students develop more sophisticated understanding of movement of water at the same time that they develop understanding of movement of substances, or does understanding of movement of substances develop more slowly? Furthermore, continuing data collection and analysis will help us characterize trends in levels of achievement across grade levels. Our intention is then to be able to use the learning progression to develop instructional approaches and teaching materials that support students in learning the secondary Discourse of science and achieving higher levels of understanding about water in socio-ecological systems.

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