USING A WATER SYSTEMS LEARNING PROGRESSION TO DESIGN FORMATIVE ASSESSMENTS AND TOOLS FOR REASONING

Abstract

Learning progressions are useful research constructs for describing how student accounts of phenomena in a domain changes to become progressively more scientifically model-based and sophisticated. They have been hailed as tools for bringing coherence to science curriculum assessments, and classroom instruction. However, in order to influence classroom instruction, learning progressions must become useful tools for teachers. In the Reasoning Tools for Understanding Water Systems project, we have developed formative assessments and tools for reasoning linked to the Water Systems Learning Progression for teachers to use in supporting students in developing more sophisticated accounts of water and substances in water moving through environmental systems. Design criteria for these instructional materials are that they must support teachers in 1) developing the capacity to recognize and construct scientific model-based accounts of water, 2) using the Water Systems Learning Progression to elicit, analyze, and respond to student thinking, 3) implementing instruction that presses students for scientific explanations and predictions, and 4) facilitating classroom norms for the social construction of understanding. In addition, the instructional materials must allow for flexible use with students demonstrating various levels of understanding, in a variety of classrooms situations, using a diversity of curriculum materials. We describe how our formative assessments and tools for reasoning meet these design criteria and provide examples of how teachers and students are using these instructional materials to develop more scientific accounts of water and substances in water moving through environmental systems.

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Learning progressions are descriptions of students' successively more sophisticated understandings of a big idea (National Research Council, 2007). They are hailed as a tool to bring coherence to currently fragmented and unconnected science curriculum, assessments, and classroom instruction (Duncan & Hmelo-Silver, 2009; National Research Council, 2007). As a relatively recent construct in science education, most of the work on learning progressions has focused on developing the assessments and frameworks necessary to describe learning progressions for various topics such as astronomy (Plummer & Krajcik, 2010), biodiversity (Songer, Kelcey, & Gotwals, 2009; Zesaguli, et al., 2009), carbon cycling (Gunckel, Mohan, Covitt, & Anderson, in press; Mohan, Chen, & Anderson, 2009), genetics (Duncan, Rogat, &

Yarden, 2009), evolution (Cately, Lehrer, & Reiser, 2005), force and motion (Alonzo & Steedle, 2009), the molecular nature of matter (Smith, Wiser, Anderson, & Krajcik, 2006), and water in socio-ecological systems (Gunckel, Covitt, Salinas, & Anderson, in review; Gunckel, et al., in press). However, in order to influence classroom instruction, learning progressions must move beyond being a research construct to also become a tool useful to teachers (Furtak, Roberts, Morrison, Henson, & Malone, 2010).

Recent efforts in this direction include work by Furtak and colleagues, who developed the concept of an educative learning progression that would be useful to scaffold not only student learning, but also teacher learning in a conceptual domain (Furtak, et al., 2010). In Furtak et al.'s framing, educative learning progressions are a suite of tools that include information about common student ideas, suggestions for responding to student ideas during instruction, and professional development related to the learning progression (Furtak, et al., 2010). Similarly, work conducted as part of the Pathways for Environmental Literacy project has focused on developing learning progression-based curriculum materials, teaching strategies, and professional development for teachers in the domains of carbon cycling, water in socio-ecological systems, and biodiversity (Moore, Berkowitz, Parker, Doherty, & Johnson, 2012).

In the Reasoning Tools for Understanding Water Systems project, we are currently developing instructional supports to make the Water Systems Learning Progression (Gunckel, et al., in review; Gunckel, et al., in press) useful to middle school teachers teaching about the water cycle. The Water Systems Learning Progression describes students' progressively more sophisticated accounts (explanations and predictions) of water and substances in water moving through environmental systems. To provide a way for educators to use the Water Systems Learning Progression in the science classroom, we are developing learning progression-based instructional materials that teachers can integrate into their curriculum units to support students in developing more sophisticated accounts. In particular, we are developing two types of materials: 1) formative assessments that teachers can use to identify student levels of achievement with respect to the learning progression and then inform development of instruction that is responsive to student thinking and 2) tools for reasoning that teachers can integrate into their curriculum units to support students in moving to higher levels of achievement.

In this paper, we describe the design criteria that we are using to guide the development of the formative assessments and tools for reasoning. We provide the theoretical and empirical grounding for our design criteria and illustrate how we have used these criteria to develop our assessments and tools. We also provide a few examples of how the tools have been used with teachers and students in our research project.

The Water Systems Learning Progression

An important practice of environmental science literate citizens is being able to use model-based reasoning to explain how water and substances in water move through environmental systems, and to predict potential consequences of the movement of water and substances for particular courses of action. We call explanations and predictions accounts. The Water Systems Learning Progression describes characteristics of student accounts of water and substances in water moving through environmental systems (Gunckel, et al., in review; Gunckel, et al., in press). These systems include the surface water, soil and groundwater, atmospheric, and biotic systems. Environmental systems include both natural and human-engineered components.

Four levels of achievement are described in the learning progression. The lower levels, levels 1 and 2, are characterized by force-dynamic reasoning, in which phenomena and events are described as the result of actions taken by actors with purposes. In level 1 accounts, water is usually described in isolated, visible locations, such as lakes, rivers, bathtubs, or puddles. Level 1 accounts are also human-centric, with water typically fulfilling the needs of people or with people as the primary agents that move and change water. At level 2, accounts show more recognition of connections among visible parts of systems. Although still force-dynamic in nature, Level 2 accounts are less human-centric and include mechanisms (often informal ones) that move water and substances in water.

Levels 3 and 4 comprise the upper half of the learning progression. At level 3, accounts are characterized as school science stories. These accounts are more sophisticated than level 2 accounts because they trace water along more complex pathways, including through invisible or hidden parts of systems. These accounts put events in order and name processes that move water and substances. Level 3 accounts span microscopic to landscape scales. Level 4 accounts represent model-based reasoning. Unlike level 3 accounts, level 4 accounts use causal mechanisms to explain why and how events occur (Braaten & Windschitl, 2011), recognizing the driving forces and constraining factors that define the pathways along which water and substances in water move. Level 4 accounts also provide descriptions across scales ranging from atomic-molecular to landscape.

Level 4 accounts represent the knowledge and reasoning necessary for environmental science literacy. We define environmental science literacy as the capacity to use model-based reasoning to make evidence-based decisions about environmental issues, such as issues affecting the distribution and quality of fresh water. Level 4 accounts also meet the expectations for science understanding and practices for students at the end of high school described in the *Framework for K-12 Science Education* (National Research Council, 2012). However, data from student assessments show that the majority of high school students currently provide accounts of water and substances in water between levels 2 and 3 (Gunckel, et al., in review). In order for school science to support students in becoming citizens capable of developing and using level 4 accounts to inform environmental decision-making, teachers need to have access to and know how to use instructional materials that can scaffold level 4 learning.

Design Criteria

In order to help teachers understand how to use the Water Systems Learning Progression in productive ways in classroom instruction, learning progression-based instructional materials must assist teachers in 1) understanding fundamental science knowledge and practices concerning Earth's hydrologic systems represented by the Water Systems Learning Progression and 2) understanding how to teach water systems science in ways that reflect and support development of fundamental knowledge and practice. Learning progression-based instructional materials are not curriculum materials in the sense of lesson plans, units or textbooks (Ball & Cohen, 1996); they are instructional materials or supports intended for use by teachers to scaffold student learning. In designing these supports, we have established the following design criteria. Learning progression-based instructional materials should support teachers in:

1. Developing the capacity to construct scientific model-based (i.e., level 4) accounts of water in environmental systems, and learning the characteristics of accounts at each level of achievement in the Water Systems Learning Progression.
2. Using the Water Systems Learning Progression to elicit, analyze, and respond to student thinking.
3. Implementing instruction that presses students for scientific explanations and predictions.
4. Facilitating classroom norms for the social construction of understanding.

In addition, instructional materials should be:

5. Flexible to allow implementing instruction that is appropriate for students who perform at all levels of achievement on the water learning progression, and to be useful with a variety of curriculum materials and common instructional activities.

We elaborate on these criteria below.

#1 Develop Teachers' Capacity to Recognize and Construct Scientific Model-Based Accounts

Teachers need deep and conceptually connected science content knowledge and practices in order to teach science effectively (Abell, 2007; National Research Council, 2007). Teachers with strong and interconnected knowledge of both intra and interdisciplinary scientific concepts are more likely to know how to identify and focus 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 knowledge is also necessary for teachers to assess student ideas, measure progress, and build on student ideas to support the capacity to develop and evaluate scientific explanations and predictions (Grossman, Schoenfeld, & Lee, 2005; Van Driel, Verloop, & de Vos, 1998).

Unfortunately, research conducted with both pre-service and in-service teachers has shown that many teachers have general science content knowledge and practices, including capacities to develop scientific accounts, that are not sufficiently deep or integrated across topics to support effective instruction (Windschitl, 2009). For example, pre-service science teachers often hold alternative science conceptions that are similar to those held by their future students (e.g., Sanders, 1993; Songer & Mintzes, 1994). With regard to scientific practices, K-12 teachers often view science as less of a process and more of a body of accepted facts about the material world. A common view among teachers is that scientific practice involves proving ideas through a set scientific method (Lederman, 2007) rather than through diverse methodological approaches that involve uncertainty, tentativeness, and social consensus building (National Research Council, 2012). More traditional instructional practices (e.g., verification labs in science classes), which portray science as a body of certain facts, also correlate with the way many teachers were taught themselves (Trumbull & Kerr, 1993).

Similar evidence exists within the specific area of hydrologic systems content knowledge and practices. Studies conducted with both pre-service and in-service teachers show weak understanding and capacity to develop scientific explanations of physical properties of water (Ginns & Watters, 1995), water cycle processes such as condensation (Stoddart, Connell, Stofflett, & Peck, 1993), environmental processes such as the formation of acid rain (Dove, 1997), and definitions of concepts such as watersheds (Shepardson, Harbor, Cooper, & McDonald, 2002). In our own research with K-12 teachers, we found that the majority of teachers, on average, provide level 3 school science stories to explain events in water systems (Gunckel, Covitt, & Anderson, 2010). These stories trace water along pathways by ordering locations and naming processes (e.g., water evaporates from a puddle, becomes water vapor in the air, then condenses to form clouds). Although in general teachers tend to provide accounts at higher levels than high school students, teachers' level 3 school science stories still fall short of goal level 4 model-based scientific explanations (Gunckel, et al., 2010).

Given what we know about the current state of teachers' knowledge and practices related to science concepts, we realized that instructional materials related to the Water Systems Learning Progression would need to support teachers in developing deeper, more connected scientific knowledge and providing scientific accounts of water and substances in water. In addition, these materials would need to support teachers in developing not only their own scientific accounts, but also in understanding the nature of scientific, model-based accounts and how level 4 model-based accounts differ from accounts representing the other levels of achievement. Thus, instructional materials would need to be explicitly connected to the Water Systems Learning Progression and designed to scaffold teachers in developing and using model-based accounts of water systems phenomena. In particular, formative assessments and tools for reasoning would need to support teachers in focusing on aspects of model-based accounts that we have found in our research to be particularly challenging. For example, because teachers' (and students') accounts often fail to include driving forces and constraining factors as explanatory mechanisms, we knew that it would be useful to design assessments and tools that could focus attention on this particular aspect of an account. Teachers would then be better able to support students in also developing model-based accounts for water and substances in water.

#2 Support Eliciting, Analyzing, & Responding to Student Thinking

One of the strengths of a learning progression, and what distinguishes a learning progression from a standards scope and sequence document, is that a learning progression links students' initial ways of thinking about a topic to more sophisticated understandings. Therefore, a learning progression is ideally suited to support teachers in assessing student thinking and identifying instructional moves that will scaffold students in reaching the next level of achievement. What is missing, however, is an avenue that provides teachers with access to the power of a learning progression for identifying the level of student achievement and suggestions for instructional moves and strategies that match student thinking and push students to develop more sophisticated knowledge and practices (Duncan, et al., 2009; Furtak, et al., 2010). One solution to this problem is to design formative assessments that link to the learning progression and provide guidance to teachers for scaffolding student thinking (Alonzo & Steedle, 2009; Furtak, et al., 2010; Shepard, 2009).

Formative assessments have long been touted as productive tools for instruction. Formative assessments that are embedded in instruction and provide teachers and students with immediate targeted feedback on student performance can have positive impacts on student achievement (Black & Wiliam, 1998a, 1998b; Wilson & Sloane, 2000). Yet, Coffey et al. (2011) note that while there have been many suggestions for formative assessment instructional strategies that can elicit student thinking, and many efforts to provide professional development around those strategies, often, when enacted, these strategies remain at the level of procedural implementation and do not support teachers in attending to the disciplinary substance of student responses. In order for formative assessments to be effective, teachers must be able to interpret student ideas and use those ideas to inform instruction (Jones & Moreland, 2005; Otero & Nathan, 2008; Ruiz-Primo & Furtak, 2007). Often, however, teachers' evaluation of student responses remains at the level of deciding if students provided the correct answer the teacher was trying to elicit, rather than making sense of the reasons why students might give the answers they provide and what insight those reasons might offer into student thinking (Coffey, et al., 2011). Furthermore, even if teachers attend to the disciplinary substance of student responses, they have few resources for knowing how to respond in ways that support students in developing more sophisticated ideas (Heritage, Kim, Vendlinski, & Herman, 2009).

In designing learning progression-based supports for teachers, we realized that we needed instructional materials that would guide teachers in eliciting student thinking and then connecting student responses to the descriptions of student accounts and reasoning articulated in the Water

Systems Learning Progression. Designing formative assessments seemed like the most productive approach for achieving this goal. However, in order for the formative assessments to be more than merely another strategy for teachers to implement, we realized that the formative assessments would also have to support teachers in understanding the levels of achievement described in the Water Systems Learning Progression. This step would be critical for helping teachers attend to the disciplinary substance of student responses and interpret student responses in terms other than whether or not students could parrot the expected canonical terms and phrases. Furthermore, our formative assessments would have to offer suggestions to teachers for how to respond to student thinking. As such, formative assessments linked to the Water Systems Learning Progression would have to provide teachers with guidance for building on the intellectual and cultural resources students bring to learning about water to support students in building more sophisticated understandings.

#3 Support Pressing For Explanations

Because the Water Systems Learning Progression articulates goals for what students should be able to explain about hydrologic systems, structures, and processes, teaching that supports students' construction and evaluation of scientific explanations is of particular concern in our work. When students' and teachers' knowledge of science is limited to descriptions of *what* happens, and does not include explanations of *how* and *why*, then their capacity to use science in model-based reasoning will be limited. Causal mechanisms (i.e., explanatory how's and why's) are a key aspect of scientific models (Schwarz, et al., 2009). Knowing how and why something happens facilitates the ability to apply understanding in new situations to explain and predict what will happen in diverse contexts and situations and/or in the future. This is the type of reasoning that is needed to make informed decisions about environmental issues, including issues related to our freshwater supplies. Teachers engaging students with scientific explanations that both *describe* what is happening and *explain* the causes and mechanisms that underlie phenomena is also a key focus of reform science education articulated in the new *Framework for K-12 Science Education* developed by the National Research Council (2012).

While pressing for explanation in teaching is a critical component of learning science and learning to become an environmental science literate citizen, it is currently not a common practice among K-12 science teachers in classrooms. Instead, it is more common for science lessons to involve asking students to repeat descriptive information about phenomena, and/or engaging students in making observations and carrying out experiments without developing associated explanations for those observations and experiments (Banilower, Smith, Weiss, & Pasley, 2006; Braaten & Windschitl, 2011; Horwood, 1988; National Research Council, 2007; Osborne & Dillon, 2008; Roth & Garnier, 2006). Thus, it was important that the instructional materials we developed would help teachers engage student in moving beyond describing only *what* happens in hydrologic systems, to also articulate the *hows* and *whys* underlying the *whats* in water systems events and phenomena. Designing the formative assessments and tools for reasoning to support teachers in pressing students for explanation, and to help teachers understand the importance of pressing for explanation was another central design criterion.

#4 Facilitate Classroom Norms for the Social Construction of Understanding

One way that reform science education pedagogy reflects practices of scientists engaged in conducting scientific research is evident in science being a socially mediated process. Just as scientific knowledge cannot be generated, validated, and advanced by one individual working alone, current best practices in science education emphasize that learning science is a social process involving interactive classroom discourse (Windschitl, 2009). While engaging students in first-hand scientific "activities" may be important for learning science, activities are not sufficient to support student development of scientific understanding and practices. Students need to make sense of what they are doing and learning, and this sense making takes place through interactive and participatory discussion in the classroom (Mortimer & Scott, 2003).

Traditionally, classroom science discourse has been limited in nature. For example, leading I-R-E discourses (involving teacher *initiation* with a question, student *response*, and teacher *evaluation* of the student response) have been and continue to be common practice for K-12 science teachers (Windschitl, 2009). Such teacher-controlled discourse is aimed at convincing students to remember and accept scientific facts (Ogborn, Kress, Martins, & McGillicuddy, 1996). The teacher asks questions to see if the student can provide the expected answer. The student is not required or expected to "communicate anything previously unknown, put forth a claim, justify or debate a point, or offer a novel interpretation" (National Research Council, 2007, p. 187). In contrast, student-centered discourse in the classroom is aimed at engaging students in scientific practices (scientific argumentation in particular) in ways that model development of scientific consensus in professional scientific communities.

Thus, reform science instruction asks teachers to facilitate a much broader range of discourse patterns beyond I-R-E in the classroom. These include patterns of talk in which students share and compare their own understanding with that of peers, and in which student talk and activity models scientific practices such as collaboratively formulating questions to be investigated, building and critiquing alternative theories, collecting and analyzing data, developing and defending explanations, and evaluating and communicating findings (Rosebery, Warren, & Conant, 1992). These types of talk cannot involve only teacher-student communications. Productive argumentation in the classroom requires that students work and talk with one another (Eichinger, Anderson, Palinscar, & David, 1999).

In order to support learning consistent with sociocultural perspectives of education, it is important that our Formative Assessments and Tools for Reasoning can function as foci around which participatory, social discourse of science can take place in the classroom. What's more, this participatory, student-discourse centered use should be clear to teachers and practical for them to implement when using the assessments and tools in lessons.

#5 Flexible Use

An important consideration in designing instructional supports for using the Water Systems Learning Progression in the classroom is that any formative assessment and tool for reasoning must be accessible for students at all levels of achievement. Likely, elementary students will provide lower level accounts (level 1.9 on average) than students in middle school (level 2.3 on average) and high school students are likely to provide the highest level accounts, on average (level 2.5 on average) (Gunckel, et al., in review). However, within a single classroom, there will generally be students who provide accounts at higher or lower levels than the class average. Potential variation in students' levels of achievement creates an additional challenge in designing assessment instruments and tools for reasoning that are accessible to students at all levels of achievement. In our previous work, we have found it challenging to write assessment items that elicit higher level accounts from students who can provide such accounts and that at the same time, are understandable to students who are only able to provide lower level accounts (Gunckel, et al., in review; Gunckel, et al., in press; Mohan, et al., 2009). Therefore, formative assessments and tools for reasoning must be sensitive enough to identify differences among students within a class, and broad enough that students at all levels of achievement will find the assessment instruments and tools for reasoning comprehensible.

An additional design constraint for formative assessments and tools for reasoning is that students may not provide accounts at the same level of achievement for all parts of the water system. For example, students on average provide higher level accounts of the surface water (level 2.6 on average, for middle and high school students combined) than they do of soil and groundwater (level 2.3 on average) or substances in water (level 2.2 on average). Students also have more difficulty providing accounts for connections between natural and human-engineered components of water systems (Gunckel, et al., 2010). Therefore, in order to be useful to teachers, any instructional supports must be able to support students at different levels of achievement and help teacher respond to the variation in levels of achievement across the class and across the curriculum.

Finally, within the usual school science curriculum, topics that address water in environmental systems may be fragmented across multiple grades and courses (Covitt, Gunckel, & Anderson, 2009). For example, students may study the water cycle in elementary or middle school, groundwater in middle or high school Earth science courses, topics related to the particulate nature of matter in middle school physical science courses, and solution chemistry in high school. Within all of the courses, a variety of curriculum materials and approaches may be used. These approaches may be research-based instructional sequences or merely collections of water-related activities. Teachers may have mandated curriculum sequences that they are required to follow, or they may have great flexibility for their own curriculum design and innovations. Any formative assessments and tools for reasoning linked to the Water Systems Learning Progression must be able to support teachers in using the existing curriculum materials and instructional sequences that they have available.

Water Systems Learning Progression-based Instructional Tools

In this section we describe examples of the formative assessments and tools for reasoning that we have designed and explain how we met the design criteria in constructing each.

Formative Assessments

One set of instructional materials that we have designed are a set of six formative assessment packages that teachers can use to elicit, analyze, and respond to student thinking (Design Criterion #2). Each package consists of a question or prompt that a teacher can administer to students, a detailed guide for interpreting student responses, and suggestions for instructional moves for students at each level of achievement. Each formative assessment package aligns with a different environmental system in the Water Systems Learning Progression (i.e., surface water, soil and groundwater, atmospheric, and biotic). Four of the formative assessment packages address processes that move water (i.e., transpiration, runoff, and infiltration) and two of the packages address concepts related to mixing, moving, and separating substances with/from water. Two of the six formative assessment packages also address students' use of representations (e.g., maps and cross-sections). Thus, a variety of formative assessment packages are available for teachers to use, depending on their curricular focus and the curriculum materials they are using (Design Criterion #5). A middle school teacher who is teaching about watersheds, for example, may choose the River Cleanup formative assessment package, while a high school chemistry teacher teaching about solutions and suspensions may to use the Fertilizer and/or Construction Site packages. Table 1 shows the formative assessment packages available and their alignment with the Water Systems Learning Progression. The complete formative assessment packages are available on our project website at www.umt.edu/watertools.

Table 1
Formative Assessment Packages

Formative Assessment Package Title	Content Assessed	Connection to the Water Systems Learning Progression
River Cleanup	Runoff processes	Moving water: Surface water system
What Happens Inside a Plant?	Transpiration processes	Moving water: Biotic system
Infiltration (2 versions available)	Infiltration processes; cross-section representations	Moving water: Soil and groundwater system
School Map	Map representations	Moving water: Surface water system
Fertilizer	Solutions	Substances in water: Surface, soil & groundwater, and atmospheric systems
Construction Site	Suspensions	Substances in water: Surface, soil & groundwater, and biotic systems

Formative assessment prompts are designed to be quick checks for student levels of achievement. As such, we intend that teachers would be able to administer each assessment within ten minutes of class time. Each assessment is one page and includes between 1 and 4 brief assessment items. Some of the formative assessments use an ordered multiple-choice format (Alonzo & Steedle, 2009; Briggs, Alonzo, Schwab, & Wilson, 2006), in which each of the choice options aligns with a level of achievement on the Water Systems Learning Progression. For example, in the River Cleanup Formative Assessment (see Appendix A), students read a short scenario about five friends who are picking up garbage along a riverbank. In the scenario, one of the friends asks where a bottle floating in the river would go. Five responses are given, one for each friend in the scenario. The student is asked to pick the response they think makes most sense. Each response aligns with a level of achievement on the Water Systems Learning Progression. Students are also asked to explain their choice. Other formative assessment items prompt students to draw a picture or to fill in a table. Teachers can then collect the assessments and make a quick scan of student answers to get a sense of the overall class average level of achievement for the aspect of the Water Systems Learning Progression that the assessment measures. Teachers may sample a few students from each class period, or may target a few students in particular to get a closer picture of student performance.

Each of the formative assessments is designed to be accessible to students who, at the time it is administered, perform at diverse levels of achievement with respect to the learning progression. The probe questions are simple and relate to common experiences students will be at least moderately familiar with (e.g., a bottle floating down a river, a plant using water, a map of a school campus, someone putting fertilizer on grass). While the probe questions are accessible to diverse students, the responses that students can provide vary widely. For example, students who are asked to draw what it looks like where there is water underground after a puddle soaks in may provide a variety of pictures, from showing underground human-built tanks of water to showing water existing in cracks and pores between rocks and soil (Covitt, et al., 2009; Dickerson, Callahan, Van Sickel, & Hay, 2005; Dickerson & Dawkins, 2004). The formative assessments can provide teachers with learning-progression linked information about the ideas of students performing at all levels of the learning progression (Design Criterion #5).

To support teachers in analyzing and interpreting student responses, the detailed guide to student responses is provided. In the guide to student answers, typical responses to the formative assessment items are described for each level of achievement. For the ordered multiple-choice items, a teacher needs only to glance at the student choice to get a quick idea of the level of achievement at which that student is performing. For other item formats, teachers can quickly match common student responses to the descriptions in the guide to interpret student responses. The guide also includes a short explanation of the implications of students' level of achievement for learning about the content assessed by the prompt. For example, on the River Cleanup Formative Assessment, the guide explains that students who chose the level 2 answer may believe that water can flow to any connected location. As such, level 2 students do not consider that water only flows from places of higher elevation to lower elevations. In this way, teachers learn more about the structure of the Water Systems Learning Progression (Design Criterion #1), and are able to interpret student responses efficiently (Design Criterion #2). The detailed guides also support teachers in developing their own understanding of water and substances moving through environmental systems, including understanding the nature of accounts at each of the levels (Design Criterion #1).

Finally, each formative assessment package includes instructional suggestions for teachers for students at each level of achievement. For example, on the River Cleanup Formative Assessment, the instructional suggestions for students who pick the level 2 multiple-choice response include having students map out possible connections among water pathways, such as tracing water along tributaries into larger rivers and noting elevation differences along the water pathways. In addition, suggestions for how to use the tools for reasoning (described in the next section) are also included. These types of suggestions support teachers in adapting curriculum materials and instructional strategies to meet students' learning needs and support them in moving to the next level of achievement (Design Criterion #2).

Tools for Reasoning

In addition to the formative assessment packages, we have also developed a set of four tools for reasoning that teachers can use to support their water systems instruction. Each tool for reasoning takes a form that looks much like a graphic organizer. Graphic organizers are representations that teachers can use to help students visually organize a body of content (Hawk, 1986). The purpose of the tools for reasoning goes beyond organizing content, however. Rather, the tools are intended to scaffold teachers and students to focus on, make predictions about, investigate, discuss, and develop accounts of Earth's water systems. Each tool is intended to be used to support students in reasoning about specific, rather than generalized, pathways. In this section, we first provide brief descriptions with illustrations of the four tools. Then, below we discuss examples of how the tools are intended to be used by teachers, and how these uses fit the learning progression-based instructional materials design criteria.

The Pathways Tool. This tool scaffolds students in considering the multiple and diverse pathways that water can take to and from a given location in a water system. The Pathways Tool

(Figure 1) can also be used to support students in considering places where other substances that can mix with water might originate and go. A specific location is identified and represented in the small center square. Using maps, cross-sections, or text, students trace the pathways along which water moved to arrive at the location represented in the center. Moving to the right of the center square, students similarly trace the water along the pathways that it could take away from that location. As students move more distally from the location of interest represented in the center square, the pathways become more branching and divergent.

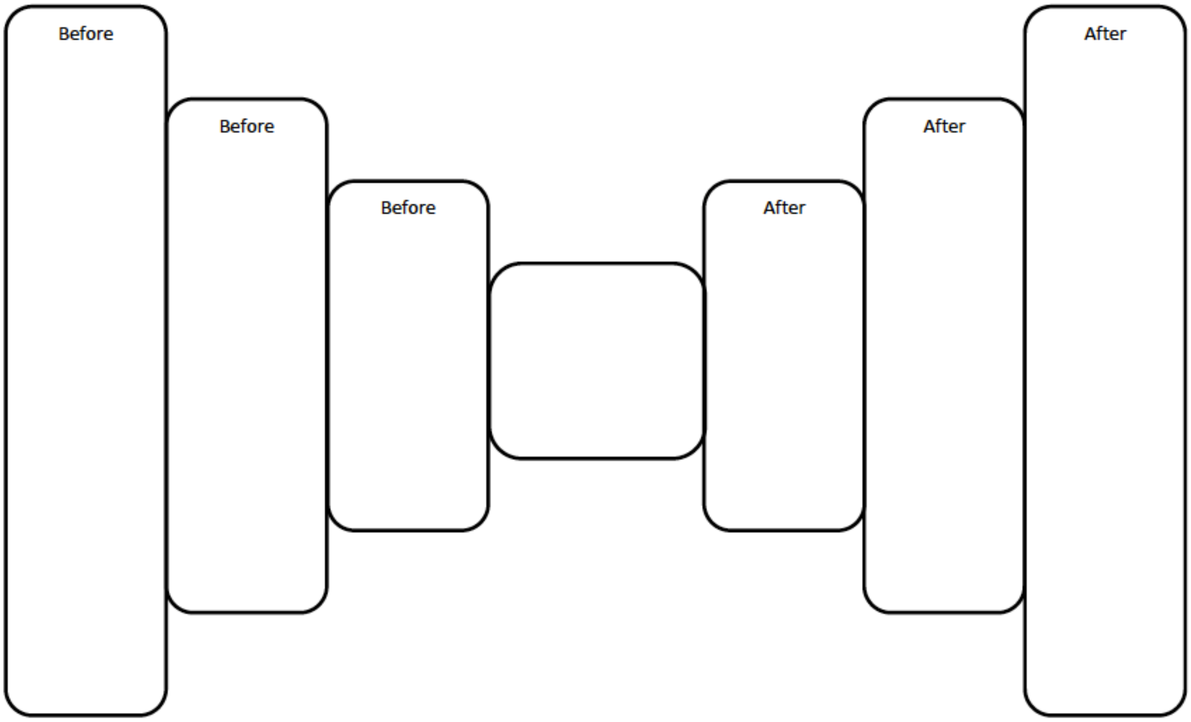


Figure 1. Pathways Tool

The Drivers and Constraints Tool. This tools scaffolds students in reasoning about the driving forces and factors that constrain water movement along possible pathways through water systems (Figure 2). For each pathway, a starting location is initially identified in the left-most box. Again using maps, cross-sections, photographs, textural descriptions, or other available data, students trace where water might go and identify the process that moves the water to that location (e.g., evaporation, infiltration, etc.). The tool prompts students to further identify the driving forces (e.g., gravity), and the factors that constrain water flow along the pathway (e.g., topography, permeability). For example, water in a puddle may infiltrate into the soil because gravity pulls it down and the soil is permeable.

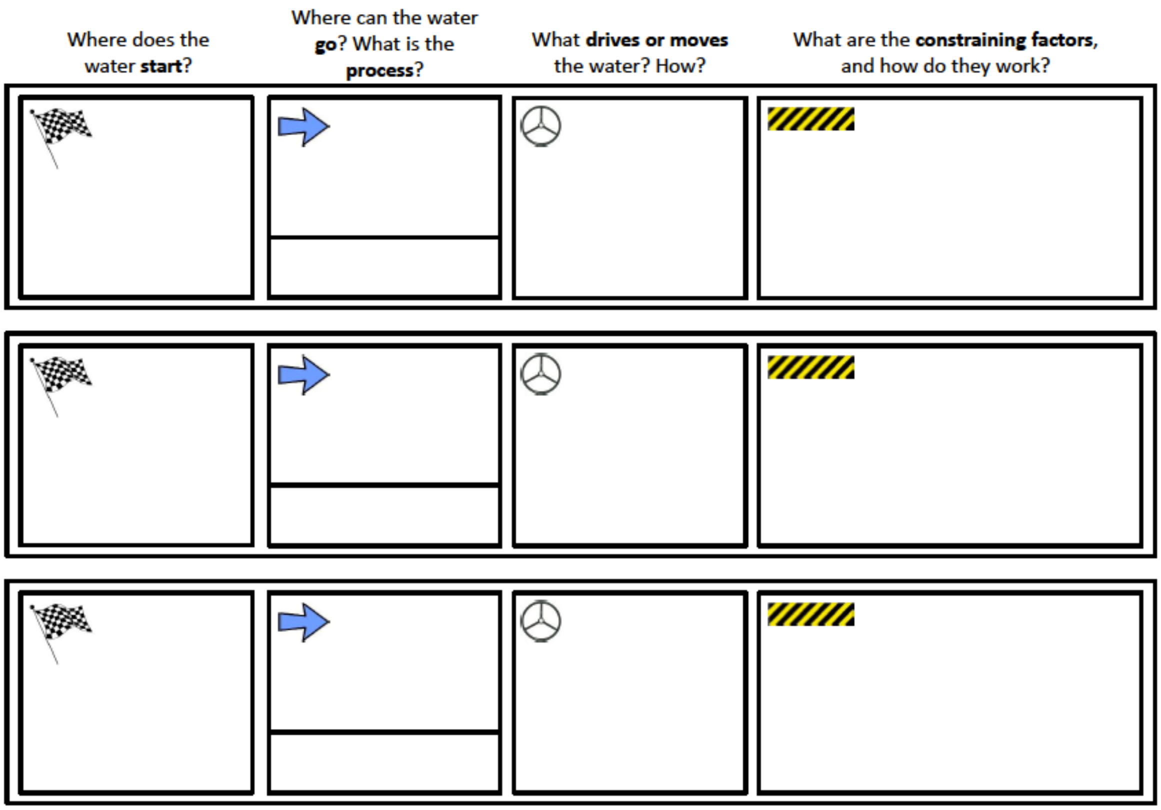
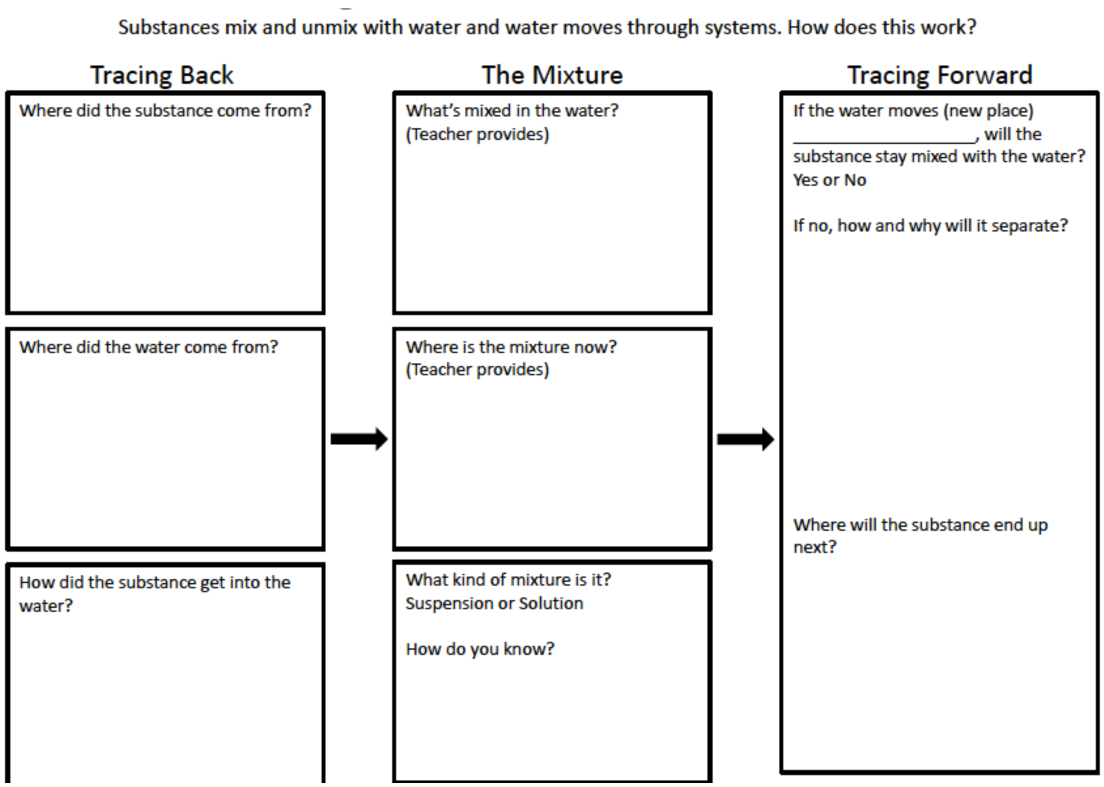


Figure 2. Drivers and Constraints Tool

The Tracing Mixtures with Water Tool. This tool scaffolds students in reasoning about other substances mixed with water and how these mixtures move through connected environmental systems (Figure 3). The tool also supports students in learning about when substances will stay mixed with water or separate from water as the mixtures move through Earth's connected water systems. In this tool, students begin in the center of the graphic organizer. The mixture and a location are identified (e.g., sediment in river water). Students then note whether the mixture is a suspension or a solution. Using available pictures, maps, or texts, student trace where the substance may have originated and how it mixed with the water. Tracing forward, students hypothesize whether the substance will move or separate from the water. This tool supports students in reasoning about the differences between solutions and suspensions.



Substances mix and unmix with water and water moves through systems. How does this work?

Tracing Back

Where did the substance come from?

Where did the water come from?

How did the substance get into the water?

The Mixture

What's mixed in the water?
(Teacher provides)

Where is the mixture now?
(Teacher provides)

What kind of mixture is it?
Suspension or Solution

How do you know?

Tracing Forward

If the water moves (new place) ________________, will the substance stay mixed with the water?
Yes or No

If no, how and why will it separate?

Where will the substance end up next?

Figure 3. Tracing Mixtures Tool

The Scale Tool. This tool supports students in identifying and comparing the scale of different objects and components in the water system (Figure 4). Students can place representations of locations or substances within the general atomic-molecular, microscopic, macroscopic, and landscape scales. One use of this tool, for example, might be in scaffolding students in comparing substances, for example and reasoning about whether substances are likely to mix in suspension or solution.

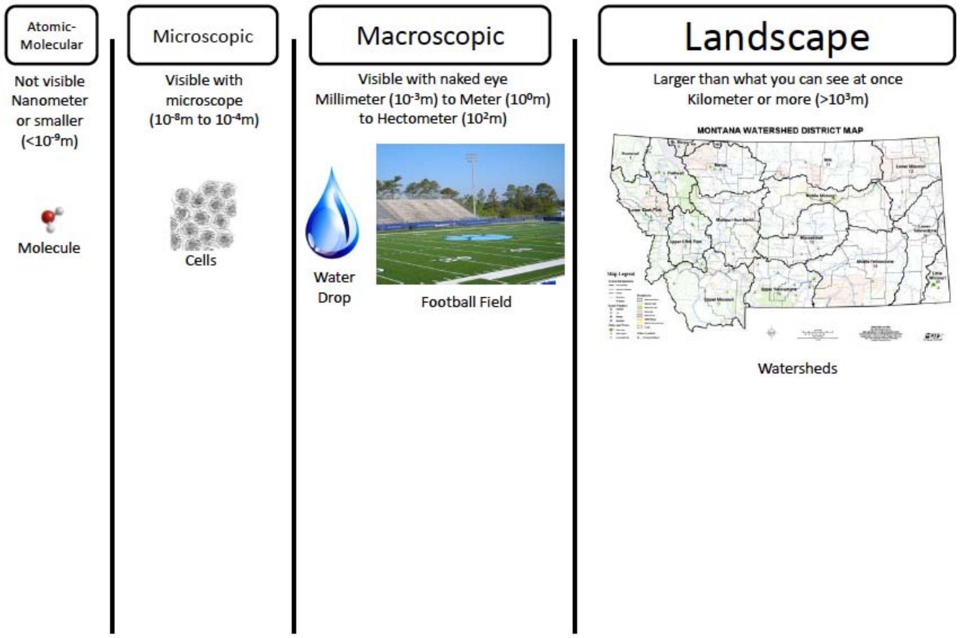


Figure 4. Scale Tool

In addition to the tools, a set of picture cards has also been created that can be used in conjunction with the tools. The cards include place cards (e.g., river, toilet, etc.), process cards (e.g., evaporation, transpiration, etc.), drivers cards (e.g., gravity, thermal energy, etc.), substance cards (e.g., fertilizer, dog poop, etc.), and constraining factors cards (e.g., permeability, solubility, etc.). Students can choose from the cards to complete the tools. The cards can also prompt students to consider locations, drivers, or constraints that they might not have readily recalled. In this way, students can quickly create possible pathways and consider various options for tracing water and substances in water through environmental systems.

While the tools can be printed and completed by students as 8.5”x11” sheets, they are not intended to serve as worksheets for individual students to complete. Rather, the tools are intended to function as scaffolds for social construction of understanding (Design Criterion #4). Tools can be integrated with learning activities for group use. Students can talk and argue about various potential pathways. Tools completed by groups of students can be projected using a document camera and discussed by a class. Blank tools can also be projected onto a white board to facilitate class discussion. For example, a class might use the Pathways and/or Drivers and Constraints Tools with investigations of water systems, and data and representations such as maps and cross-sections to explain and predict what is happening in different water systems instances. These social uses of the tools for reasoning allow for emphasis on scientific argumentation and scientific modeling practices.

The tools are also designed to be usable with a diversity of curricular materials that teachers may already be using, or that teachers may be required to use within their classrooms (Design Criterion #5). This design criterion was especially important to us because we knew that the teachers we were planning to work with had multiple constraints on what materials they are able to teach. For example, one group of teachers from Arizona who are working with us on our project has a required water curriculum that they must teach in the sixth grade. This curriculum consists of a sequence of *Project Wet* activities. During a summer workshop with our project teachers, we were able to offer initial ideas of how the tools could be integrated with the activities we knew they were required to teach. The teachers took this initial introduction further, devising new and different ways to integrate the tools. We also have a group of teachers from Montana in our project. Many of the Montana teachers have more flexibility to develop and teach science units of their own devising, as long as those units align with grade level benchmarks in their district’s science curriculum. Both Arizona and Montana teachers shared ideas for tool use at our summer workshop, and have subsequently integrated these diverse uses into their classroom instruction and lessons. For example, one teacher used the Pathways Tool in a scenario-based lesson he developed that asked students to trace where pollution in water might travel if an accident occurred and gasoline was spilled into a river near where the students live.

The Drivers and Constraints Tool is particularly suited to address Design Criteria #1 and #3. In our work, we have found that the Drivers and Constraints Tool may be used to help teachers reflect on and refine their own scientific knowledge and practices concerning how and why water moves through connected systems (Design Criterion #1). Second, the tool is helpful for supporting teachers in improving their pedagogical content knowledge with respect to designing and enacting instruction that encourages students to develop scientific explanations for (rather than just description of) Earth’s water systems processes (Design Criterion #3). Both of these uses reflect how the Drivers and Constraints Tool explicitly focuses on how and why water moves through connected systems.

As concerns teachers' own scientific explanations, we have found that the Drivers and Constraints Tool can provide a new lens or perspective for teachers as they engage in the scientific practice of explaining movements of water through connected environmental systems (Design Criterion #1). On our Water Systems Learning Progression Assessment (the same assessments we gave to students) (Gunckel, et al., in review; Gunckel, et al., in press), we found that teachers often provided school science narratives (level 3 responses) to open-ended questions. Because the Drivers the Constraints Tool explicitly prompts reasoning about forces that drive movements of water and factors that constrain movement, this tool challenged teachers to go beyond the easy answer (i.e., naming a process) to consider how and why a process moves water in specific situations. The teachers in our workshop were often surprised at how the water phenomena about which they had initially felt confident describing using school science stories were more complex and difficult to explain scientifically than they had realized. Thus the Drivers and Constraints Tool helped the teachers question and develop their own understanding of explanations and predictions of events and processes in water systems.

After questioning and constructing their own understanding, the teachers began to see the usefulness of this tool for pressing their students for more sophisticated explanations of how and why water moves through connected systems (Design Criterion #3). In observations of teachers' use of the tool with classrooms of middle school students, we and the middle school teachers have seen that although the Drivers and Constraints Tool is initially challenging for students to understand, after modeling and discussing use of the tool with a few examples, the students are able to use the tool in groups to discuss explanations for phenomena that they have observed either in school or out of school. For example, one project researcher observed a group of students who were trying to figure out the constraining factors for water in clouds moving to rain. They initially thought there might not be any constraining factors, but when the researcher asked them if they had ever seen a cloud that didn't have rain coming out of it, they realized that there must be factors that constrain the movement of water from clouds to rain. In this case, the Drivers and Constraints Tool provided a context for a small group discussion that focused students on thinking about deeper explanations of a phenomenon that are often glossed over and treated in a shallow manner in many school science lessons about the water cycle.

Conclusion

The formative assessments and tools for reasoning that we are currently developing, testing, and refining are designed to support teachers in shifting from worrying about covering curriculum standards to attending to student thinking during instruction and anticipating how students at various levels of achievement will respond to classroom learning activities. The design criteria that we describe above have helped us to consider and explore how the formative assessments and tools can best be used, refined, and adapted to help teachers scaffold students toward the model-based reasoning about water systems that we hope all students will achieve by the time they graduate from high school. Through collaborating with teachers to test the formative assessments and tools for reasoning in PD workshops and science lessons with students, we are learning more about how these instructional materials currently model the design criteria, and how they can be refined to do so even more. Though we are still early in the process of testing and refining these instructional materials in professional development and classroom contexts, we believe that the materials hold promise for providing a means to move learning progressions from academic research constructs to practitioner-accessible frameworks that support teacher use of learning progressions in classroom instruction.

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Teaching* (pp. 1105-1149). Mahwah, New Jersey: Lawrence Erlbaum.

Alonzo, A. C., & Steedle, J. T. (2009). Developing and assessing a force and motion learning progression. *Science Education, 93*(3), 389-421.

Ball, D. L., & Cohen, D. (1996). Reform by the book: What is - or might be- the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher, 25*(9), 6-8, 14.

Banilower, E. R., Smith, P. S., Weiss, I. R., & Pasley, J. D. (2006). The status of K-12 science teaching in the United States: Results from a national observation study. In D. W. Sunal & E. L. Wright (Eds.), *The impact of state and national standards on K-12 science teaching* (pp. 83-122). Greenwich, CT: Information Age Publishing.

Black, P., & Wiliam, D. (1998a). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7-74.

Black, P., & Wiliam, D. (1998b). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan, 80*(2), 139-148.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education, 95*(4), 639-669. doi: 10.1002/sce.20449

Briggs, D., Alonzo, A., Schwab, C., & Wilson, M. (2006). Diagnostic assessment with ordered multiple-choice items. *Educational Assessment, 11*(1), 33-63.

Cately, K., Lehrer, R., & Reiser, B. J. (2005). Tracing a prospective learning progression for developing understanding of evolution. *Paper commissioned by the National Academies Committee on Test Design for K-12 Science Achievement.*

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching, 48*(10), 1109-1136. doi: 10.1002/tea.20440

Covitt, B. A., Gunckel, K. L., & Anderson, C. W. (2009). Students' developing understanding of water in environmental systems. *Journal of Environmental Education, 40*(3), 37-51.

Dickerson, D., Callahan, T. J., Van Sickel, M., & Hay, G. (2005). Students' conceptions of scale regarding groundwater. *Journal of Geoscience Education, 53*(4), 374-380.

Dickerson, D., & Dawkins, K. (2004). Eighth grade students' understandings of groundwater. *Journal of Geoscience Education, 52*(1), 178-181.

Dove, J. E. (1997). Student preferences in the depiction of the water cycle and selected landforms. *International Research in Geographical and Environmental Education, 6*(2), 135-147.

Duncan, R. G., & Hmelo-Silver, C. E. (2009). Learning progressions: Aligning curriculum, instruction, and assessment. *Journal of Research in Science Teaching, 46*(6), 606-609.

Duncan, R. G., Rogat, A. D., & Yarden, A. (2009). A learning progression for deepening students' understandings of modern genetics across the 5th–10th grades. *Journal of Research in Science Teaching, 46*(6), 655-674.

Eichinger, D., Anderson, C. W., Palinscar, A. S., & David, Y. M. (1999). *An illustration of the roles of content knowledge, scientific argument, and social norms in collaborative problem solving*. Paper presented at the Paper presented at the annual meeting of the American Educational Research Association, Chicago.

Furtak, E. M., Roberts, S., Morrison, D., Henson, K., & Malone, S. (2010). *Linking an educative learning progression for natural selection to teacher practice: Results of an exploratory study*. Paper presented at the American Educational Reserach Association, Denver, CO.

Gess-Newsome, J., & Lederman, N. G. (1995). Biology teachers' perceptions of subject matter structure and its relationship to classroom practice. *Journal of Research in Science Teaching, 32*(3), 301-325.

Ginns, I. S., & Watters, J. J. (1995). An analysis of scientific understandings of preservice elementary teacher education students. *Journal of Research in Science Teaching, 32*(2), 205-222.

Grossman, P., Schoenfeld, A., & Lee, C. D. (2005). Teaching subject matter. In L. Darling-Hammond, J. Bransford, P. LePage, K. Hammerness & H. Duffy (Eds.), *Preparing teachers for a changing world: What teachers should learn and be able to do*. San Francisco, CA: Jossey Bass.

Gunckel, K. L., Covitt, B. A., & Anderson, C. W. (2010). *Teacher responses to assessments of understanding of water in socio-ecological systems: A learning progressions approach*. Paper presented at the National Association for Research in Science Teaching, Philadelphia, PA.

Gunckel, K. L., Covitt, B. A., Salinas, I., & Anderson, C. W. (in review). A Learning Progression for Water in Socio-Ecological Systems. *Journal of Research in Science Teaching*.

Gunckel, K. L., Mohan, L., Covitt, B. A., & Anderson, C. W. (in press). Addressing challenges in developing learning progressions for environmental science literacy. In A. Alonzo & A. W. Gotwals (Eds.), *Learning Progressions in Science*. Boston, MA: Sense Publishers.

Hawk, P. (1986). Using graphic organizers to increase achievement in middle school life science. *Science Education, 70*(1), 81-87.

Heritage, M., Kim, J., Vendlinski, T., & Herman, J. (2009). From evidence to action: A seamless process in formative assessment? *Educational Measurement: Issues and Practice, 28*(3), 24-31.

Horwood, R. H. (1988). Explanation and description in science teaching. *Science Education, 72*(1), 41-49.

Jones, A., & Moreland, J. (2005). The importance of pedagogical content knowledge in assessment for learning practices: a case-study of a whole-school approach. [Article]. *Curriculum Journal, 16*, 193-206.

Lederman, N. G. (2007). Nature of science: past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831-880). Mahwah, N.J. : Lawrence Erlbaum Associates.

Mohan, L., Chen, J., & Anderson, C. W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. *Journal of Research in Science Teaching, 46*(6), 675-698.

Moore, J., Berkowitz, A. R., Parker, S., Doherty, J., & Johnson, M. (2012). *Development and implementation of learning progression-based teaching strategies for environmental science literacy*. Paper presented at the Learning Network Conference, Washington, D.C.

Mortimer, E., & Scott, P. (2003). *Meaning making in secondary science classrooms*. Philadelphia: Open Univ Press.

National Research Council. (2007). Taking science to school: Learning and teaching science in grades K-8. In Committee on Science Learning Kindergarten through Eighth Grade, R.

A. Duschl, H. A. Schweingruber & A. W. Shouse (Eds.). Washington, D.C.: National Academies Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, D. C.: National Academies Press.

Ogborn, J., Kress, G., Martins, I., & McGillicuddy, K. (1996). *Explaining science in the classroom*. Buckingham, England: Open University Press.

Osborne, J., & Dillon, J. (2008). Science education in Europe: Critical reflections. *London: Nuffield Foundation*.

Otero, V. K., & Nathan, M. J. (2008). Preservice elementary teachers' views of their students' prior knowledge of science. *Journal of Research in Science Teaching, 45*(4), 497-523.

Plummer, J. D., & Krajcik, J. (2010). Building a learning progression for celestial motion: Elementary levels from an earth-based perspective. *Journal of Research in Science Teaching, 47*(7), 768-787. doi: 10.1002/tea.20355

Roehrig, G. H., & Luft, J. A. (2004). Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. . *International Journal of Science Education, 26*(1), 3 - 24.

Rosebery, A., Warren, B., & Conant, F. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences, 2*(1), 61-94.

Roth, K., & Garnier, H. (2006). What science teaching looks like: An international perspective. *Educational Leadership, 64*(4), 16.

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching, 44*(1), 57-84.

Sanders, M. (1993). Erroneous ideas about respiration: The teacher factor. *Journal of Research in Science Teaching, 30*(8), 919-934.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., et al. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632-654.

Shepard, L. A. (2009). Commentary: Evaluating the validity of formative and interim assessment. *Educational Measurement: Issues and Practice, 28*(3), 32-37.

Shepardson, D. P., Harbor, J., Cooper, B., & McDonald, J. (2002). The impact of a professional development program on teachers' understandings about watersheds, water quality, and stream monitoring. *The Journal of Environmental Education, 33*(3), 34-40.

Smith, C., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic molecular theory. *Measurement: Interdisciplinary Research and Perspectives, 4*(1&2), 1-98.

Songer, C. J., & Mintzes, J. J. (1994). Understanding cellular respiration: An analysis of conceptual change in college biology. *Journal of Research in Science Teaching, 31*(6), 621-637.

Songer, N. B., Kelcey, B., & Gotwals, A. W. (2009). How and when does complex reasoning occur? Empirically driven development of a learning progression focused on complex reasoning about biodiversity. *Journal of Research in Science Teaching, 46*(6), 610-631.

Stoddart, T., Connell, M., Stofflett, R., & Peck, D. (1993). Reconstructing elementary teacher candidates' understanding of mathematics and science content. *Teacher & Teacher Education, 9*(3), 229-241.

Trumbull, D., & Kerr, P. (1993). University Researchers. *Science Education, 77*(3), 301-317.

Van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673-695.

Wilson, M., & Sloane, K. (2000). From principles to practice: An embedded assessment system. *Applied Measurement in Education, 13,* 181-208.

Windschitl, M. (2009). Cultivating 21st century skills in science learners: How systems of teacher preparation and professional development will have to evolve: National Academies of Science.

Zesaguli, J., Wilke, B., Hartley, L., Tan, E., Schenk, C., & Anderson, C. W. (2009). *Developing a K-12 Learning Progression for Biodiversity in Environmental Systems*. Paper presented at the National Association of Research in Science Teaching, Garden Grove, CA.

Appendix A

River Cleanup Formative Assessment

Alberto, Brenda, Cheng, Deja, and Elan were volunteering for the annual river clean-up in their town. They were finding lots of plastic water bottles, tires, shoes, and other garbage in the river. As Elan put yet another plastic water bottle in their trash bag, he asked, “If we didn’t pick this bottle out of the river, where do you think it would go?” Everyone had an idea.

Alberto: Maybe the bottles follow the water from this river to a smaller river.

Brenda: I think the bottles float downstream.

Cheng: I think the bottles float away.

Elan: Well, the bottles could go to the town of Pueblo Rio. The river in Pueblo Rio is connected to this creek.

Deja: I disagree because Pueblo Rio is up in the hills. This river goes to the town of Sweetwater, which is in the lowlands.

Who do you agree with most? ______________________

Explain your reasons. If you agree with no one, please write your own answer to the question.

Purpose

When your students are learning about watershed, one of the features that they will be exploring is determining the pathways for surface water runoff. In doing so, students must reason about where surface water flows and why. Our research shows that through their direct experiences with water, students realize that water flows downhill. However, students do not often use this embodied understanding to reason about where flowing on the surface goes or why. This formative assessment probe is designed to efficiently provide you with some insight into your students' reasoning about where water flows before you begin studying watersheds. By understanding how your students are thinking about surface water, you can provide more focused guidance to help them reason about pathways for runoff, what forces drive surface water flow, and what variables constrain surface pathways.

Target Understanding (upper anchor)

In reasoning about where surface water flows and why, students must consider driving forces and constraining factors. The driving force for surface water is gravity. Water on Earth's surface flows downhill because the force of gravity pulls water downhill. The actual pathway that the water takes depends on the topography that shapes the land surface and the permeability of the surface that the water is moving across.

Suggestions for Administration

This assessment is designed so that you can give the prompt to students at the beginning of lessons about watersheds. You can provide a copy of the prompt for each student to write on and turn in to you at the end of the class period, or you can project the prompt and have students write their answers in their science notebooks.

Connecting Student Responses to the Learning Progression Framework

Each person in the scenario offers an answer and a reason that aligns with a level of achievement in the learning progression framework. The descriptions below link each response with a level of achievement and explain the characteristics of student thinking at that level.

Level 1: Force Dynamic Accounts

Cheng: I think the bottles float away:

Description: Students who give Level 1 answers do not yet make the connection between two different locations. These students see that water in rivers flows and that it flows away from them, but they do not yet explain where the water goes when they no longer see the water. They also do not explain about where the water flowing in the river comes from. To them, rivers by definition just have water in them.

Implications: Students who give Level 1 answers will find it difficult to trace where water will go if there is no visible water flowing. These students may identify gutters as places water will flow because gutters are supposed to have water in them. They will have more difficulty tracing overland flow on surfaces covered by vegetation or bare soil.

Suggestions: When you are outside, have students look for evidence that water was flowing on the surface. Look for places where leaves or sediment have been moved by water flowing in the past. Follow gutters and other obvious water pathways to see where they lead. You could also pour some water on the ground and have students draw pictures or write about where they see the water going.

Level 2: Force-Dynamic Accounts with Mechanisms

Alberto: Maybe the bottles follow the water from this river to a smaller river.

Description: Students who agree with Alberto trace water from somewhere to somewhere else and give reasons for the pathways that water takes. Our research shows that one heuristic students use to explain where water in rivers goes is that water flows from “big water to smaller water.” That is, students explain that since water is always flowing in a river, there must be a large source upstream, such as a large lake or bigger river, that supplies all of the water in the river. Otherwise, the river would run out of water. By extension, then, the water in this river must be providing water for smaller streams somewhere else.

Elan: Well, the bottles could go to the town of Pueblo Rio. The river in Pueblo Rio is connected to this creek.

Description: Students who agree with Elan are also at Level 2. Level 2 students often trace water flowing to other connected water. That is, water in a river flows into other rivers. For Level 2 students, the connection is the main focus. If there is a connection, the water will flow there. Their answers do not account for the role of topography in constraining the direction that water flows.

Implications: Students at Level 2 may also have difficulty tracing where surface water flows if there is no visible water flowing, especially on surfaces covered by vegetation or bare soil. These students may note connections between possible pathways, such as places that are connected to gutters or drainages or creeks. They may also notice the relative size of pathways (such as bigger gutters, bigger drainages, or large puddles).

Suggestions: As with Level 1 students, you may begin by pointing out evidence that water has flowed across surfaces in the past, including places where it may have flowed across surfaces that are permeable. Then, have students map out possible connections among pathways. Note relative sizes of pathways and guide students in recognizing that as two smaller pathways converge, the volume of water in the merged pathway becomes larger. Pour water across various surfaces from two different locations to observe what happens when the water in two pathways comes together. Also, note higher and lower elevations and make explicit that the water doesn’t just flow to connected water, it flows to places that are downhill.

Level 3: School Science Accounts

Brenda: I think the bottles float downstream.

Description: Students who agree with Brenda explain the direction of water flow. They often describe many pathways that water can follow, including runoff, infiltration, and evaporation. These students also explain that water flows downhill. Brenda’s answer, however, references downstream as a direction and does not include a reason for why the water flows in that direction. Students who use the term “downstream” are not necessarily indicating that the land surface in that direction is a lower elevation. “Downstream” is the term that they have used to describe the direction that water flows. Level 3 students are good at correctly describing where water goes, but are not yet practiced in providing reasons why the water will flow that way. To Level 3 students, all pathways are equally possible.

Implications: Level 3 students will be good at identifying possible pathways for water to flow on impervious surfaces such as parking lots and sidewalks, even if there is no water visibly flowing. They may also identify possible surface pathways on vegetated or bare soil surfaces. They may not yet articulate why water will flow in some places and not others.

Suggestions: Support students at Level 3 to consider variables that will influence whether water on a surface will infiltrate or runoff. Push students to consider why water will flow on the surface on some surfaces and not others. Help them think about where the water goes on permeable surfaces and what some reasons are for why water might sometimes flow across surfaces that seem relatively permeable. For example, after a long rain event, the soil-covered surfaces may be saturated and water will collect and flow off some soil-covered surfaces. Also, provide students with tools for determining relative elevations of various points on the school yard. Such tools could be topographic maps, levels and surveyor sticks, or even just rolling balls or pouring water across surfaces to see where they go.

Level 4: Model-Based Accounts

Deja: I disagree because Pueblo Rio is up in the hills. This river goes to the town of Sweetwater, which is in the lowlands.

Description: Deja's answer is the only Level 4 answer. Deja gives a reason for her answer that indicates she is thinking about topography and elevation in controlling where the water flows. She notes not just the direction, but also explains why the water goes one direction and not another.

Implications: Students who agree with Deja can explain the influence of gravity and topography on surface water. This assessment item does not prompt students to describe the influence of permeability on surface water flow. Therefore, like students who responded at Level 3, students who choose the Level 4 response may or may not distinguish surface water pathways of more permeable surfaces or provide reasons for why water might sometime flow across such surfaces.

Suggestions: Students who agree with Deja will also likely benefit from support considering the role of permeability in controlling surface runoff. Support students at Level 4 using the same suggestions listed above for Level 3 students.