

Teachers' Uses of Learning Progression-Based Tools for Reasoning in Teaching about Water in Environmental Systems

Abstract

Learning progressions are a potentially powerful tool for supporting students in developing model-based reasoning. Using learning progressions to scaffold student learning in the classroom requires learning progression-based instructional resources. In this project we designed formative assessments and graphic reasoning tools that teachers could use across a variety of instructional sequences to elicit and respond to student thinking and engage students in activities that would support increasingly sophisticated reasoning about water in environmental systems. We used a quasi-experimental design to test these tools. Ten middle school teachers participated in a four-day workshop on integrating the tools into their instruction. Eight teachers who did not attend the workshop served as comparison teachers. We administered the Water Systems Learning Progression Assessment to students in all teachers' classes, pre and post instruction about water. Assessments were coded using the levels of achievement in the Water Systems Learning Progression. Overall, students in participant teachers' classes showed a significantly greater pre-post gain on the assessment than students in comparison teachers' classes ($t(461) = 3.59, p < .01$). Within the participant teacher group, we compared the teaching practices of a teacher with a large effect size on mean student gains with a teacher with no effect size. Both teachers targeted instruction at level 3 school science stories. However, the teacher with the large effect size engaged in practices that could lead to supporting model-based reasoning, while the teacher with no effect size did not. These findings suggest that while integrating learning progression-based reasoning tools into instruction may have a positive effect on student reasoning, the impact of these tools may depend on how teachers use the tools in their teaching practices.

Kristin L. Gunckel, University of Arizona

Beth A. Covitt, University of Montana

Ivan Salinas, University of Arizona

Disclaimer: This research is supported in part by grants from the National Science Foundation: Targeted Partnership: Culturally relevant ecology, learning progressions and environmental literacy (NSF-0832173), and Tools for Reasoning about Water in Socio-ecological Systems (DRL-1020176). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Please visit our website: www.umt.edu/watertools

TEACHER USES OF REASONING TOOLS

Teachers' Uses of Learning Progression-Based Tools for Reasoning in Teaching about Water in Environmental Systems

Learning progressions are a potentially powerful tool for supporting students in developing model-based reasoning. In theory, they can support teachers in identifying learning goals appropriate for student learning; using formative assessments to elicit, analyze, and respond to student thinking; and engaging students in scientific practices such as arguing and constructing explanations from evidence that lead to model-based reasoning (Moore, Berkowitz, Gunckel, & Tschillard, 2013). However, supporting teachers in using learning progressions to inform their instruction requires that teachers have curriculum resources, including assessments, curricula, and teaching tools, designed to make learning progressions accessible and useful to teachers. To date, few learning progression-based curriculum materials exist for teachers.

In this project, we designed learning progression-based instructional tools intended to support teachers in scaffolding students' reasoning about water in environmental systems. These tools include formative assessments and graphic reasoning tools that are aligned with the Water Systems Learning Progression (Covitt, Gunckel, & Anderson, 2012; Gunckel, Covitt, Salinas, & Anderson, 2012). We then investigated how teachers used these instructional resources and whether instruction using these materials made a difference in student learning. The goal of our research was to develop learning progression-based instructional tools and to identify promising teaching practices that make effective use of these resources. Our research questions were:

1. How does incorporation of learning progression-based formative assessments and graphic reasoning tools into instruction impact student learning?
2. How do teachers use learning progression-based formative assessments and graphic reasoning tools?

Frameworks

Water Systems Learning Progression

The Water Systems Learning Progression describes characteristics of student accounts of water and substances in water moving through environmental systems (Covitt et al., 2012; Gunckel, Covitt, et al., 2012). Environmental systems include both natural systems (i.e., surface water, soil and groundwater, atmospheric, and biotic systems) and human-engineered components (i.e., wells, water treatment plants, human-altered landscapes including roads, buildings, parks, canals, etc.). The learning progression includes four levels of achievement that traces student progress across five elements of accounts: systems and interconnected structures; scale, from atomic-molecular through landscape; scientific principles; representations; and human agency and dependency.

Achievement levels 1 and 2 describe accounts that reflect force-dynamic reasoning. These accounts frame events as resulting from actions taken by actors to achieve certain purposes, such as fulfilling needs or preventing phenomena (Pinker, 2007). In level 1 accounts, water is usually described in isolated, visible locations, such as lakes, rivers, bathtubs, or puddles. Level 1 accounts are also

TEACHER USES OF REASONING TOOLS

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 informal mechanisms that move water and substances in water.

School science stories characterize Level 3 accounts. 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. However, these accounts are often incomplete and may have errors that result from inattention to underlying scientific principles.

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). These accounts identify 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, utilize representations as models, and recognize human dependence on environmental systems. Level 4 accounts represent the knowledge and reasoning necessary for environmental science literacy, defined as the capacity to use model-based reasoning to make evidence-based decisions about environmental issues (Gunckel, Covitt, et al., 2012; Gunckel, Mohan, Covitt, & Anderson, 2012; Mohan, Chen, & Anderson, 2009). Level 4 accounts also meet the expectations for science understanding and practices for students at the end of high school as described in the *Framework for K-12 Science Education* (National Research Council, 2012).

Learning Progression-supported Instruction

Learning progressions have been hailed as promising frameworks that can potentially bring coherence to curriculum, instruction, and assessment (Alonzo & Gotwals, 2012; Black, Wilson, & Yao, 2011; Corcoran, Mosher, & Rogat, 2009; Duncan & Hmelo-Silver, 2009; National Research Council, 2007). Because learning progressions connect the logic of the learner to the logic of the discipline and are sensitive to instruction, they can be a potentially rich resource for informing instruction that is attentive to student thinking and scaffolds students in developing model-based accounts of the world (Corcoran et al., 2009; Duschl, Maeng, & Sezen, 2011; National Research Council, 2012). We see learning progressions as supporting teaching in the following ways.

1. *Establishing learning goals that support students in developing more sophisticated understandings.* The *Framework for K-12 Science Education* and the *Next Generation Science Standards* use learning progressions to organize key learning goals for the disciplinary core ideas, cross-cutting concepts, and scientific practices across grade bands (Achieve, 2013; National Research Council, 2012). Learning progressions can support teachers in identifying appropriate learning goals based on students' levels of achievement that will move students toward developing more scientific conceptions (Furtak, 2012; Furtak & Heredia, 2013).

TEACHER USES OF REASONING TOOLS

2. *Using formative assessments to guide instructional choices.* Learning progressions can support classroom-based formative assessment by providing teachers with specific goals for instruction, highlighting aspects of student knowledge and practice that are helpful for building more scientific understanding, identifying intermediate indicators of progress, and pointing to potential pathways for instruction that support students in developing more sophisticated ideas (Alonzo, 2011; Black et al., 2011; Corcoran et al., 2009; Furtak, Thompson, Braaten, & Windschitl, 2012; Heritage, 2008).
3. *Scaffolding model-based reasoning.* A challenge that many teachers face is responding to students once they have assessed student learning needs (Coffey, Hammer, Levin, & Grant, 2011; Heritage, 2008). Learning progressions can support teachers in providing learning experiences that scaffold student model-based reasoning through use of appropriate visualizations, classroom discourse, and engagement in scientific practices (National Research Council, 2012). Among the practices that are important for building scientific reasoning are modeling, constructing explanations, and engaging in arguments from evidence (Berland & McNeill, 2010; Schwarz et al., 2009).
4. *Situating science content and practice to students' place, culture, and real world issues.* The Water Systems Learning Progression attends to students reasoning about local and global water issues (Gunckel, Covitt, et al., 2012). We argue that scientific model-based reasoning is necessary for citizens to participate in the democratic decision-making about local and global water resources. Therefore, instruction based on the Water Systems Learning Progression should be situated in local place, culture, and water-related issues so that students see first-hand the need for sophisticated reasoning to make sense of and make informed decisions about pressing issues in their communities.

Formative Assessments and Graphic Reasoning Tools

In this project, we developed two types of instructional tools to support teachers in using the Water Systems Learning Progression to inform their instruction (Covitt et al., 2012). Formative Assessment Packages were designed to provide teachers with a quick assessment prompt and supporting documentation for interpreting and responding to student answers. These packages included a description of the purpose of the assessment prompt, a target student response indicating level 4 reasoning, and a key for interpreting common student responses based on the Water Systems Learning progression. Each assessment package also included suggestions for instruction for students at each level. Six formative assessment packages were developed covering surface water systems, soil and groundwater systems, biotic and atmospheric systems, and substances in water.

Reasoning Tools consisted of graphic organizers designed to scaffold students in developing model-based accounts of water and substances in water moving through environmental systems. These graphic reasoning tools specifically address challenges that students often face in developing level 4 model-based reasoning, such as attending to driving forces (e.g., gravity and pressure) and constraining factors (e.g., topography, permeability, heat energy), considering the likelihood of multiple water pathways, and reasoning about water at multiple scales (e.g., atomic-molecular to landscape scale). Two commonly used reasoning tools include the Pathways Tool that engages students in tracing water forwards and backwards

TEACHER USES OF REASONING TOOLS

from a specific location, and the Drivers and Constraints Tool designed to support students in reasoning about the drivers and constraints acting on water along specific pathways. The intent is for teachers to use these tools to support students in building models, constructing arguments, and developing explanations and predictions about water phenomena. Both the formative assessments and the reasoning tools are intended to be integrated into the instructional programs and do not in and of themselves constitute a specific curriculum.

Methods

Study Design

In this study, 10 middle school teachers (grades 6-8) from two states participated in a four-day workshop to learn about the water systems learning progression, the graphic reasoning tools, and teaching strategies for engaging students in scientific practices while learning about water. Teachers then incorporated the tools for reasoning into their existing science curriculum for teaching about water topics, including watersheds and surface water systems and processes. In addition, eight middle school teachers who also taught about water but did not participate in the workshop or use the tools for reasoning in instruction served as comparison teachers.

All teachers taught instructional units on water in environmental systems that lasted between four and nine weeks. In this study we did not provide teachers with a particular instructional sequence or curriculum materials. Instead, teachers integrated the formative assessments and graphic reasoning tools into their existing curriculum. Some teachers, for example, had school-district mandated curriculum materials while other teachers used instructional sequences and activities they had developed in previous years.

All teachers administered the Water Systems Learning Progression Assessment pre and post instruction. This assessment included ten items that prompted students to trace water and substances in water through natural and human-engineered systems. Items were clustered into four groups. Table 1 shows the number of items and associated water systems for each cluster. Appendix A lists all of the items. This assessment was used to compare student learning between students in participant and comparison teachers' classes.

Table 1

Clusters of Items on the Water Systems Learning Progression

Cluster	No. of Items	Water Systems
Soccer Field	3	Surface, soil and groundwater, atmospheric, biotic
River Map	2	Surface
Groundwater	2	Soil and groundwater (including engineered components)
Fertilizer	3	Substances in water in surface and groundwater systems

TEACHER USES OF REASONING TOOLS

Data and Analysis

Data included student pre and post assessments for all students. For participant teachers, data included observations of the teachers incorporating the formative assessments and graphic reasoning tools into their science lessons, teacher lesson plans for these lessons, examples of student uses of the tools for reasoning in the observed lessons, interviews with students pre and post instruction, and focus-group interviews with teachers to gather their views on their experiences using the learning progression-based tools in instruction.

Student assessment data were analyzed for change in level of achievement with respect to the water systems learning progression (Gunckel, Covitt, et al., 2012). Each student response was coded using exemplar worksheets that identify indicators of student performance for each level on the learning progression. Responses that included indicators from two adjacent levels were coded with half codes. For example, a response that included indicators from level 2 and level 3 were given a code of 2.5. After analysis we noticed that there were few 1.5 and 3.5 codes, but many 2.5 codes. Therefore, we collapsed the 1.5 codes with the 1 codes and the 3.5 codes with the 4 codes. Student responses were divided among three coders. To check interrater reliability, pairs of coders coded 10% of the items. Cohen's Kappa for interrater reliability for responses with two coders was 0.5, which indicates moderate reliability.

We then used item response theory analysis (Wilson, 2005) to analyze the distribution of these codes. We produced Wright Maps that aligned student proficiency with item difficulties for each item. Table 2 shows how the Wright Map steps aligned with the learning progression coding categories.

Table 2

Learning Progression Coding Categories & Analysis

Coding Categories	IRT Steps
Level 1	
Level 2	Step 1
Transition 2.5	Step 2
Level 3	Step 3
Level 4	Step 4

Data for participant teachers using the formative assessments and graphic reasoning tools were analyzed qualitatively. For this study, we used extreme sampling to compare a teacher who had a high effect on student learning gains and a teacher who had no effect. For each teacher, we examined teacher practice with respect to the four ways that learning progression-based instructional tools support teaching: Establishing learning goals, using formative assessments, scaffolding student reasoning, and situating science content in students' place, culture, and real world issues. Using grounded theory and constant comparative methods (Strauss & Corbin, 1990) we developed codes that characterized how teachers engaged in each of these practices. For example, codes related to teachers' learning goals identified if teacher learning goals aligned with the big ideas of the Water Systems Learning Progression and what level on the learning progression teachers' learning goal targeted. Codes for formative assessment use included codes for the match between the use of the formative assessment and teachers' learning goals,

TEACHER USES OF REASONING TOOLS

purpose for use of formative assessment (e.g., to identify general class level, as a tool for piquing student interest, or as a tool for identifying misconceptions to be fixed). Codes for scaffolding student reasoning categorized how teachers used the graphic reasoning tools (e.g., open brainstorming, engaging students in arguments from evidence, worksheets). We also coded for how teachers situated examples, such as in local contexts or abstract, hypothetical contexts. For each teacher, we then wrote summary research memos that characterized each teacher's instructional practices and identified major themes in how the teachers used the learning progression and learning progression-based instructional tools.

Findings

Impact of Tools on Student Learning

Using the four learning progression levels for our coding scheme, achievement gain for students of participant teachers ($n = 250$) reflected a shift from a pre-test mean of 1.89 ($SD = 0.29$) across all clusters to a post-test mean of 2.07 ($SD = 0.34$) for an overall mean gain of 0.18 ($SD = 0.30$). Achievement gains for students of comparison teachers ($n = 213$) reflected a shift from a pre-test mean of 1.72 ($SD = 0.28$) across all clusters to a post-test mean of 1.81 ($SD = 0.26$) for a mean gain of 0.09 ($SD .023$). Overall, there was a significant difference between pre-post student change (gain) for participant vs. comparison teachers ($t(461) = 3.59, p < .01$). These results suggest that using the formative assessments and graphic reasoning tools during instruction had a positive impact on student learning, although overall growth appears small.

The Water Systems Learning Progression is built to trace learning across long periods of time spanning six to eight years. The instructional units that most teachers taught lasted only four to six weeks in duration. In order to see the nature of the growth on student learning, we focused on the transition from level 2 to level 3. The Wright Map in Figure 1 shows an intermediate step in item difficulties between steps 1 and 3 (black triangles) that corresponds to a transition level between levels 2 and 3, coded in the data as 2.5. A response coded as a 2.5 shows indicators of both level 2 and level 3, suggesting a student in transition between levels 2 and 3. The Wright Map shows that there is not much separation between the intermediate step 2 and step 3. However, the gain in student proficiencies at the 0 logit level from pre to post for participant teachers, shown on the left side of the Wright map, lines up with these steps. This histogram shows that the percentage of students in participant teachers' classes who showed a 50% likelihood of performing near steps 2 and 3 increased 100% (from 14% of students to 30% of students). There is no corresponding gain for students in comparison teachers' classes. We claim that this situation suggests that in a short-duration unit of instruction, teacher use of the formative assessments and graphic reasoning tools supported students in making progress on the learning progression, and that this progress suggests to us that the small increase in student proficiencies on the post-test represents real and significant growth.

TEACHER USES OF REASONING TOOLS

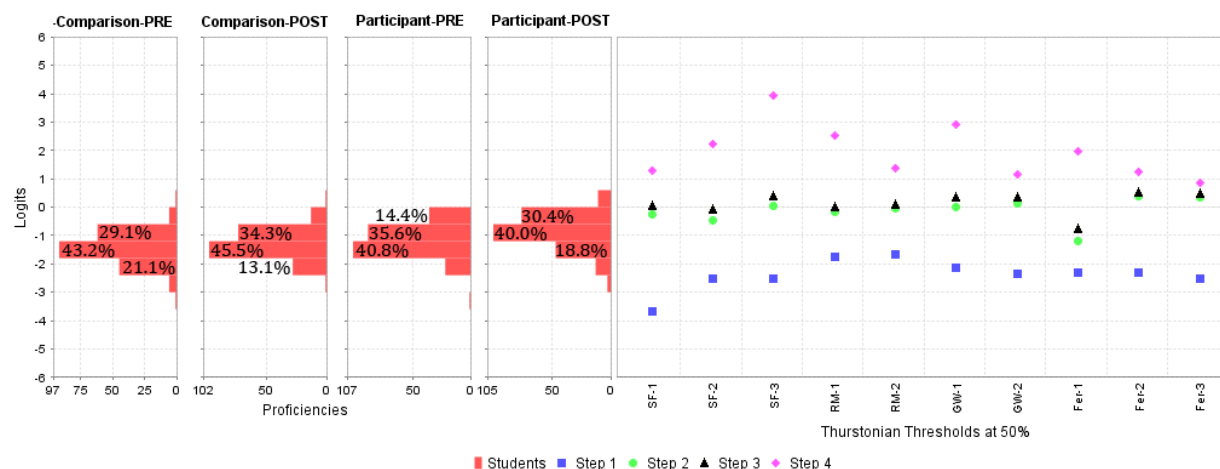


Figure 1: Wright Map showing pre- and post-assessment distributions of students from comparison and participant teachers. Item difficulties are anchored on student post-assessment responses.

Comparison of Teacher Practices

Comparison of effect sizes for pre-post changes for participant teachers is shown in Table 3. This heat map shows that there was a wide range in effect of the tools across participant teachers. Six of the nine teachers showed large to medium effect sizes, while one teacher had a small effect and two teachers showed no effects. These results suggest that there may be important differences in how teachers used the learning progression-based tools in their instruction. To explore this hypothesis, we compared how a teacher with a large effect used the graphic reasoning tools with how a teacher with no effect used the tools during instruction.

Table 3

Heat Map of Effect Size by Participant Teacher

Participant Teachers	Hedges' g	Effect Size
Lexi Masters	1.23	Large
Alana Moore	1.22	Large
Ann Elton	1.03	Large
Caryn Worth	0.85	Large
Becca Thomas	0.68	Medium
Renee Bond	0.54	Medium
Claudio Castillo	0.32	Small
Jonah Booker	0.12	None
Phillip Grant	0.03	None

Large Effect Teacher. Ann Elton taught sixth grade in a middle school in a small, northern Rocky Mountain city. She taught a 3-week unit on water that covered such topics as how people use water, the distribution of water on Earth, the water cycle, watersheds, aquifers, and wetlands. In listing her learning goals for her students, Ann stated that she wanted student to be able to explain how water moves through the water cycle, what makes a watershed, and what an aquifer is.

TEACHER USES OF REASONING TOOLS

Her wording of these statements suggests that the word “explain” was a synonym for “describe” or “tell;” she wanted students to be able to trace water through the water cycle, identify a watershed, and describe how people get water from aquifers. Many of the topics of Ann’s instructional unit aligned with the Water Systems Learning Progression and her learning goals aligned with school science narrative goals (level 3).

Ann used a variety of instructional materials to meet her instructional goals, borrowing from activities that were demonstrated in the Water Tools Professional Development as well as using activities that she had developed in previous years. She incorporated the Water Systems Formative Assessments into her instructional sequence. She used formative assessments prior to teaching related content and then used the rubrics associated with the formative assessments to interpret how her students’ ideas aligned with the learning progression. For example, in using the River Cleanup and School Map formative assessments, Ann determined that her students were at level 3. She said, “They may see the entire land piece but not see how small watersheds come together to create a larger one.” In response, she focused her instruction on “using maps to demonstrate how our local [small] watersheds create a larger one.” Ann used the formative assessments to identify a general class level (in this case, she said it was level 3) and then targeted her instruction towards that level. She specifically attended to students’ understanding of the structure of watersheds, an important element of accounts in the Water Systems Learning Progression. Her focus on the relationship of small watersheds to large watersheds aligned with level 3 school science stories about watersheds.

Ann also incorporated some of the graphic reasoning tools into her instruction. For example, one day Ann had students build a model of their local watershed using three-dimensional objects covered with a tarp. She had students identify local features on the model, such as nearby mountains and rivers. She then had students trace the water through the model watershed using the Pathways Tool. During this activity, she noted that students were tracing water in big jumps, for example, from the mountain to the ocean. She suggested to students that they use “baby steps” in following the water pathways. Ann used the Pathways Tool to make her students’ thinking visible, identify challenges her students were experiencing tracing water through systems, and responding to support her students in thinking about where water goes and where it comes from. Emphasizing the “baby steps” was an appropriate adjustment that fit her students’ level of achievement on the learning progression and supported students in putting events in order, an important feature of level 3 school science reasoning.

During the tarp watershed model activity, Ann had her students work together in small groups. Each student was assigned to complete a Pathways Tool, but she told the students they should discuss the pathways together. She encouraged students to brainstorm possible pathways that water could take as they were filling out their Pathways tools. She noted that if students disagreed with their group, they could fill out their own tool differently. She then had groups share their completed Pathways Tools with the whole class using smart board technology. Ann engaged students in a similar, brainstorming activity when she later used the Drivers and Constraints tool.

While Ann did not explicitly press students toward evaluating each other’s arguments during these activities, she did engage them in reasoning about

TEACHER USES OF REASONING TOOLS

mechanisms that drive and constrain water through systems. The modeling of the watershed and use of the graphic reasoning tools together in instruction provided opportunities for students to explore the structure of systems in depth and to begin to consider the mechanisms that move water through these systems. While the open reasoning did not align with level 4 scientific model-based explanations, the experiences in which she engaged students appropriately attended to moving students in the level 2 range toward level 3 by emphasizing the structure of connected systems and the pathways and processes of water moving among those systems.

On the Water Systems Assessment, Ann's students moved from a mean pre-test level of 1.88 to a mean post-test level of 2.11, (SD = 0.22). This gain represents a large effect on student learning (1.02). Ann's use of the Water Systems Formative Assessments and graphic reasoning tools supported her students in learning the structure of systems through which water moves and tracing water through those systems by putting steps and events in order. This instruction emphasized strong school science goals and supported students in moving toward the capacity to provide level 3 school science accounts about water.

No Effect Size Teacher. Philip Grant taught a nine-week elective science course called Environmental Engineering to eighth grade students in a large Southwest city. During the course, students learned about the water cycle and were tasked to design a city water system. In order to teach about watersheds and aquifers, Philip relied on the standard science curriculum from his school district for teaching about water, which included a large number of *Project Wet* activities (Council for Environmental Education, 1995).

Each day, Philip posted his objectives on the board for his students to see. The objectives were written in a standard format required by the school district, such as, "SWBAT [Student will be able to] recognize that population growth and change in land use can affect runoff within a watershed." This learning goal is encompassed within the scope of the Water Systems Learning Progression. It makes reference to some constraining factors that influence the volume of runoff, but does not suggest that students will learn to reason about how or why land use affects runoff. Therefore, this goal, like most of Philip's learning objectives, aligns most closely with a school science narrative goal (level 3).

Philip used many of the Water Systems Formative Assessments. He had students complete the assessment at the beginning of class and then collected them, putting them aside. He stated that he liked to use the formative assessments "as an anticipatory set piece, just to get the kids brainstorming and thinking about what's going on." He stated also that he often gave the same assessment as a pre-test and a post-test so that he and his students could see "the progression." He said, "It's exciting to see that there are kids that kind of, might have been blowing it off at the beginning, and now they're actually like, 'Oh well, I know this.'" He also stated that he used the assessments to decide if he needed to "reteach" a concept. Philip did not use the learning progression-based rubrics associated with each assessment. Instead, he said, "I kind of just came up for my kids what was the level four based on what knowledge I had given them. Because it became very evident to me that they didn't have very much background knowledge." Philip's uses of the formative assessments indicate that Philip viewed student progress on the learning progression as moving from not knowing much about water to

TEACHER USES OF REASONING TOOLS

acquiring the correct ideas. This perspective on formative assessments and the learning progression did not align with the notion of a learning progression as representing changes in sophistication of students' ideas and reasoning. Philip's use of the formative assessments suggests he was providing them as tools to pique student interest but was not focused on eliciting and responding to student thinking.

Philip also used some of the graphic reasoning tools in his instruction. Usually, he would teach a *Project Wet* activity from the required curriculum and then add in a selected tool. For example, when teaching about watersheds, he had students do an activity called "Color Me a Watershed" that required students to color code three maps showing changes in land use in a watershed across time. He then led students through calculating how much water ran off the watershed based on the land use patterns in each map. At the end of the lesson, he passed out a Drivers and Constraints Tool to the students and had them complete it individually. Philip asked students leading questions about drivers and constraints for water moving through the watershed and then told them to finish the tool for themselves. At the end of class he collected the tools and set them aside. He stated that he felt that the Drivers and Constraints Tool provided closure to his lesson. This use of the graphic reasoning tool did not align with the intended use of the tool. Rather, it functioned mostly as a worksheet that students completed in class.

Philip was required by the school district to demonstrate certain practices, which the school district called Elements of Effective Instruction (EEI) (Hunter, 1994). These elements included teaching to an objective, providing an anticipatory set to prompt student prior knowledge, monitoring student progress, and providing lesson closure. Philip viewed his use of the Water Systems Learning Progression, formative assessments, and graphic reasoning tools as aligning with these elements. He also felt that his students learned a lot during his course. However, his students showed no progress from pre- to post-assessment on the Water Systems Assessment. Philip's students' pre-tested on the Water Systems Assessment with a mean of 1.85 and post tested with the same mean ($SD = 0.26$). Although learning progressions-based instruction and EEI do not have to be mutually exclusive, Philip's use of the Water Systems Learning Progression and associated instructional tools in ways that did not align with the intent of the tools or the learning progression suggests that he was performing EEI rather than supporting student reasoning. As a result, his instruction and use of the learning progression-based tools had little effect on student learning about water.

Comparison and Contrasts between Teachers. Table 3 shows a general comparison between Ann and Philip. Both Ann and Philip enacted instruction in ways that they believed aligned with the learning progression. However, neither teacher was able to enact instruction that engaged students in level 4 model-based reasoning. Both teachers enacted a version of school science instruction. Yet, Ann's school science instruction aligned with the learning progression in more productive ways than did Philip's. Ann's instruction supported students in understanding structures of systems and putting events in order, a necessary foundation for moving to model-based reasoning about water in environmental systems. She also engaged students in open brainstorming that moved away from a focus on one right answer and may be a precursor to constructing explanations and arguments. Furthermore, Ann situated this reasoning in local contexts familiar to students. This

TEACHER USES OF REASONING TOOLS

may have allowed students to focus specifically on the characteristics of the situation rather than only on general principles. Philip's instruction, on the other hand, appeared on the surface to demonstrate elements of effective instruction but failed to attend to students' understandings. He viewed learning as a process of accumulating correct answers and used the learning progression as a measure of how much knowledge students accumulated rather than to make sense of how students were thinking about situations. While he used terms such as "drivers and constraints" associated with level 4 reasoning, he treated these terms as vocabulary and did not support students in developing conceptual understanding of these words or using these concepts to reason about particular situations. Instead, he treated the reasoning tools as worksheets that required correct answers. In addition, Philip situated his instruction in the context of hypothetical examples that had little relevance to students' lives. As a result, students were trying to apply general principles to abstract situations with little support or success. These differences in how these two teachers used the learning progression-based tools suggest that the ways the teachers used the tools are associated with the gains their students showed on the Water Systems Learning Progression Assessment.

Table 3
Comparison of Large and No Effect Size Teachers

Comparison Feature	Large Effect Size (Ann Elton)	No Effect Size (Philip Grant)
Learning Goals	Level 3 "Explain what makes a watershed"	Level 3 "SWBAT recognize that population growth affects runoff in a watershed"
Curriculum Materials	Activities from workshop	<i>Project Wet</i> activities
Formative Assessments	Identify class level on LP Target instruction	"Anticipatory set" to hook student interest & activate prior knowledge
Graphic reasoning tools	Open brainstorming; beginning press for explanation	Worksheets; Level 4 language but no support for reasoning; no press for explanation
Situation in Local Places	Situated activities in local watershed	Generic, abstract, or hypothetical watersheds
Use of LP	Identify student level and target instruction	Grade students
Alignment of instruction	School Science Stories (level 3) on the way to beginning MBR (level 4)	Not aligned (unproductive school science)

TEACHER USES OF REASONING TOOLS

Discussion

Based on the findings from this study, learning progression-based instructional resources such as formative assessments and graphic reasoning tools have the potential to support student learning. However, the tools themselves are not sufficient to support students in reaching model-based reasoning. The findings from this study suggest that teachers' attention to student thinking, goals for science teaching, and conceptions about how student learn science may play a role in how teachers use learning progression-based instructional resources. Others have noted the ways that teachers' orientations to teaching shape how teachers view students and learning (Furtak, 2012; Park & Chen, 2012). This study suggests that how teachers view students and learning may influence how they use learning progression-based tools. Productive use of the tools requires attention to student thinking and not just performance of expected elements of instruction.

The findings also points out the strong influence of school science reasoning (level 3) on classrooms and teaching. A focus of instruction on putting events in order, naming processes, and using correct vocabulary is the norm for classroom teaching. Engaging students in arguments from evidence and pressing students for explanations is the exception (Berland & McNeill, 2010; Windschitl, Thompson, Braaten, & Stroupe, 2012). This strong focus on teaching to level 3 may influence how teachers use learning progressions and learning progression-based instructional resources in their teaching. Learning progression-based formative assessments and graphic reasoning tools will not support students in reaching level 4 model-based reasoning if classroom instruction stays aligned with level 3 school science stories. We do not want to imply, however, that the burden of shifting instruction in schools to engage students in scientific model-based reasoning practices is the responsibility of teachers alone. At the same time, just having learning progression-based tools will likely not shift instruction either. Likely the entire instructional context in which teachers, students, and schools are situated will likely need to shift towards valuing and promoting model-based reasoning. Learning progressions may be a catalyst in this effort, but will likely not be the mechanism that makes the shift happen.

Nevertheless, this study does offer a glimpse of a productive way forward. There may be more and less productive school science teaching. Practices such as the open brainstorming that Ann Elton used may be precursors for both teachers and students in developing more model-based ways of thinking and teaching about phenomena. Ann Elton's practices engaging students in brainstorming may be associated with her students stronger learning gains on the Water Systems Assessment. Furthermore, moving students from level 2 to level 4 reasoning may require an intermediate focus on order of events and naming of processes. What becomes problematic is instruction that stops at this level and does not move on to level 4 reasoning. In this study, Ann's instruction showed indications that she could develop instruction that scaffolds students in level 4 model-based reasoning. Philip, on the other hand, did not use teaching practices that would take advantage of the scaffolding potential of the formative assessments or the reasoning tools.

Finally, this study shows the importance of good curriculum materials. Curriculum materials that do not engage students in scientific practices, that include situations distant and abstract to students, and that have learning goals that do not align with the learning progression-supported learning goals may not

TEACHER USES OF REASONING TOOLS

support teachers in integrating learning progression-based formative assessments and reasoning tools into instruction. Furthermore, while the Water Systems formative assessments and graphic reasoning tools are not tied to specific activities or curriculum materials, the findings from this project suggests that the tools may not be easily integrated into all curricula or used with all activities. Consideration must still be given to how the tools support the learning goals of the activities, if at all. Just using the tools will not produce learning gains if the tools and the activities in which they are integrated do not align with the content of the learning progression.

This study was exploratory in nature. Our findings are limited to these two teachers whose differences in student performance were most extreme. Our next steps are to return to the other teachers in the participant group to examine if there are features of their teaching that align more or less with Ann and Philip's instructional practices. We have data from another cohort of teachers to examine to test our hypotheses about the alignment of teacher instructional practices with student learning gains. As some of these teachers participated in our project across two years, we will also be able to notice changes in teachers' learning progression-associated practices over time and whether these changes aligned with differences in student learning or not. The findings of this study are intriguing and we hope to further identify relationships between teacher instructional practices and productive uses of learning progression-based instructional resources for supporting student learning.

References

- Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS. (2013). Next Generation Science Standards. from www.nextgenscience.org
- Alonzo, A. C. (2011). Learning progressions that support formative assessment practices. *Measurement: Interdisciplinary Research & Perspective*, 9(2-3), 124-129. doi: 10.1080/15366367.2011.599629
- Alonzo, A. C., & Gotwals, A. W. (Eds.). (2012). *Learning Progressions in Science: Current Challenges and Future Directions*. Rotterdam, Netherlands: Sense Publishers.
- Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, 94(5), 765-793.
- Black, P., Wilson, M., & Yao, S.-Y. (2011). Road maps for learning: A guide to the navigation of learning progressions. *Measurement: Interdisciplinary Research & Perspective*, 9(2-3), 71-123.
- 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
- 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
- Corcoran, T. B., Mosher, F. A., & Rogat, A. (2009). Learning progressions in science: An evidence-based approach to reform. New York: Center on

TEACHER USES OF REASONING TOOLS

- Continuous Instructional Improvement, Teachers College, Columbia University.
- Council for Environmental Education. (1995). *Project WET Curriculum and Activity Guide*. Bozeman, MT: Project WET International Foundation.
- Covitt, B. A., Gunckel, K. L., & Anderson, C. W. (2012). *Using a water systems learning progression to design formative assessments and tools for reasoning*. Paper presented at the National Association of Research in Science Teaching, Indianapolis, IN.
- 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.
- Duschl, R., Maeng, S., & Sezen, A. (2011). Learning progressions and teaching sequences: a review and analysis. *Studies in Science Education, 47*(2), 123-182. doi: 10.1080/03057267.2011.604476
- Furtak, E. M. (2012). Linking a learning progression for natural selection to teachers' enactment of formative assessment. *Journal of Research in Science Teaching, 49*(9), 1181-1210. doi: 10.1002/tea.21054
- Furtak, E. M., & Heredia, S. C. (2013). *Exploring the influence of learning progressions on unit scope and sequence*. Paper presented at the American Educational Research Association, San Francisco, CA.
- Furtak, E. M., Thompson, J., Braaten, M., & Windschitl, M. (2012). Learning progressions to support ambitious teaching practices. In A. C. Alonzo & A. W. Gotwals (Eds.), *Learning Progressions in Science: Current Challenges and Future Directions* (pp. 405-433). Rotterdam, Netherlands: Sense Publishers.
- Gunckel, K. L., Covitt, B. A., Salinas, I., & Anderson, C. W. (2012). A learning progression for water in socio-ecological systems. *Journal of Research in Science Teaching, 49*(7), 843-868. doi: 10.1002/tea.21024
- Gunckel, K. L., Mohan, L., Covitt, B. A., & Anderson, C. W. (2012). Addressing challenges in developing learning progressions for environmental science literacy. In A. Alonzo & A. W. Gotwals (Eds.), *Learning progressions in science* (pp. 39-76). Rotterdam, The Netherlands: Sense Publishers.
- Heritage, M. (2008). *Learning progressions: Supporting instruction and formative assessments*. Paper presented at the Formative Assessment for Teachers and Students Collaborative on Assessment for State Standards of the Council of Chief State School Officers.
- Hunter, M. (1994). *Enhancing Teaching*. New York: Macmillan College Publishing Company.
- 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., Gunckel, K. L., & Tschillard, R. (2013). *Learning progression-based teaching strategies for environmental science: Alignment of instructional goals with student outcomes*. Paper presented at the Learning Community Network, Washington, D.C.
- 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.

TEACHER USES OF REASONING TOOLS

- National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D. C.: National Academies Press.
- Park, S., & Chen, Y.-C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Teaching*, 49(7), 922-941. doi: 10.1002/tea.21022
- Pinker, S. (2007). *The stuff of thought: Language as a window into human nature*. Penguin.
- Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., . . . Krajcik, J. (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.
- Strauss, A., & Corbin, J. M. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*: Sage Publications, Inc.
- Wilson, M. (2005). *Constructing measures. An item response modeling approach*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education*, 96(5), 878-903. doi: 10.1002/sce.21027