Teachers' Use of Learning Progression-Based Formative Assessment in Water Instruction

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Abstract

In this paper, we draw on case studies of two teachers participating in an NSF-supported environmental science learning progression-based professional development project and implementing learning progression-based teaching experiments in their classrooms. The teachers both used instructional materials from a teaching experiment developed by the project. The materials addressed water movement through environmental systems and integrated learning progression-based lessons and formative assessments. We also report findings from a larger group of project teachers who completed learning progression-based science content and pedagogical content knowledge assessments. We examined how the teachers: 1) understood and used a water systems learning progression in their instruction, 2) described the purpose of formative assessment, 3) elicited and interpreted their students ideas with respect to a water systems learning progression framework, and 4) responded to their students' ideas with instruction. Findings suggest that for many teachers, their knowledge and practices are consistent with instruction likely to support students in developing descriptive rather than model-based understanding of water systems. Further work with

teachers will lead to better understanding of how professional development programs can build on the strengths that teachers already have, and help teachers adopt more challenging learning progression-aligned knowledge and practices that will support students in developing the model-based reasoning reflected in the NGSS and needed for use of science to inform real world decision-making.

Presented at the annual meeting of NARST, March 2014, Pittsburgh, PA

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.

Introduction

In the past decade, learning progressions have become increasingly prominent in science education. Education scholars in disciplines spanning from astronomy and physics to environmental science and biology have developed learning progressions that describe trajectories of students' ideas and pathways for learning (Alonzo & Steedle, 2009; Berland & McNeil, 2010; Gunckel, et al., 2012a; Gunckel, et al., 2012b; Jin & Anderson, 2012; Mohan et al., 2009; Plummer & Krajcik, 2010; Schwarz et al., 2009). Now that many learning progressions have been developed, some attention is shifting to the question of how they can be used by teachers to support effective science instruction in the classroom (Duschl et al., 2011). One instructional practice that may be particularly suited to learning progression-based teaching is formative assessment. This practice involves teachers using learning progression (LP) frameworks to support elicitation and interpretation of, as well as instructional responses to, students' ideas.

Early work addressing how teachers can use LP-based formative assessment in their classrooms has shown both promise and challenge (Furtak, 2012; Gunckel, 2013; Kim et al., 2013). While examples of productive use of learning progression-based instruction have been documented in the classroom and, in a few cases, even connected to student learning gains, these same studies have also found several prominent challenges. Impediments to effective and widespread use of learning progression-based formative assessments in K-12 classrooms may stem from 1) the availability of few LP-based instructional materials that are conceptually accessible to teachers (i.e., moderately easy to use in appropriate ways), and 2) the fact that many teachers have not yet attained the requisite suite of knowledge and practices required for productive utilization of learning progressions and learning progression-based formative assessment in instruction.

In this study, we draw on case studies of two teachers participating in an NSF-supported environmental science learning progression-based professional development project and implementing LP-based teaching experiments in their classrooms. The teachers both used instructional materials from a teaching experiment developed by the project. The materials addressed water movement through environmental systems and included learning progression-based lessons and formative assessments. We also report findings from a larger group of teachers in the project who completed written learning progression-based science content and pedagogical content knowledge assessments. This larger group of teachers provides an opportunity to contextualize the knowledge and practices demonstrated by the two case study teachers within a larger sample of middle and high school teachers from four sites distributed across the United States.

The two case studies provide a context for exploring the current early state of learning progression-based science instruction in middle and high school classrooms. The case research questions focused on the interplay between teaching materials and teacher knowledge and practice. In particular, we examined how the teachers: 1) understood and used a water systems learning progression in their instruction, 2) described the purpose of formative assessment, 3) elicited and interpreted their students' ideas (with respect to the water systems LP framework), and 4) responded to their students' ideas with instruction.

Drawing on the cases, we examined how the teachers' ideas and practices are similar to and different from targeted knowledge and practices we envisioned as we developed the LP framework and associated instructional materials. These similarities and differences provide insights into aspects of knowledge and practice that may be particularly challenging for teachers, and also particularly important for efforts to help teachers make effective use of learning progressions in science instruction. Understanding how early adopter teachers use learning progression-based instructional materials in their classrooms will be useful for both refining learning progression-based instructional materials to make them more accessible to teachers, and for designing professional development that addresses the challenges teachers encounter as they begin to integrate learning progressions into their instructional knowledge and practice.

Background

Learning Progressions for Environmental Science Instruction

Learning progressions are descriptions of increasingly sophisticated ways of reasoning about a topic that students may build over extended periods of time (NRC, 2007). Over the past eight years, the authors have collaborated on development of a learning progression describing a span of students' less to more sophisticated ideas about how water moves through connected environmental systems (Gunckel, et al., 2012a). Concurrently, we have worked with colleagues who have been simultaneously developing related learning progressions addressing carbon cycling and biodiversity (Hartley et al., 2011; Mohan, Chen & Anderson, 2009). All three environmental science learning progressions share an overarching conceptual framework wherein progress along a learning progression reflects shifts in discourse and reasoning from informal, force-dynamic reasoning toward scientific model-based reasoning.

We have found that consistently, across the topics we have studied, many middle and high school students respond to questions about environmental systems and processes by providing force-dynamic responses. Informal force-dynamic accounts frame events as stories about actors trying to achieve purposes with the help of enablers, and while facing hindrances from countervailing actions of antagonists (Pinker, 2007; Talmy, 1988). For example, a student might say that a tree's purpose is to grow, which is helped by water and sunlight and hindered by loggers. Through instruction and across grades, relatively few students transition to the more sophisticated practice of accounting for phenomena by drawing on scientific model-based reasoning. In scientific model-based accounts, events and phenomena are constrained and governed by underlying scientific principles such as conservation of matter and energy. Mechanisms and causes are integrated into scientific model-based accounts, and reasoning about events and processes connects what's happening across scales from atomic-molecular to large scale, as appropriate. Individuals who have access to scientific model-based reasoning can use it not only to describe events and phenomena, but also to explain how and why systems and processes work, and to make predictions about future events based on their deep, connected and flexible knowledge.

In between informal force-dynamic reasoning and scientific model-based reasoning, we have found that some middle and high school students achieve a type of intermediate reasoning that is neither force-dynamic nor model-based in nature. We call this intermediate level “phenomenological reasoning,” or, less formally, “school science stories.” Phenomenological reasoning involves describing, rather than explaining scientific events and phenomena (Braaten & Windschitl, 2011). Phenomenological descriptions often include ordered names of events and processes (e.g., “the water cycle begins with water evaporating from the surface into the air, then water condenses and forms clouds, etc.”). This type of phenomenological account is common in schools and among students because it reflects the kind of fact-focused knowledge that has traditionally been highlighted in standards documents and on standardized assessments (Britton & Schneider, 2013).

Phenomenological reasoning represents an important conceptual shift from force-dynamic reasoning; phenomenological accounts are scientific accounts rather than informal accounts. However, they differ from scientific model-based accounts in that they are descriptive rather than explanatory (Braaten & Winsdschitl, 2011). Because they are descriptive in nature, phenomenological accounts do not provide students with the conceptual resources needed to explain and predict scientific events and phenomena in flexible and real world contexts. Thus, phenomenological reasoning falls short of the type of scientific reasoning that students will need to employ in their lives to use science to inform their decisions about pressing socioscientific issues related to water resources, climate change, health, and technology.

Our environmental science learning progressions provide resources for instruction aimed at moving students toward model-based scientific reasoning. The learning progressions and associated materials include:

1. Descriptions and examples of students’ environmental science ideas spanning from force-dynamic to scientific model-based. Our learning progressions are based on grounded research conducted over the past eight years with thousands of

elementary, middle, high school and college students as well as K-12 teachers from around the United States (Doherty et al., 2013; Gunckel et al., 2012a; Mohan, Chen & Anderson, 2009). The learning progression frameworks may be used to identify common ideas students bring to science class that can be built on to help students develop more sophisticated understanding. In addition, the frameworks can be used to identify common difficulties and challenges that students encounter as they learn about environmental systems.

2. Formative assessments with associated teacher support materials designed to help teachers identify and respond to students' ideas with responsive instruction. The formative assessment materials help teachers not only with analyzing their students' ideas, but also with thinking about what specific instructional responses may be helpful for supporting student learning.
3. Learning progression-based tools for reasoning are generally content-specific instructional materials designed to engage students in discourse and sense-making reflective of or building toward scientific model-based reasoning (e.g., Berkowitz et al., 2012; Covitt et al., 2012; Mohan et al., 2009; Plummer and Krajcik, 2010; Schwarz et al., 2009; Songer et al., 2009; Stevens et al., 2010).
4. Lessons and instructional units that integrate learning progression frameworks and formative assessments to support students in transitioning toward model-based reasoning.

Through conducting professional development with teachers, and through collaborating with teachers to enact teaching experiments, we continue to build deeper understanding of students' ideas and practices, of teachers' ideas and practices, and of how professional development and classroom instruction can support both student and teacher learning.

Teachers' Knowledge and Practice Related to Science Learning and Students' Ideas

Now that learning progressions have been developed for multiple science topics, science educators are beginning to consider how they can be used by teachers to support learning in the classroom (Duschl et al., 2011). Promising directions include using learning progressions to inform classroom-based formative assessment practices (Alonzo, 2011; Black et al., 2011; Furtak et al., 2010; Shepard, 2009) and responsive instruction that builds on the ideas that students bring with them to school (Corcoran et al., 2009; Duschl and Hamilton, 2011; Duschl et al., 2011). Instructional materials and supports to help teachers engage in these LP-related practices include the types of frameworks, formative assessments, tools, lessons and units described above.

In theory, the expectation associated with learning progression-based materials is that they can be useful resources for teachers' planning, assessment and instruction. In practice, however, effective use of learning progression-based instructional materials by teachers relies on a constellation of knowledge and practice that is not yet common among K-12 teachers in the United States. A sample of the knowledge and practices associated with ambitious teaching, and we hypothesize, with effective learning progression-aligned instruction likely to support student movement toward model-based reasoning, is described below. In addition, we review research describing the current state of US teacher capacity related to these areas of knowledge and practice.

Knowledge of Science Content and Practice

Science education research indicates that teachers' deep and connected understanding of science content and practice is a prerequisite for effective instruction that supports student learning (Magnusson et al., 1992; Windschitl, 2009). Model-based reasoning is a core goal for science education in current standards documents such as the NGSS (NGSS, 2013). Model-based reasoning reflects a deep understanding of science that involves not only factual information, but also principle-based mechanistic, causal and explanatory reasoning that supports integration of science accounts across diverse phenomena, events, processes and scales. Attaining this type of understanding requires participation in scientific practices (e.g., model-building and refining, constructing scientific explanations, developing arguments based on evidence) and engagement in active sense making about science (NGSS, 2013).

Given that most of the science learning that teachers themselves experienced when they were students tended to be traditional and didactic in nature, it is perhaps not surprising that many teachers in the United States today do not demonstrate the deep knowledge of science content and practice required for teaching for model-based reasoning. Many pre and in-service teachers hold informal ideas about science content and practices similar to the ideas held by K-12 students (Salloum & BouJaoude, 2008; Stoddart et al., 1993). Even teachers who hold more accurate "factual" conceptions of science topics often demonstrate scientific knowledge that is more consistent with phenomenological rather than model-based reasoning (Gunckel et al., 2010).

Teachers who demonstrate phenomenological reasoning orientations may also be more likely to hold traditional and outmoded conceptions of scientific practices for the classroom. For example, while the academic field of science education shifted from a "one scientific method" conception of the nature of scientific practice several decades ago (Rutherford & Ahlgren, 1991), many teachers still hold onto "the scientific method" as their tool for teaching students how science is conducted (Windschitl, 2004). Other studies have shown that many teachers conceive of scientific inquiry in the classroom as a procedural endeavor that involves collecting and organizing data, but not connecting findings to underlying scientific explanations (Windschitl, 2009). In general, targets for teacher knowledge of scientific content and practice reflecting deep and interconnected understanding, scientific model-based reasoning, and conception of scientific practices consistent with NGSS are not the norm among K-12 teachers in the United States today.

The Purpose and Practice of Formative Assessment

In a recent article addressing teachers' views of student ideas, Larkin (2012, p. 955) suggests that, "…if student misconceptions are viewed as models with explanatory and predictive power themselves, teaching strategies that seek to test and revise these models may prove quite powerful." Larkin's statement provides a useful encapsulation for what a goal teacher practice for valuing and using learning progression-aligned formative assessment might look like. Larkin's view of students' ideas as "models," provides a productive connection to instruction aimed at developing model-based reasoning, and to Braaten and Windschitl's (2011, p. 666) notion of investigating science ideas as involving use of "tentative or partial explanatory models as the basis for investigation."

Following Larkin and others (Alonzo, 2011; Furtak, 2012; Smith, diSessa & Roschelle, 1993), we identify targets for teacher ideas about the purpose and practice of learning progression-aligned formative assessment as follows. Formative assessment can be used by teachers to identify students' ideas and ways of thinking (situated within a learning progression framework). Teachers can then use understanding of students in practice through designing and implementing instruction that acknowledges, responds to, and builds upon students' ideas. This responsive instructional practice may take the form of engaging students in developing and refining explanatory models of phenomena, and working toward student capacity to produce and use model-based explanations of phenomena.

For many teachers in the United States today, the capacity to use learning progression-aligned formative assessment in science instruction has not yet been attained. Studies of teachers' formative assessment practices, and of their learning progression-aligned formative assessment practices, highlight evidence of both strengths and challenges. Regarding strengths, multiple studies have found that teachers, including pre-service and in-service teachers, believe that it is important to pay attention to students' ideas (Black & Wiliam, 1998). Notwithstanding a belief in the importance of students' ideas, a national survey of science teachers found that only 1 in 6 science lessons included pre-assessments to elicit students' ideas about the topic to be studied (Weiss, Banilower, McMahon & Smith, 2001).

Another potential strength in teacher formative assessment practice is reflected in findings from some studies of teachers' use of formative assessment that have shown that many teachers are able to use formative assessment to identify the ideas that their students hold, including naïve ideas inconsistent with canonical scientific thinking (Horizon Research, 2003). Balancing this strength, however, in many cases, the pre-assessments that teachers use are not well aligned with the learning goals that teachers have identified (Weiss et al., 2003). In instances where pre-assessments do not align with learning goals, it is unlikely that teachers will be able to identify relevant ideas held by their students.

Another formative assessment practice that research suggests is quite challenging for teachers is that of responding to students' ideas in generative ways that are consistent with a social-constructivist view of science learning and that are likely to help students move toward model-based reasoning (Smith, diSessa & Roschelle, 1993). It is common, for example, for teachers to perceive of students' ideas as either missing information or as misconceptions that need to be fixed or replaced (Larkin, 2012). This view of students' ideas is consistent with a traditional, didactic, or transmissive orientation to science learning and teaching. If learning is construed as the accumulation of facts or knowledge, then teaching by extension should involve the transmission of appropriate and correct knowledge (Park & Chen, 2012).

When asked about their formative assessment practices, many teachers talk about their intent to enact instruction that fills in gaps in students' understanding; and/or instruction that squashes, eliminates or replaces students' misconceptions with correct science. As Larkin describes in his 2012 article, the prevalence of this orientation toward fixing or eliminating students' misconceptions is understandable in light of the common usage of language consistent with this approach in the science education and science teacher education literatures.

Only a few studies have specifically examined teachers' use of learning progression-based formative assessment. Furtak (2012) examined teachers' use of learning progression-based formative assessment addressing the topic of natural selection. She found that while the teachers did use the learning progression to interpret and highlight students' ideas during class discussion, the teachers were more likely to emphasize one aspect of the learning progression (related to variation) rather than another (related to survival/reproduction). Furtak also found that while a few teachers conceived of learning progression-based formative assessment as a tool for understanding students' ideas so they could respond with instructional experiences, the majority of teachers saw LP-based formative assessment as a tool to help them identify and “squash” students misconceptions. For these teachers, students’ ideas were not conceived as resources to be built upon, but rather as problems that needed to be eliminated or fixed.

Findings from our own learning progression-based professional development project are similar. Teachers who had participated in the project for at least one year completed written assessments in which they wrote learning goals related to project science content areas, analyzed example student responses to science content questions, and described instructional activities they would enact for a student who provided that content response. Overall, fewer than 50% of the teachers made use of or referenced the learning progression for writing learning goals, interpreting students’ responses to assessment questions, or planning instructional moves in response to students’ ideas (Gunckel, 2013; Moore et al., 2013). In summary, much of the available research on teachers’ science education formative assessment practices, including learning progression-based formative assessment practices, suggests that teachers may need additional professional support to develop the knowledge and practices necessary to make effective use of LPs in their instruction.

Study Context

Our two case studies provide a real world context for examining the interplay between learning progression-based instructional materials and teacher knowledge and practice in the classroom. While a suite of knowledge and practice hypothesized to support effective learning progression-aligned instruction is described above, below we set the stage for our investigation of teacher learning progression-related knowledge and practice in the context of teaching about surface water movement through environmental systems. The context of our study includes descriptions of:

1. The water systems learning progression
2. The *School Water Pathways* learning unit (teaching experiment)
3. The School Map Formative Assessment that the case study teachers used during their teaching experiments, while teaching about surface water movement, and

4. Target knowledge and practices for interpreting students' ideas about surface water movement and responding to those ideas with instruction.

Research Questions

The teacher cases that we investigated, as well as data from a larger set of project teachers, inform our findings concerning the following research questions.

1. How did the teachers understand the water systems learning progression and use it in their instruction?
2. How did the teachers describe the purpose of formative assessment?
3. How did the teachers interpret their students' ideas (with respect to a learning progression framework)?
4. How did the teachers respond to their students' ideas and ways of thinking with instruction?

Water Systems Learning Progression

Table 1 shows the general framework for the Water Systems Learning Progression. Levels 1 and 2 show characteristics of force-dynamic accounts. Level 1 accounts tend to focus on visible components of systems and human actions, structures and needs. While Level 1 accounts are common in responses provided by elementary school students, by middle school, many students provide Level 2 force-dynamic accounts. Level 2 accounts still describe events as stories about actors with purposes, but the actors in Level 2 accounts tend to be non-human entities rather than people (e.g., the sand soaks up the water, or the river travels to all connected places). Level 3 accounts provide greater detail about systems and describe components of systems that may not be visible because they are underground or too small to see with the human eye. Level 3 accounts tend to be descriptive rather than explanatory in nature. In contrast, Level 4 accounts draw on scientific principles (e.g., drivers such as gravity and constraints such as topography and permeability) to explain events and processes occurring in connected natural and human-engineered systems at scales spanning from atomic-molecular to large scale. The Water Systems Learning Progression Framework can be used to characterize and interpret students' accounts provided in response to formative assessment questions about water moving through environmental systems.

A LEARNING PROGRESSION FOR WATER

Table 2
Characteristics of accounts at each level of achievement

	Elements of Accounts				
Level of Achievement	Structures & systems	Scale	Scientific principles	Representations	Dependency & human agency
Level 4 Qualitative model-based accounts	Provide multiple, detailed, accurate pathways through environmental systems Account for chemical nature of substances during mixing and moving	Atomic-molecular through large landscape	Include driving forces (e.g., gravity, pressure) Include constraining factors (e.g., permeability, topography)	Interpret constraining factors inferred from representations	Identify limitations to human agency or dependence on environmental systems
Level 3 Incomplete school science accounts	Provide multiple pathways through hidden and invisible connections, including human-engineered systems in moderate detail Identify different types of substances in water	Microscopic to landscape scale May refer to smaller particles such as atoms or molecules	Put events in order No driving forces or constraining factors included	Connect representations to three-dimensional physical world Do not infer driving forces or constraining variables	Include human systems as part of environmental systems Do not recognize limitations of either human agency or environmental systems
Level 2 Force-dynamic accounts with mechanisms	Identify familiar and visible connections, including general connections to human systems Water quality is referred to as a function of "good" and "bad" stuff	Broader macroscopic to large-scale focus across familiar and visible dimensions	Identify mechanism Rely on actors or agents Fit particular circumstances	Include limited (e.g., 2 dimensional) connections from representations to the physical world	Portray human systems as operating separately from natural systems but human systems can be impacted by natural systems
Level 1 Force-dynamic accounts	Water is represented only in isolated, visible locations Water quality is referred to as a function of types of water	Limited to macroscopic and immediately visible structures or phenomena	Focus on human structures, actions or needs No mechanisms for phenomena included	No connections from representations to the physical world	Portray humans as sources and movers of water Portray water as serving human needs

Table 1. The Water Systems Learning Progression Framework

Methods

Study Design

This paper draws on data collected with two case study teachers participating in a learning progression-based professional development project. In addition, data collected with a larger set of project teachers is used to provide a broader context of teacher knowledge and practice within which the two case study teachers can be situated. The two teachers whose cases are explored in this paper were two of three teachers who participated in our within project study of teachers' use of formative assessment while teaching about water. The researchers approached teachers who were planning to teach the *School Water Pathways* water teaching experiment in Spring 2013, asking if they would be willing to participate in a focus study exploring their use of formative assessment while enacting the water teaching experiment with their students. Three teachers volunteered to participate and the data sources described below were collected with all three teachers. After examining the data, we found that two teachers were similar in their knowledge and practice. Thus, we decided to focus on two of the three teachers who provide a contrast in approaches to using formative assessment and learning progressions in their instruction, and for whom we had the most complete data sets.

Participants

The two case study teachers include a middle and a high school teacher, both female. We adopt pseudonyms for the teachers, using Laurie for the middle school teacher and Jen for the high school teacher. Jen teaches high school Biology and Ecology on the east coast. She has been teaching for seven years and has an undergraduate teaching degree with an environmental science minor. She had participated in other science related professional development before joining our project and, at the time of the study, had been participating in the learning progression-based professional development project for one year. Jen had also completed extensive college level course work in science, with credits in biology, chemistry, ecology, geology, physics and other topics.

Laurie teaches 8th grade Earth and Physical Science on the west coast. She has been teaching for seventeen years and has a Master's degree in elementary education with a middle school focus. At the time of the study, Laurie had been participating in the learning progression professional development project for three years. Before joining the learning progression professional development project, Laurie had participated in other professional development projects, including four years of research experience for teachers (RET) work. Like Jen, Laurie had also completed extensive college level course work in science, with course credits in biology, chemistry, physiology and other topics.

In addition to the two case studies, we also report findings from a larger set of teachers in the project who completed written assessments addressing learning progression-related science content knowledge and pedagogical content knowledge. Assessments were administered to middle and high school teachers participating in the project. The teachers are from four project sites including east coast, mid-west, mountain west and west coast locations. Teacher data is reported for 98 teachers (42 middle school) who completed the assessment in Spring 2012, and 55 teachers (28 middle school) who completed the assessment in Spring 2013. The teachers include some who had only participated in the project for one year, and some who had participated for up to three years. Teachers also varied in how many times they had taught the *School Water Pathways* teaching experiment. Some had never taught the unit, others had taught it once or several times over the previous few years.

School Water Pathways Teaching Experiment

The two case study teachers used the *School Water Pathways* learning unit with their students in Spring 2013. The unit aligns with the Water Systems Learning Progression Framework and has formative assessments and learning progression-based teacher materials integrated into lessons and activities. The unit lessons engage students in examining how much water falls on their school campus each year, and in tracing that water along pathways through and beyond their school campus. Lessons engage students in investigating the following topics: 1) Mapping surfaces on the school campus, 2) Tracing surface water runoff, 3) Tracing water that evaporates from the campus, 4) Tracing water that transpires from plants on the campus, 5) Tracing water that infiltrates into the ground, 6) Compiling results to characterize water pathways on the school campus, and 7) Comparing school water use with the amount of water that falls on campus each year.

Most of the investigation lessons begin with a short formative assessment probe that supports teachers in examining their students' ideas related to the topic to be explored. For example, the transpiration lesson investigation begins with students completing a formative assessment probe in which they choose from different explanations of where most of the water that a plant takes up goes. After students choose an option they agree with most, they provide a one or two sentence explanation describing why they chose that option. The unit teacher materials include supports intended to help the teachers interpret and respond to their students' ideas while teaching the unit lessons.

Several learning progression-based tools for reasoning are also integrated into the School Water Pathways lessons, including the Pathways Tool (Figure 1) and the Drivers and Constraints Tool (Figure 2). The Pathways Tool, which is designed to be used in conjunction with activities involving maps or models, supports students in tracing water along multiple pathways backwards and forwards from a given location. While the Pathways Tool can be used in ways that are consistent with model-based reasoning (e.g., providing students with a place along a river on a topographic map and having them reason about where the water could possibly come from and go to along surface water pathways), in many ways, the Pathways Tools is a natural fit for supporting students in engaging in Level 3 phenomenological reasoning (i.e., naming ordered pathways for water moving through connected systems). In contrast, the Drivers and Constraints Tool more directly supports students in attempting to use model-based reasoning by identifying the drivers and constraints that govern water movement along particular pathways through connected systems. This tool is intended to be used in conjunction with lessons and activities that involve modeling, mapping or diagramming (e.g., on a groundwater cross section) movement of water through systems.

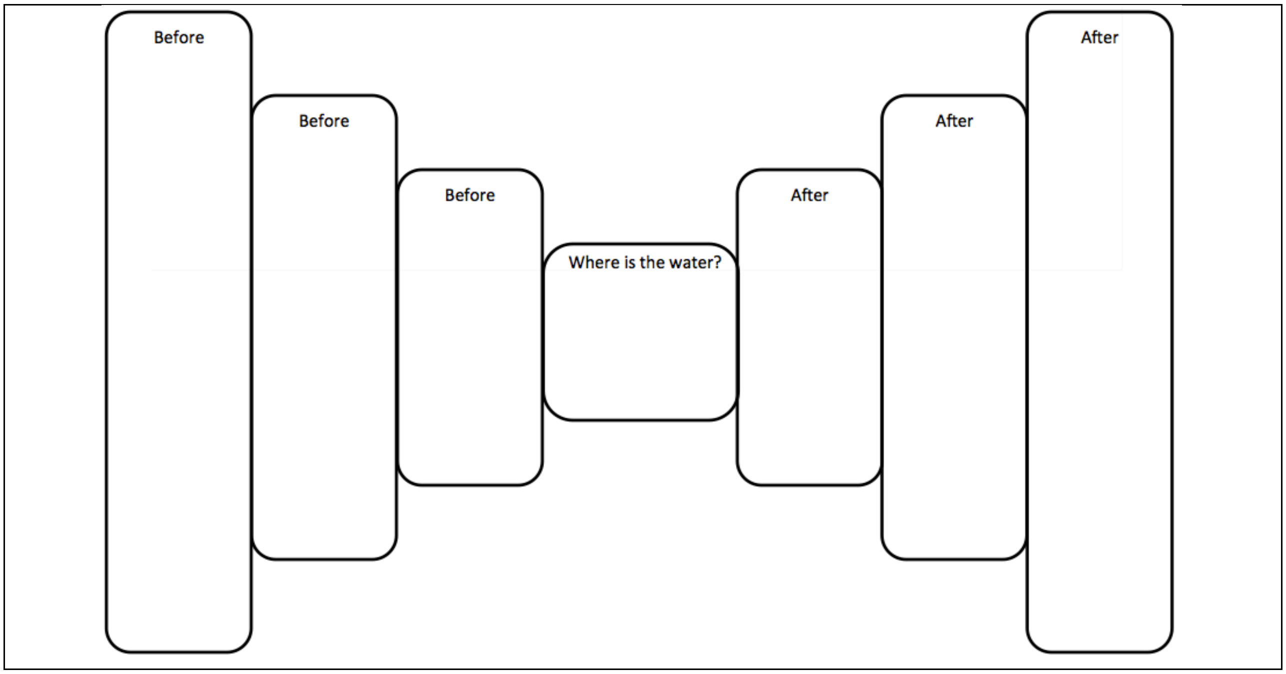


Figure 1. Pathways Tool

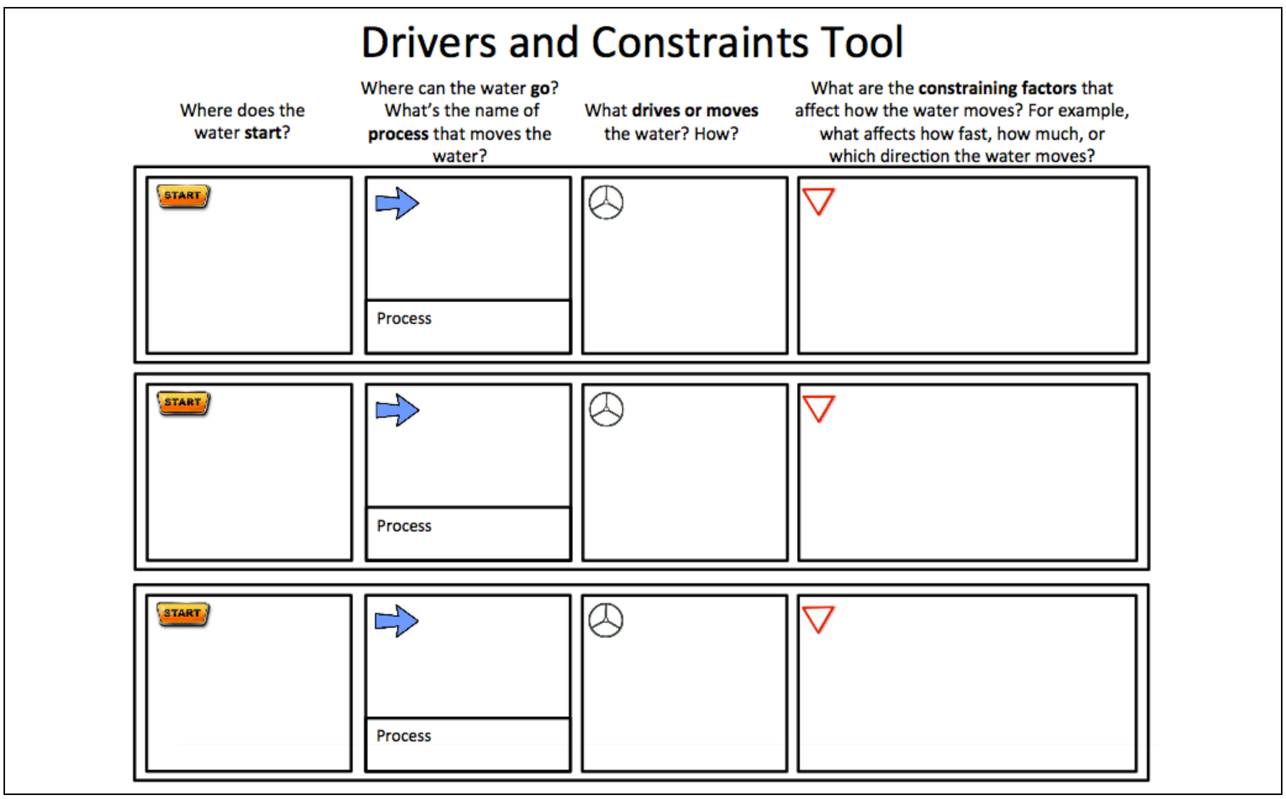


Figure 2. Drivers and Constraints Tool

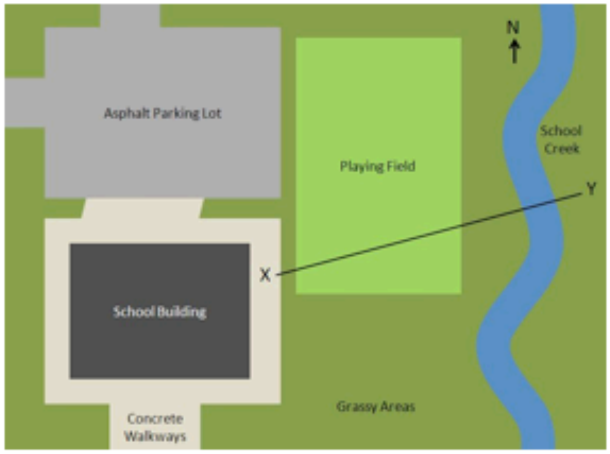
School Map Formative Assessment

The teachers participating in our focus study enacted formative assessments from the *School Water Pathways* teaching experiment while teaching the unit. In particular, we asked the teachers to focus on the use of one of the formative assessments, The School Map formative assessment (Figure 3). The School Map formative assessment is a one-page probe that students complete to demonstrate their ideas about the relationship between the shape of the land and surface water location and movement. The assessment is accompanied by teacher instructional materials including a table showing typical target (Level 4) and other level responses as well as suggestions for responsive instruction for students initially performing at different levels on the probe.

Table 2 shows characteristics of student responses representative of the levels of the learning progression. Levels 1 and 2 responses tend to describe water as an actor that has a purpose or natural tendency to move to certain areas. Level 3 responses often rely on school rules rather than principles. For example, a Level 3 response might indicate that you can't tell what direction the stream flows because streams always flow into other streams or lakes, and no other stream or lake is shown.

Note that an important distinction in the levels is that, while Level 4 scientific principles may be used for model-based reasoning and applied generally (i.e., river flow direction is always governed by elevation and gravity), Level 3 school rules are based on stories rather than principles, and may be limited in application (for example, contrary to the school rule that rivers flow into lakes, a dammed lake or a mountain lake could flow into a river).

Below is a map of a school campus.



1. If you were looking from the side instead of from above, what would the shape (height) of the land be like across the distance from Point X to Point Y? (Circle the answer you think is the best.)

A 	D 
B 	E 
C 	F There's no way to know.

Explain your reasons for your answer.

2. Circle which direction you think School Creek is flowing:

a. North b. South c. You can't tell from the map

Explain how you know.

Figure 3. School Map Formative Assessment

Level	Characteristics of Accounts
Level 4	Uses principle-based understanding of drivers (e.g., gravity) and constraints (e.g., topography) to make inferences about shape of land and direction of water flow on map.
Level 3	Uses school science stories or rules (e.g., rivers flow into lakes) rather than scientific principles to interpret map and direction of water flow.
Levels 2 & 1	Uses informal, force-dynamic interpretation of map (e.g., water always flows south (L1), water wants to flow to all connected places (L2)).

Table 2. LP Levels for Tracing Movement of Surface Water Using 2-Dimensional Maps

Teachers' enactment of the School Map formative assessment within their teaching experiments, including their interpretation of students' answers to the probe, and their instructional response based on reviewing students' answers, provided a focal context for the cases.

Targeted Practice

While generalized learning progression knowledge and practice targets are described in the background section, below we briefly describe several specific practice targets for teachers enacting the *School Water Pathways* teaching experiment and using the School Map formative assessment.

Understanding of the Water Systems Learning Progression

Targeted teacher knowledge and practice related to the Water Systems Learning Progression relates to both science content and practice as well as to a view of how the learning progression can be used to support instruction. Teachers who have attained target knowledge and practice demonstrate Level 4 understanding in their own responses to learning progression-based science content assessments. In various contexts (e.g., classroom discussions, interviews, lesson plans), their talk and writing is generally scientific model and principle-based and is accurate and appropriate for the given context.

With regard to use of a learning progression for instruction, the target goal for teacher knowledge and practice is that teachers are sufficiently familiar with the levels of the Water Systems learning progression such that they can use it as a tool for enacting responsive instruction that builds on the particular reasoning strengths and challenges demonstrated by their own students. While teachers often describe learning progressions as tools that can be used for this purpose in general, fewer teachers, in talk and practice, integrate reference to specific ideas from the learning progression into their instruction.

Interpreting Students' Ideas

Targeted teacher practice for using the School Map formative assessment includes being able to situate students' responses within the learning progression framework and being able to identify strengths and conceptual challenges in students' responses. Thus, teachers should recognize that students providing Level 2 responses demonstrate understanding that the map represents a landscape, but that these students had trouble connecting the two-dimensional map representation to a three-dimensional conceptualization of land and water within the landscape. For Level 3 responses, teachers should recognize that students are making (or trying to make) inferences about the shape of the land using the map, but that students are generally not governing their inferences with use of scientific principles (i.e., gravity as a driving force and topography as a constraining factor).

Responding to Students' Ideas with Instruction

Responding to students' ideas with appropriate instruction involves building on the ideas students already have and addressing the particular challenges they evince in their assessment responses. Administering assessments to students across our project over multiple years has shown that most students perform around Level 2 on initial assessments. A moderate portion of students, particularly high school students, may provide Level 3 responses on formative assessments. Given that most students are likely to perform at Level 2 on the School Map formative assessment, targeted instructional response by teachers should generally involve building on students' understanding that the map is a representation of a landscape and providing first-hand experiences that help students connect two-dimensional map representations with three-dimensional (either real world or model) landscapes. Also, in efforts to help students transition toward model based-reasoning, instruction should scaffold students in the use of drivers (gravity) and constraints (topography and elevation) to explain water movement in landscapes and on maps.

Data Sources

Data sources for the case studies and for the larger teacher data set are described below.

Case Studies

Data sources for the case studies included:

1. Pre instruction teacher interviews. Structured pre-instruction interviews with the case study teachers provided information concerning teachers' past use of formative assessment (both within and outside of our project), ideas about the purpose of formative assessment, and intended practices for use of formative assessment in their upcoming teaching experiment enactment.
2. Lesson observations with observation protocols and video. The lesson observations and associated protocols and video provide evidence concerning how the teachers enact the *School Water Pathways* teaching experiment including the School Map formative assessment and subsequent instruction with their students.
3. Teacher written assessments addressing science content and pedagogical content knowledge (PCK, see section below).
4. Completed (and sometimes scored by teachers) School Map formative assessments from the teachers' students.
5. Teacher post-instruction interviews. Post interviews provided information concerning teachers' enactment of the teaching experiment including their use of formative assessment in instruction, what they learned about their students and instruction from the unit and from formative assessment enactment, their changing ideas about

formative assessment use, and their ideas about the benefits of using formative assessment in instruction.

Water Teacher Pedagogical Content Knowledge and Science Content Knowledge Data

The data source for the larger set of contextualizing evidence for teacher knowledge and practice came from a written assessment administered to project teachers in Spring 2012 and Spring 2013. The Water Systems Learning Progression written assessment for teachers included some items that were the same as science content items that project students answered on pre and post-tests around their teachers' water instruction. In addition, the teacher assessments included pedagogical content knowledge items asking teachers to:

1. Describe water systems learning goals for their students
2. Interpret example student responses to science content items
3. Describe instructional responses they would use for a student who provided the example response.

Data Analysis

Grounded theory and constant comparative methods (Strauss and Corbin, 1998) were used to develop and code text and responses in the context of themes related to the case research questions. Themes were developed through a combination of inductive process through cycles of text analyses of collected data as well as through reference to themes that have emerged through previous and ongoing project research efforts. Examples of themes related to the research question "How do teachers respond to students' ideas with instruction?" included, "What reasons does teacher give for instructional choices?" and "How does teacher use knowledge of student ideas in planning?" Multiple coders reviewed and discussed themes and codes in repeated research sessions, developing consensus around interpretations of teacher talk and writing.

Coding of science content data followed data analysis methods previously developed during construction and validation of the water systems learning progression

(Gunckel, et al., 2012a). Coding of PCK data followed a similar process of inductive analysis aimed at identifying themes and categories of teacher pedagogical knowledge and practice. Three researchers engaged in iterative cycles of coding, comparing, and refining coding exemplars and data analysis. All PCK codes reflect consensus among the researchers for each individual teacher response.

Analysis and Findings

Case Studies

Results related to the case research questions are presented for each of the two teachers and then for the larger set of project teachers who completed the learning progression-based written assessment.

Jen

Jen's Understanding of the Water Systems Learning Progression

Sources including a written response to an assessment item and discourse from pre and post interviews are drawn on to characterize Jen's understanding of the Water Systems Learning Progression. Jen's response to the River Map question (Figure 4), which is an item on both student and teacher written assessments, provides some insight into how Jen thinks about water movement through environmental systems.

Jen's response is characteristic of a Level 3 descriptive response. The description is correct, but the explanation does not rely on principles (i.e., gravity and topography) to answer the "why" part of the question. "Upstream" and "downstream" might be implicit shorthand for elevation, but the principles in the explanation are not explicit, and clinical interviews with students and teachers have shown that the terms upstream and downstream are often used in ways that are conceptually disconnected from topography. The response suggests that Jen is reasoning at least at Level 3. While it's likely that she could have access to Level 4 model-based reasoning, evidence for Level 4 reasoning is not present in her answer.

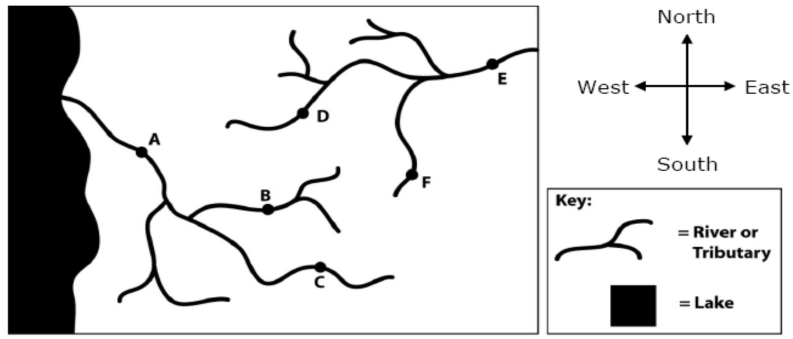
Can pollution in the river water at Town B get to Town C? Explain why or why not.	
Jen's response: No. Pollution in river water at B cannot get to C because B intersects the other river downstream from C. Water would not flow upstream; therefore, the pollution from B would not reach C.	

Figure 4. River Map Question and Jen's response.

Evidence concerning Jen's ideas about water systems, and how those translate into her instruction is also provided in the video of the lesson in which the School Map formative assessment was discussed, and in her post-teaching interview. In class, Jen led a discussion with her students after they had completed the School Map formative assessment. Some of Jen's students are convinced that F (there's no way to know) is the best answer to the formative assessment probe. Jen tries to reason with them about what the land will look like. During the discussion, Jen says:

> You have that stream bank, so if you took the water out… if you're taking the water out and you're looking at the side view. So there's a creek bed there. If you took the water out it would be below the banks, correct? Do you understand what I'm saying? If you have a river and you took all the water out of the river is the land going to be straight flat across?

After a student answers "no," Jen continues, "No, there's going to be a dip, right? Because there's water there."

Jen is reasoning about the shape of the land and the location of water with her students (suggesting that Jen has access to Level 4 model-based reasoning). She does not explicitly discuss gravity while talking with the class about the probe, perhaps assuming that students have implicit understanding that water will reside in lower places. This seems likely given the quick treatment Jen gave to gravity during a PowerPoint presentation that preceded this discussion during the lesson. As she showed slides and presented various terms, Jen stated, “A couple of different vocab words for you to know. I think you know what gravity is, so we’re good.” After this statement, Jen moved on to a definition of watersheds. Overall, Jen’s talk suggests that she can probably access Level 4 model-based reasoning related to the School Map formative assessment, but that in her internal and classroom discourse Jen is not committed to emphasizing models (i.e., reasoning about systems through reference to drivers and constraints).

Evidence of Jen’s ideas about learning progressions and their usefulness for instruction is demonstrated in talk from her pre-instruction interview. When asked about her ideas concerning the purpose of formative assessments, Jen responded by discussing learning progressions:

Jen: Definitely it was the learning progressions trying to see where students are and how to push them up has definitely helped. I really wasn’t aware of flowing progression stuff before doing this workshop. I probably could have said that student is on a different level than that student but not really known what the progressions were or how to – where to place them, I guess. So it helps in doing that.

Interviewer: And so that’s kind of what you’re seeing the purpose of these are is just to figure out where they are… in that learning progression…

Jen: And what things I either pull in that maybe I would have skipped over before because I wasn’t aware that they didn’t know it, or focusing more on, or taking a little time to describe something instead of just glazing over it.

In this exchange, we see that Jen views a learning progression as a tool to help her identify where students are and to consider what her instructional response should be. In language such as “skipped over” and “taking a little time to describe something” we see that Jen has an orientation to instruction that, at least in part, reflects coverage of materials and transmission of information to students.

We also see a suggestion that Jen is more comfortable with viewing and using learning progressions as tools for teaching for phenomenological (Level 3) understanding in her pre-interview talk about the reasoning tools. When asked if she was planning to use the tools for reasoning in her instruction, Jen stated, "I like the Pathways Tool better than the Drivers & Constraints Tool. I think the Drivers & Constraints Tool is a little bit confusing." The Pathways Tool can most readily be used to support Level 3 reasoning, whereas the Drivers & Constraint Tool is designed to more directly scaffold students in constructing model-based accounts that address the how and why parts of explanations for water movement.

During the post-instruction interview, Jen reasserts similar ideas concerning the purpose of learning progressions. She states, "I think overall it [the learning progression] definitely opened my eyes to looking to see where students started from and then raising them to a level – it might not be a four, but just raising them a level somehow and getting them to be a deeper thinker I think is what it's about." Jen's view of learning progressions does characterize them as tools for helping students move toward more sophisticated understanding, but her notion of how that learning occurs focuses on transmissive rather than constructivist learning experiences, and her goal for student understanding may be phenomenological rather than model-based reasoning.

Jen's View of the Purpose of Formative Assessment

Both before and after enacting the School Water Pathways teaching experiment, Jen demonstrates a view of the purpose of formative assessment as a tool for helping her find out what her students know and do not know so that she can respond by not spending time on concepts students already know and by focusing on instruction that covers ideas that students are missing or "not getting." Jen's following statements about her use of formative assessment suggest this orientation.

> (Pre-interview) I do a drill at the beginning of class. I'll put something on the board that is either an introduction to a topic we're going to discuss or

> is something we did the previous class to jog their memory… Right now we're looking at Cnidarians… so I just put on the board, "list four characteristics of Cnidarians." We had already talked about two classes of them, so just general characteristics… Of course you can look at a page and write down what you have but actually thinking and giving your own terms, that kind of stuff.
>
> (Post-interview) Before I just kind of thought of it as an intro activity and didn't see the use of it in the rest of the lesson. But now I see it more as a planning tool to see where most of my students are starting out. What can I assume they do know? … And then I constructed a lesson around what concepts that they're lacking, I guess, or what misunderstandings they have. So I think it helps to keep me from wasting time with stuff I don't need to really go over and really putting the focus on what they're not getting."

For the most part, Jen's language suggests a view of formative assessment as a tool to identify what's missing or wrong in students' ideas so that the correct information can be provided. There is a tension associated with the beginnings of a more social-constructivist view of using formative assessment to support student learning involving reasoning rather than just acquisition of ideas. This is evident in Jen's language about students "actually thinking" in the pre-interview excerpt above and, in the previous section, in Jen's discussion of "getting them [students] to be a deeper thinker." Jen's language suggests initial and somewhat general ideas about establishing ambitious goals for student learning and reasoning; those more ambitious goals are not explicitly described as representing model-based reasoning though.

Jen's Interpretation of Student Ideas

Because Jen had taught the *School Water Pathways* teaching experiment and used the School Map formative assessment previously, we are able to examine both pre and post-instruction interview dialogue reflecting how Jen is interpreting and making sense of her students' responses. Dialogue excerpts from both interviews are provided below:

> (Pre-interview) Some of them were able to use kind of common sense and figure out the answer before we even talked about stuff, so that was pretty good. Some of them did assume water was flowing north to south regardless of what was going on around the water or the schoolyard. Some gave answers that were completely off the wall… More of them answered with a solid answer than I thought would so I was actually surprised at their results, how good they were.
>
> (Post-interview) I definitely think translating a 2-D image and trying to see it as a cross section was difficult for some of them. A lot of them, like I said, assume that water flows north to south or they thought the arrow indicating "N" indicated that the stream flowed toward the north instead of just using that as a general direction thing, as a compass.

Across these two interviews, we see subtle changes in how Jen analyzes her students' responses. In the pre-interview dialogue, Jen provides mostly general statements approximating how right or wrong students' responses were (e.g., "completely off the wall" versus "solid answer"). In the post-interview, Jen's talk focuses more on students' particular ideas and conceptual challenges. For example, she discusses the challenge students encounter in making inferences from a two-dimensional image, their ideas about direction of water flow from north to south, and their use of the compass rose on the map. By the time of the post-instruction interview, Jen's interpretation of her students' ideas recognizes some specific characteristics of how students are reasoning about the School Map formative assessment. However, she does not connect her students' responses to specific Water Systems learning progression levels of achievement. Her growing perspicuity about student reasoning, which still falls short of explicit reference to the learning progression, suggests that developing facility with learning progression-based formative assessment is likely a practice that develops slowly over time and with experience.

Jen's Instructional Response

The instructional move that Jen enacted after administering the School Map formative assessment was to show a PowerPoint presentation and lead a discussion emphasizing vocabulary related to maps and water flow. Beginning the presentation to students, Jen told them:

> Ok. Open your notebooks and turn to your notes section. I'm going to show you a quick PowerPoint. Rather than having a separate vocab list, we're just going to hit the vocab as we go through. Most of the stuff is probably words you guys have seen before, but it's going to give it a definition.

In the post-interview, Jen discussed this instructional move, stating, "I looked at kind of trying to erase some of their preconceived notions that were not correct like water flows from north to south." This response is consistent with a phenomenological instructional orientation. The emphasis is placed on vocabulary as facts to be learned. Little focus is placed on scientific principles to be used as reasoning tools. When drivers and constraints were addressed in the PowerPoint presentation, the teacher presented them as facts to be written down rather than as tools to be used to support model-based reasoning.

Even though Jen was aware that her students had difficulty making inferences about three-dimensional land shapes from two-dimensional images, she chose to present a two-dimensional, informational slide show as the follow-up instructional move after students completed the School Map formative assessment. Overall, we see that for the most part, Jen demonstrates understanding of science content, ideas about science teaching and learning, and instructional choices that are consistent with teaching and learning likely to result in students developing Level 3 phenomenological reasoning about water systems.

Laurie

Laurie's Understanding of the Water Systems Learning Progression

Laurie's response to the River Map question provides insight into her reasoning about water systems. She answered, "No. Water flows from high point to low point. The lake is the lowest point so the water will flow from B towards A towards the lake. Any water underground will flow away from point C because point C is higher than point B." We see that Laurie uses the constraining factor of topography to explicitly govern reasoning about the direction of water flow. One of her inferences about topography does go beyond what can be determined from the map however. There is not enough information on the map to conclude that point C is higher than point B. Overall, however, Laurie's response demonstrates that she uses model-based reasoning (i.e., with explicit reference to constraining principles) to provide an account of direction of water flow based on the map.

In the post-instruction interview, Laurie's talk about using learning progressions in instruction demonstrates a sophisticated perspective. She states,

> Learning progression-based teaching is very similar to teaching from a child development perspective. I see this as a way to really monitor what children at specific developmental stages are thinking and how they are reasoning. For example, the ability to spatially identify things in your surroundings, it appears that this is a developmental task and that many students have not developed this ability. Is it developmental or just unlearned ability? I like the way the unit allows me, as a teacher, to become more of a researcher of child development instead of just an instructor trying to pass on concrete information. Being the researcher while teaching really allows me to not only teach specific content but deliver instruction that will scaffold the child's current knowledge to more difficult concepts and move the student more effectively on the learning progression line.

Laurie's description of the use of learning progressions for her instruction demonstrates sophistication in several areas. For example, she situates her ideas within specific aspects of reasoning (e.g., spatial reasoning) relevant to the water systems learning progression. She characterizes learning as conceptual development, rather than acquisition of "concrete information." Laurie also characterizes teaching as a profession requiring the skills of a researcher who uses instructional tools such as learning progressions to scaffold students in developing the ability to reason about increasingly challenging concepts. Laurie's talk reflects a developmental and constructivist, rather than a transmissive and acquisitive, view of learning.

Laurie's View of the Purpose of Formative Assessment

Laurie's focus on learning as changes in reasoning, rather than changes in factual knowledge, is also reflected in her talk about the purpose of formative assessment. When asked to discuss her use of formative assessment during the post-interview, Laurie offered the following thoughts:

> In the past I have performed formative assessments in the form of KWL charts; open-ended questions to which students write a response, share with their partner, then share out loud and in informal class discussions. So this form of formative assessment was different in that it is more concrete. It gets at the students' reasoning level and provides better insight as to how to direct my teaching. Being able to align a learning progression score to the students' answers is beneficial in being able to target specific reasoning skills in specific students.
>
> And,
>
> I am beginning to really look at and analyze where the misconceptions are in student thinking and reasoning. This is helping to guide my instruction… I am now thinking of it more in terms of the learning progression and not just getting the students to regurgitate concrete facts of knowledge gained.

While Laurie does mention misconceptions in her talk about formative assessment practices, she does not characterize students' misconceptions as ideas that need to be fixed or eliminated. Rather, she conceives of misconceptions within the context of using the learning progression as a tool to support students in developing more sophisticated reasoning.

Laurie's Interpretation of Student Ideas

Laurie discussed her interpretation of her students' ideas about the School Map formative assessment several times during the post-interview. Several of her comments include the following:

> I saw that most of the student responses were around a 2.5.
>
> Common ideas were that the landscape is a straight line and that either the water is flowing south or you can't tell from the map. Very few were able to provide concrete supporting data or reasoning to their responses.
>
> Having developed spatial relations and transferring three-dimensional space onto a two-dimensional space is still difficult at the 6th grade level. I ran into this when trying to teach topographical mapping.

Laurie's comments show that she is focused on the ideas and reasoning that her students demonstrate, and not solely on what they don't know or can't do. She does identify a specific conceptual challenge for her students (i.e., spatial reasoning); she contextualizes students' difficulties with spatial relationships as a developmental issue, rather than as information that students are missing or that needs to be "covered" in instruction. Laurie also relates her students' responses directly to the learning progression framework, noting which level of achievement was most common among their responses. Overall, Laurie's comments demonstrate fairly good alignment with the target teacher knowledge and practice associated with interpreting students' ideas.

Laurie's Instructional Response

The instructional move that Laurie enacted after administering and reviewing students' School Map formative assessments was to take out a three-dimensional watershed model and a water dropper, and demonstrate and discuss with students the direction of water flow in environmental systems. In the discussion, Laurie also repeatedly referred to and asked students to reason about direction of water movement in the local mountain range near where they lived. Laurie discusses her instructional move in the following comment from the post-interview.

> The majority of students chose option C. Their reasoning was that if they were standing and looking at the river it would be a straight line, which indicates they are not taking into account terrain and the 3-D landscape. What I did to address this misconception was to first pull out a watershed model and discuss with students the path water takes when traveling downhill and why it takes that path (path of least resistance). We also discussed how, in the model, the rivers (or paths the water flowed down) were indented and at a lower elevation than the area surrounding the river path.

Laurie recognized the particular challenges her students were encountering with the School Map formative assessment, and she chose an instructional response that provided an experience with a three-dimensional watershed model to help them see water movement through a landscape firsthand. Rather than trying to replace or fix their misconceptions, Laurie attempts to use experience to help students build more sophisticated understanding. In her instruction, she presses students to make inferences about water flow from topography. Connecting the lesson to the local mountain range provides an opportunity for students to build on their personal funds of knowledge while developing understanding of water systems. Students' familiarity with the local area serves as a resource for learning.

Laurie does mention a school science type of rule (i.e., path of least resistance) both in the lesson itself and in her verbal reflection about the lesson. School science rules tend to be rules of thumb that often work, but that are fallible because they do not invoke principles. Overall, Laurie's instructional response after administering the School Map formative assessment was responsive to the particular challenges her students were dealing with, and was designed to build understanding through experience, rather than to transmit information for students to acquire or replace previous ideas.

Synopsis of cases

Jen and Laurie reflect two contrasting case examples concerning how early adopter teachers may integrate use of learning progressions and learning progression-based instructional materials and approaches into their teaching. Table 3 provides a summary of the characteristics of knowledge and practice associated with learning progression-based instruction that we observed in the two cases.

Facet	Jen's Knowledge & Practice	Laurie's Knowledge & Practice
Understanding of LP	• Jen's answers and talk reflect reliance on Level 3 understanding with access to Level 4 reasoning. • She sees LP as useful for supporting student learning with goal of Level 3 phenomenological reasoning.	• Laurie's answers and talk demonstrated Level 4 reasoning with some minor problems with details. • She views LPs as a tool for planning instruction that builds' students' reasoning through experience.
Purpose of formative assessment	• Jen views learning as acquisition of facts. FA allows her to assess facts students do or do not know so that she can cover appropriate content.	• Laurie situates FA practice w/in the framework of the LP (identifying students' LP-aligned ideas and practices) and w/in the framework of developing understanding (developmental perspective).
Interpreting students' ideas	• Jen recognizes challenges students demonstrate in FA responses, but does not situate those w/in LP. • She often interprets students' responses in terms of right/wrong.	• Laurie describes what students know and do, as well as what they have challenges reasoning about. • She identifies specific challenges (i.e., spatial reasoning) in students' responses.

Instructional response to formative assessment	• Jen's instructional response is consistent with teaching for Level 3 phenomenological reasoning. It…
	  ○ Is didactic in method
	  ○ Focuses on vocabulary and terminology rather than reasoning with
		• Laurie provides a relevant experience viewing and discussing a 3-D watershed model to respond to students' challenge with spatial reasoning. She also connects to local topography to help students reason about relevant concepts from personal experience.

	principles ○ Does not address students' need for a firsthand experience connecting 2-D representations with 3-D landscapes	

Table 3. Summary of learning progression-based knowledge and practice

Contextualizing Jen and Laurie among project teachers using PCK and content data

The two cases of Jen and Laurie provide some insights into how two early adopter teachers make sense of and use learning progressions in their instruction about water in environmental systems. In order to situate Jen and Laurie within a broader context of middle and high school teachers from multiple locations around the United States, we refer to a larger data set of written responses addressing science content knowledge and pedagogical content knowledge collected with 153 teachers who participated in our learning progression professional development project between 2011 and 2013.

The written assessment that teachers completed included both a subset of science content questions that are the same as ones answered by project students on pre and post assessments, as well as a set of pedagogical content knowledge questions designed to elicit responses concerning teachers' learning goals for students, their interpretations of students' responses to science content questions, and their choices for instructional responses to students' ideas. The science content questions were coded using the four-point scale corresponding to the learning progression levels of achievement. The pedagogical content knowledge questions were coded using three categories, with category A corresponding to knowledge and practice not aligned with the learning progression, category B corresponding to knowledge and practice reflective of instruction likely to support Level 3 phenomenological reasoning in students, and category C corresponding to knowledge and practice likely to support the development of scientific model-based reasoning.

A sample of the findings are presented in Table 4, separated for project years 2011-12 and 2012-13, to provide a general overview of the state of project teacher knowledge and practice related to learning progression-based instruction.

Assessment Item	2011-2012 (N=98 teachers)		2012-2013 (N=55 teachers)	
Learning Goals: The water strand focuses on tracing water and substances in water through environmental systems at multiple scales. Briefly state up to three goals that you hope your students will achieve when they study water movement through environmental systems.	Category A	47%	Category A	32%
	Category B	49%	Category B	59%
	Category C	4%	Category C	9%
River Map Question (see Table 3)	Level 1	1%	Level 1	0%
	Level 2	19%	Level 2	21%
	Level 3	61%	Level 3	65%
	Level 4	19%	Level 4	14%
River Map Student Response Interpretation: When asked which way the water at point F flows, a students said, "I believe that the direction of the river is flowing toward point D." Why might this student give this answer? In other words, what ideas about flowing water could this student have?	Category A	28%	Category A	11%
	Category B	60%	Category B	72%
	Category C	12%	Category C	17%
River Map Instructional Response: In order to respond to this student's ideas, which of the following would you choose as a next step in instruction? (Four choices are provided) Why do you think the next step you chose is the best one for this student?	Category A	32%	Category A	23%
	Category B	53%	Category B	64%
	Category C	15%	Category C	13%

Table 4. Project teacher performances on science content and PCK assessments.

Summarizing these results, across all items, the mode teacher response is consistent with thinking and/or instruction aligned with Level 3 phenomenological reasoning (see shading). These results suggest that the knowledge and practices demonstrated in Jen's case are similar to those common among the majority of teachers participating in our project.

Discussion

The cases of Jen and Laurie's learning progression-based water instruction provide two interesting examples that deepen our understanding of how early adopter teachers may be using learning progressions to inform their science teaching. While Jen generally reflected more characteristics of knowledge and practice consistent with teaching for phenomenological reasoning, and Laurie reflected more characteristics consistent with teaching for model based reasoning, there was no hard and fast line dividing the two teachers. For example, Jen's talk about the shape of the land in her class discussion with students about the School Map formative assessment suggests that she is able to access Level 4 reasoning and, at times, tries to engage students in using this type of reasoning as well. On the other hand, Laurie is also not completely consistent in her use of reasoning and instructional talk reflective of Level 4 model-based reasoning. For example, during the class discussion about the School Map formative assessment, she sometimes used language invoking drivers and constraints, and at other times used language invoking school science rules such as "tributaries flow into rivers."

Our study of early adopter teachers' knowledge and practice associated with learning progression-aligned water instruction raises additional questions worthy of inquiry regarding teacher use of learning progressions for instruction. In continuing efforts we plan to investigate questions including 1) How, if at all, do students of teachers like Jen and Laurie differ in learning gains as a result of engaging in LP-based learning experiences?, 2) Jen and Laurie came to our project with different amounts and types of previous research-based professional development experience - How do teachers' previous professional development experiences impact the ways that they learn about and integrate LPs into their instruction?, 3) Orientation to learning and teaching (e.g., a transmission versus a social-constructivist model of learning) seems to be important - To what extent are these teacher orientations to teaching and learning trait-like versus malleable?, 4) To the extent that they are malleable, what types of professional development experiences are helpful for moving teachers toward adoption of social-constructivist orientations?, 5) How closely is a teachers' reasoning level on a learning progression (i.e., phenomenological versus model-based) related to their orientation to learning and teaching (i.e., transmissive versus social constructivist)?, And, 6) Is Level 4 reasoning necessary but NOT sufficient for teaching for model-based reasoning, or do they generally go hand-in-hand (i.e., do teachers who provide model-based reasoning responses on content questions also tend to teach for model-based reasoning)? Continuing exploration of questions like those above will help us to begin to fulfill the promise of learning progressions for supporting teachers in enacting ambitious science instruction aimed at developing students' capacity for model-based reasoning.

Conclusion

The two cases of Jen and Laurie, as well as the results from the larger set of project teachers, provide an initial picture of what learning progression-based teaching in the classroom might look like for early adopter teachers. The two cases provide interesting insights into how teachers' science content knowledge, pedagogical content knowledge, and orientations to teaching and learning interact with their understanding and use of learning progressions and learning progression-based instructional materials.

As with students, we find that even teachers who do not demonstrate goal knowledge and practice in their instruction have multiple strengths in the ideas and practices that they bring with them to professional development opportunities and to the classroom. For example, Jen's ideas about science, students, learning, and instructional practice evinced several important conceptions that could be built on with professional development including interest in and inclinations toward 1) analyzing students' ideas and using them to inform instruction, 2) helping students become "deeper thinkers," and 3) helping students develop accurate accounts of events and processes in environmental systems. Further work with teachers can help us gain a better understanding of how professional development programs can build on the strengths that teachers already have, and help teachers build and adopt more challenging learning progression-aligned knowledge and practices that will support students in developing the sophisticated model-based reasoning reflected in the *NGSS* (NGSS, 2013) and needed for effective use of science to inform real world decision-making.

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