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# Multiple Perspectives on Teacher Implementation of Learning Progression Teaching Strategies in Environmental Science

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The work reported here is part of a national project across middle and high schools in the U.S. to develop learning progression frameworks (descriptors and assessments) for three core strands of environmental science: *biodiversity*, the *carbon cycle*, and the *water cycle*. The nature of instruction expected by the developers of the project's learning progressions-based approach means that some teaching practices are more aligned with progressions-based assumptions than others. The objective of the work reported here is to address the question: **How do teachers implement target instructional strategies while teaching the topics in their science classes?** A sub-purpose is related work on triangulating what we learn about the use of learning progression-supportive instructional strategies from (1) teacher perceptions (gathered in survey, interview, and teaching documents), (2) researcher perceptions (by way of classroom observation and data analyses) and (3) student perceptions (through survey and focus group interview). Here we focus on the last, student reports of their experience of the target instructional strategies.

## **Theoretical Perspective**

The theoretical perspective for the study combines existing frameworks for the development of science pedagogical content knowledge (Park & Chen, 2012; Shulman, 1986) with emerging work on building teacher knowledge of learning progressions as a type of professional and classroom discourse (Gunckel, 2013). In the context of our project, that means examining the shadows cast in classroom practice and student experience for indicators of progression-based instruction. Conceptual coherence across curriculum and classroom practice is sparse in science (Alonzo & Gotwals, 2012). The ideas and assessments that make up a learning progression offer a language and approach for instruction that can enrich teachers' orientations to science and knowledge of curriculum, deepen attention and response to student thinking, harness the power of formative and diagnostic assessments in service of student learning, and provide a self-reflective tool for teachers in planning, instructing, and reflecting on their work. However, what we do not yet know is *how* this happens nor how certain aspects of engaging in learning progression-based teaching may be counter-productively collapsed (assimilated) into existing orientations towards science instruction.

Situating the research aimed at addressing the research question relies on three sets of ideas and associated definitions: the nature of classroom *discourse*, what we mean by teachers' science *pedagogical content knowledge (PCK)*, and the structure of our environmental science *learning progressions*. We define and exemplify each of these before moving on to a description of how the research on student experience speaks to the research question about teacher instructional strategies.

### Discourse: How do language and culture shape teaching and learning?

Meaning is situated. Consider how to interpret: "The coffee spilled, get a mop" and "The coffee spilled, get a broom," (Gee, 1999, p. 48). In each case, cultural models (context-based "storylines" that may or may not be consciously considered) are connected to the word "coffee." The cue of "mop" is likely to trigger a situated meaning for coffee as a liquid while, depending on one's experience and available cultural models, "broom" may be more likely to bring to mind dried beans (perhaps whole, or perhaps ground up). Meaning in school contexts also is situated in larger conversations of current and historical societal experiences, cultural practices, and disciplinary content. Situated meanings are dynamic in that they are assembled on the spot, based on past and present experience, "customized in, to, and for context, used always against a rich store of cultural knowledge (cultural models) that are themselves 'activated' in, for, and by contexts." (Gee, 1999, p. 63). In what follows, our use of the term "discourse" is in the "big D" sense of Gee (1996):

A Discourse is a socially accepted association among ways of using language, other symbolic expressions, and 'artifacts', of thinking, feeling, believing, valuing, and acting that can be used to identify oneself as a member of a socially meaningful group or 'social network', or to signal (that one is playing) a socially meaningful 'role' (Gee, 1996, p. 131).

This perspective allows us to attend to a component of pedagogical content knowledge in Shulman's original statements about the nature of pedagogical content knowledge (1986):

The syntactic structure of a discipline is the set of ways in which truth or falsehood, validity or invalidity, are established... Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice... This will be important in subsequent pedagogical judgments regarding relative curricular emphasis. (p. 9)

In this view, pedagogical content knowledge includes knowledge for working effectively with the multiplicity of discourses students, teacher, curriculum, and school bring into the classroom. Each discourse includes a cultural context. Discourses may differ from person to person or group to group.

## Pedagogical Content Knowledge (PCK)

Since Shulman's (1986) seminal work, a rich collection of models of pedagogical content knowledge continues to grow in mathematics and science (e.g., Ball, Thames, & Phelps, 2008; Magnusson, Krajcik, & Borko, 1999). The framing of knowledge for teaching has centered on the question: What reasoning, insight, understanding, and skills *steeped in the discipline* are required for a person to teach in that discipline?

Many have worked to develop measures of teacher knowledge to address this question. In mathematics, particularly grades K-8 teaching, that work has been rooted in authentic classroom settings and cognitive interviews with teachers, most notably by Ball and colleagues (Ball, et al., 2008; Hill, Ball, & Schilling, 2008). In their work they have defined three types of subject matter knowledge (SMK) and three types of pedagogical content knowledge (PCK) as the domains of mathematical knowledge for teaching (see Figure 1).



Figure 1. Dimensions of knowledge for teaching from Hill, Ball, & Schilling (2008).

Unlike the K-8 focus in mathematics education, models of science pedagogical content knowledge development have been more focused on teaching in grades 6-12. Existing work on science PCK often includes knowledge of assessment as a component. Also, science PCK has long included another component, referred to as "orientation" (Anderson & Smith, 1987; Magnusson et al., 1999) or "disposition" (Park & Chen, 2012) toward teaching and learning of science (see Figure 2). That is, science PCK models include a melding of knowledge and beliefs about the discipline and the teaching and learning of the discipline itself.

Various orientations have been identified and named: academic rigor (Lantz & Kass, 1987), conceptual change (Roth, Anderson & Smith, 1987), discovery (Karplus & Thiers, 1967), inquiry (Tamir, 1983), and guided inquiry (Magnusson & Palincsar, 1995). A common model for teacher "orientation" unpacks each of these into two parts: goals and core strategies of instruction (Magnusson et al., 1999). Different goals may be realized with similar strategies. For example, discovery, inquiry, and conceptual change all involve students exploring and generating ideas, but the goals of each of these orientations differ and the purposes of student activity varies.

As currently used in science education, the goals associated with each orientation represent a set of valued ways of seeing the world, of favored tools and artifacts for interacting with the world. The characteristics of instruction associated with each orientation describe preferred methods for inter-generational transfer (teaching) of those values and of the uses of tools and artifacts. Each orientation is an instantiation of a culture in a broad sense and privileges certain understandings of the physical environment, actions and behavior, identities, policies, connections, and situated meanings. Moreover, each orientation presumes a particular way of noticing and handling any intercultural difference, such as that between the "institutional culture of science" encoded by the teacher's orientation and the "home culture of science" known to students (individually or collectively).

A simultaneous thread in mathematics and science education research over the last 30 years has looked at *student* orientations towards the learning and teaching of the discipline. Steeped in concerns of cultural relevance, sensitivity, and responsiveness (Gay, 2002), this effort has a focus on students. Generally, these efforts have suggested that it is the job of the teacher to guide acculturation into the disciplinary orientation, somehow to "make accessible" (and palatable) to students the academic culture of science.



*Figure 2*. Pentagon model of PCK for teaching science (from Park & Chen, 2012, p. 925). Mappings between Figure 2 and Figure 1 categories: KCS to K of C; KSU to KCT; KISR to KCT.

Only recently have mathematics and science education models begun to consider teacher *orientation to the difference* – not orientation towards teaching and learning of science, but orientation towards the differences between teacher and student orientations about science teaching and learning. Evidence of orientation to the discipline and of orientation to the difference is evidenced in the classroom in myriad ways. Researchers have investigated vocabulary and discourse practices (e.g., Ryve, 2011; Windschitl, Thompson, & Braaten, 2008), gestures (Alibali et al., 2012), and setting of norms (e.g., socio-scientific norms, Driver, Newton, & Osborne, 2000). If PCK is the reshaping and melding of knowledge and beliefs about the discipline and about pedagogy into instructional realizations in the classroom, then certainly the aspects of communication just listed are part of PCK. But where in Figures 1 and 2 are the dynamics of enacted classroom communication? In work reported elsewhere (Hauk, Toney, Jackson, Tsay, & Nair, in press), we have offered an expanded model of PCK that makes explicit the use of *knowledge of discourse*.

The category *knowledge of discourse* subsumes two parts of the Park and Chen (2012) PCK model for science: teacher orientation and knowledge of assessment. While teacher orientation is a kind of *relational* understanding guiding classroom discourse, knowledge of assessments is a kind of teacher *declarative* understanding that influences the mechanisms for communication – together the two shape accepted constructions of meaning in the classroom. Such a model might be pictured as shown in Figure 3. Each of the eight instructional strategies we posit to be supportive of learning progression-based instruction is aligned with one of the four components highlighted in Figure 3.



Curriculum

*Figure 3*. One way to visualize PCK components with Knowledge of Discourse included (from Hauk et al., in press).

*Knowledge of Discourse* is knowledge about the culturally embedded nature of discourse, including inquiry, vocabulary, and valued forms of communication in science (both in and out of educational settings). Here, for "discourse" we use Gee's (1996) "big D" meaning.

Anticipatory Thinking is ways of thinking about (strategies, approaches to) how learners may engage with content, processes, and concepts. It connects knowledge about students' understanding of science with knowledge of science and classroom discourse and includes awareness of and responsiveness to student thinking. Part of anticipatory development involves what Piaget called "decentering" – building skill in shifting from an ego-centric to an ego-relative view for seeing or communicating about an idea or way of thinking from the perspective of another (e.g., eliciting, noticing, and responding to student thinking). Teachers with complex anticipatory thinking manage the tensions among their own instrumental and relational understandings of science and its learning and those of their students (Skemp, 1976). Such perspective-shifting is deeply connected to discourse through the awareness of "other" as different from "self."

*Implementation Thinking* is ways of thinking about (strategies, approaches to) how to enact teaching intentions in the classroom. For this project, this includes thinking that connects to the target instructional strategies (more on these strategies below). Moreover, given the "big D" ideas of discourse in Knowledge of Discourse, implementation thinking also includes thinking about how to adapt teaching according to content and socio-cultural context and act on decisions shaped by one's orientations towards science and its teaching/learning. This draws on knowledge of discourse(s) and on knowledge of science-specific instructional practices. While the status quo is often an intention to enculturate (i.e., to identify a reference culture and then target instruction for students to acquire particular dispositions), we have seen implementation thinking move beyond this, driven by greater Knowledge of Discourse.

*Curricular Thinking* is ways of thinking about (strategies, approaches to) science topics, procedures, and concepts in the curriculum. This includes the vertical knowledge of pre-requisite

science topics and potential future topics, as well as the relationships among them, along with conventions for reading, writing, and speaking them, found in curricula. Learning progression-based curricula provide additional fodder for this type of thinking because learning progressions make specific the usually implicit assumptions about how students develop across their years in science learning in school.

# **Learning Progressions**

As indicated in the *Next Generation Science Standards* (2013), learning progressions are descriptions of increasingly complex understandings of a subject (e.g., the water cycle) and associated measures for the development of learner knowledge. A progression is anchored at the lower end by what we know from interviews and observations about how younger students reason. The learning progressions in our work are anchored at the upper end by what disciplinary education experts identify as the knowledge needed for college, career, and citizenship readiness. The development of the learning progression framework is grounded in teacher practice and student learning experiences.

The larger *Pathways* project, from which the work reported here has emerged, included development and implementation of sets of activities called *teaching experiments* (one set of materials for each of the three main topics of biodiversity, water cycling, carbon cycling). Each teaching experiment is a series of orchestrated lessons, concrete strategies, and instructional resources to be used in concert to support learner development of the normative standard scientific discourse. The materials are based on the project's foundational perspective of a four-level learning progression (see Table 1).

LP Level	Title	Description
4	Scientific Model-Based Accounts	Students apply fundamental principles, such as conservation of matter and energy and genetic continuity, to phenomena at multiple scales in space and time (generally consistent with current national standards).
3	Incomplete School Science Accounts	Students show awareness of important scientific principles and of models at smaller and larger scales, but they have difficulty connecting accounts at different scales and applying principles consistently.
2	Elaborated Force-Dynamic Accounts with Hidden Mechanisms	Students continue to focus on actors, enablers, and natural tendencies of inanimate materials. However, they add detail and complexity, especially at larger and smaller scales.
1	Simple Force-Dynamic Accounts	Students focus on actors, enablers, and natural tendencies of inanimate materials, using relatively short time frames and macroscopic scale phenomena.

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The project also created and implemented teacher professional development around the use of the teaching experiments. Professional development included teachers experiencing a teaching experiment as a learner before attempting to use it in their own classroom and field site activities. Each strand's curricular materials target eight *instructional strategies* for supporting teaching using a learning progression-based approach (see Table 2). Each strategy is aligned with one of

the four key PCK concepts. In the current research, developers asserted the importance of these strategies for faithful implementation of learning progression-informed instruction.

One might see several of these strategies enacted in any science classroom. As an example, eliciting students' ideas by providing opportunities for students to think and reflect on their ideas both aloud and in writing (Strategy 4) may help students move from force-dynamic reasoning to providing a phenomenological account. Group work and reflection on their own ideas and on other student ideas could help learners to make the mechanisms behind the phenomena explicit, eliminating the actors and agents in the discussion and connecting across scales, moving beyond descriptions of the macroscopic scale. Using authentic inquiry (Strategy 5) means students use experiments as a way to discover there are mechanisms at work that cause change. A teacher might implement worksheets as formative assessments (Strategy 2) to determine if students yet know there are mechanisms at play and what those mechanisms are. Multiple times across a unit, a teacher may emphasize (1) making a claim, (2) providing evidence, and (3) reasoning. Emphasizing these three pieces of scientific thinking (Strategy 8) can help students move towards principle-based reasoning by beginning with evidence-based reasoning.

Table 2. Target Strategies for Learning Progression-Based Instruction

- Strategy 1. Instruction identifies and focuses on important big ideas in the field of study. Curricular Thinking
- Strategy 2. Instructional planning appears to be based on anticipated level of student understanding of the topic at hand. Anticipatory Thinking
- Strategy 3. Development and/or use of formative assessments appears to guide selection of instructional strategies and sequences. Anticipatory Thinking
- Strategy 4. Evidence of teacher support for student learning through careful (a) eliciting, (b) attention to, and (c) response to student thinking during classroom discourse and in comments on student work. Implementation Thinking
- Strategy 5. Class engages students in guided or open inquiry with authentic events and experiences. Implementation Thinking
- Strategy 6. Evidence of teacher support/use of students engaging in increasingly complex evidence-based accounts (e.g., sense-making, story-generating) about environmental processes in socio-ecological systems (i.e., the increasing complexity moves towards principle-based reasoning). Knowledge of Discourse
- Strategy 7. Teacher and/or students link environmental science to real problems in the local context, anchoring students' learning in their culture and place. Knowledge of Discourse
- Strategy 8. Instruction encourages students to engage in and reflect on sciencebased decision-making for citizenship (e.g., using science skills and understandings to investigate, evaluate, and critique arguments, and to use science in everyday decision-making). Knowledge of Discourse

### Methods

To understand the nature of teaching strategies when teachers implement progression-based curriculum, we undertook case study inquiry at the teacher level. From the 160 teachers in the project, we recruited 10% for the case study: 16 teachers, half from middle school and half from high school settings. While a variety of student science learning outcomes and teacher knowledge development goals are the topic of a larger study, the case study reported here was designed to investigate "in the wild" implementation characteristics. To explore the variations in implementation of the eight strategies in Table 3, we have asked our research question from multiple directions: What is the nature of classroom implementation activity as observed by a research visitor? What are teacher self-reports about instructional strategies before, during, and after implementation of a learning progression-based lesson? What are student perceptions of teacher strategies in a learning progression-based implementation as a chunk (2 to 4 weeks) of a semester-long course? This report tackles these questions with a primary focus on student reports of the instruction they experienced.

This project uses a repeated concurrent triangulation approach embedded within a sequential exploratory design (Creswell, 2009) to examine how the target strategies and teacher implementation of project materials interact to influence student experiences. A summary of the student-provided part of the research design is pictured in Figure 4. This mixed methods design allows for both qualitative data (interviews) and quantitative data (surveys) to inform subsequent stages of interpretation and analysis. For some characteristics, quantitative methods are appropriate to capture and communicate what is happening. For some aspects, qualitative methods are better aligned to capture and communicate how or why. We recognize that we do not always know *a priori* which is which, so we strategically use both and compare.







## **Setting and Participants**

Participants were 16 teachers and the 333 of their students for whom we documented consent to participate. Four participating classes came from each of four regions in the US (East, Central, Mountain, and West). For this report we focus on survey and focus group interview responses by the students in one class for each teacher, with a brief glimpse at early results of analysis of classroom video recordings. Eight of the participating classes were in middle schools, eight were

in high schools. Selected teachers had regularly attended professional development meetings and had implemented project curricular units in previous years. Six teacher participants implemented the water cycle; six, biodiversity; and four, the carbon cycle. Many case study teachers implemented more than one teaching experiment, or used one in more than one class.

### **Data Collection and Analyses**

Researchers administered surveys and conducted student focus group interviews shortly after the project-designed teaching experiment in each class. This meant some data were collected in the fall term and some in the spring term.

*Student Survey.* Rather than ask students to evaluate how well (or often) their teacher engaged in a strategy, we listed observable characteristics and asked the student to evaluate their own experience of that characteristic on a four-part scale (Never, Sometimes but not enough, Enough, Too much). In order to do this, we needed to identify and describe classroom characteristics in a way accessible to students, associated with each strategy. That is, we had to determine classroom activity, interaction, or instructional behavior whose presence would be required for the strategy to be in place. After generating a list of 20 such characteristics (some strategies had one, some had up to four), we created a pilot survey and did cognitive interviews with three middle school students. These interviews verified 8 of the 20 as accessible and eliminated 12 as not reliably productive. We revised the 8 statements, based on the student feedback, and included them on the final survey. The final survey had good face validity and the cluster of items on the eight target teaching strategies proved to be fairly reliable (Cronbach's alpha .73). In addition to the items about instruction, the survey asked students to write about an example from their class.

Student Focus Group Interviews. Each student focus group interview included four to seven students and took between 25 and 45 minutes. We conducted interviews outside of class time (see appendix for summary of the protocol). After having the student focus group interviews professionally transcribed, we reviewed each, looking for evidence of student discussion around the eight teaching strategies. First, two people coded two interviews separately, then met to compare and make adjustments in the coding rubrics until reaching consensus. This was done for two more interviews and then one person continued to code the remaining 12 interviews. The second coder reviewed the interviews and the first coder's work. All disagreements were resolved by consensus. After this first round of coding was completed, the second coder met with three project experts (a researcher, a teacher educator, and a teacherleader) to validate coding. While the selection of interview content to be assigned a code never changed, which of the codes to assign was adjusted to align with expert advising. The reassignment of categories was discussed until all agreed upon clarified wording for rubrics for each of the eight categories. The second coder then made another pass through the interviews, using NVivo, to adjust assignment of categories. In a final round of expert checking, we found that the second coder and the expert agreed on all coding.

*Classroom Observations.* The larger project included video and audio capture of class meetings for four to six hours of class for each teacher during class use of project materials. Parallel to the student-focused work reported here, analysis of those video recordings is the subject of other work (Bianchini et al., 2014). To provide additional context for the student reports, we reviewed one class meeting for each of the 16 case teachers. Taken from the middle of the set of observed lessons, we watched each video once to identify use of the target strategies. We documented two things (a) whether the strategy was evidenced in the observed

class and (b) an indicator for that evidence as either an attempt to use the strategy (score of 1) or a mostly complete use (score of 2) in each of three categories: launch, explore, link. A score in the *launch* category indicated evidence of teacher initiation of the strategy; in the *explore* category there was evidence of student or teacher engagement in the strategy's target discourse, and in the *link* category a positive score indicated evidence of closure, summary, or linking with another/next activity or strategy. The resulting "depth of practice" index for the strategy use on the three subscales was the sum of these three evaluations, a value on a scale of 0 to 6 for each teacher for each strategy.

#### Results

#### Survey

Students reported experiencing classroom behavior by the teacher for most of the target teaching strategies as "Enough" with a few notable exceptions (see Figure 5). There was a statistically significantly wider distribution across teachers and the mean response, "Sometimes but not enough" was statistically significantly different from "Enough" in Category TS7 ("Talked about how the topic relates to our lives outside of school" – related to Strategy 7 in Table 2). Student response of "Sometimes but not enough" in Category TS6 ("Made and defended claims based on scientific evidence" - related to Strategy 6 in Table 3) was also statistically different from "Enough" though variability across teachers was large but not significant. A similar pattern has been seen in analysis of the teaching observation video data, with highly variable documentation of teachers and students "linking environmental science to real problems" in the classroom.



Figure 5. Student perceptions of teacher use of learning progression instructional strategies (see Table 3 for descriptions of the strategies 1 through 8). Note: Dark horizontal line is at 3-"Enough" rating to aid in reading the figure and the solid color box icons represent Bio3, Car1, Wat2, and Wat5, the four focal teachers in later discussion.

For the example-giving open-ended item, two researchers coded each student response and resolved disagreement of initial coding through consensus and, occasionally, consulting with a third researcher. The categories that emerged from this coding were named according to what was in the foreground in the example: *Relevance* (to life outside of school), *Content* (connected to life inside of school), *Correctness, Discussion, Vague*, and *Unrelated*.

While at least half of students in each class said their teachers asked students to "share thoughts or experiences" it was clear from the examples students wrote that two different things were associated with "thoughts or experiences" – either *out-of-* or *in-class* experiences. We assigned the code *Relevance* when the student-provided example described the teacher or students connecting student out-of-classroom experience or local relevance with the lesson, (related to Strategy 7 in Table 3). *Content* was for an example describing a connecting of students' previous science learning and/or lab experience to the lesson, (most closely related to Strategy 4 in Table 3). We used *Correctness* to code an example that described an incident in which the teacher focused on the correctness of thoughts/ideas, (may be related to Strategy 3 in Table 3, but further work is needed in this area). The other three codes were for examples that related to *Discussion* in general (no specifics given, e.g., "The teacher always had everyone participate and share our journal work with the class,") that were *Vague* (e.g., "She often asked us what we thought"), or *Unrelated* in the sense that the example did not address one of the target strategies (e.g., "stressed because kids were missing class").

Students offered their example for one of three scenarios: teacher elicited and used their thoughts and experiences, elicited and did not use, or did not elicit. An example in the Content category for a teacher eliciting and using an idea is "related the experience and results we got from the leaf packets to the overall lesson." As one might expect, the distributions of coding of the student-generated examples, varied across teachers.

The distribution of examples across categories is similar across the science strands (see Figure 6). While fewer examples were about Relevance in the water strand, students who experienced the biodiversity teaching experiment gave more examples about Relevance and Content; this could be because the biodiversity experiment asked students to consider a local site and to investigate what lives there.



Figure 6. Distribution of categories of student examples for each of the science strands.

We continue analysis and are considering how to use what we know about the professional development (PD) among teachers to inform the analysis. There were 4 PD sites (4 teachers in our sample from each), West Coast, Mountain Region, Central Region, East Coast. Figure 7 summarizes the same data as Figure 6, rearranged to display by site and illustrates the variation across the four sites.



Figure 7. Distribution of categories of student examples for each of the PD sites.

# **Focus Group Interviews**

When students talked about their science learning, the conversation included some science terms and many verbal flourishes such as "like" and "you know" as in: "I thought, like, you know, that the inclinometer was fun to use to see how the field sloped away from the school." As a way to explore student interview content, we visualized the interviews with word clouds. Our tool was wordle.net - an open access web-based tool. A single word cloud is called a wordle. The more frequently a word is used, the larger and bolder it appears in the cloud. The exception to this is that the tool ignores the most commonly used English words unless given override instructions (e.g., and, a, the, for). The maximum number of words included can be adjusted.

For example, Figure 8 is a 150 word cloud (wordle-150) generated from the focus group interview with students from a Mountain Region Middle School class using the Water Cycle learning progression-based materials. Notice that the biggest words, besides "water" are flourishes like "Yeah" "Well" "just" (as in "Yeah. Well, I think it really is just, kind of, important"). For each interview we generated the unexpurgated wordle using only student utterances (not including the interviewer prompts) and then created a trimmed wordle. The trimmed wordle came from considering the text of only those segments coded for a particular strategy and then generating word counts and omitting verbal flourishes (by reviewing the transcript line by line to determine whether "think" (for example) was a flourish or central (e.g., I'd think that... or We think we know what affects the water, but it turns out it goes lots of places and stuff goes into it). The trimmed version of Figure 8 is shown in Figure 9.



*Figure 8.* Unedited wordle-150 from a Mountain Middle School Water Cycle group of students.



*Figure 9*. Researcher trimmed wordle-150 from the same Mountain Middle School Water Cycle group of students in Figure 8.



Figure 10. Researcher trimmed wordle-150 from Eastern High School Water Cycle group.

While Figure 9 is from middle school students, Figure 10 represents a focus group of high school students. Notice that Figure 10 brings to the forefront several words not as readily visible (large) in Figure 10 such as "transpiration," "affects," and "stuff." Also notice the relative size difference of "how" and "know" between the two groups. For the middle school group, know is larger than how. For the high school group, it is the opposite. The shift from "know" to "how" may be indicative of a discursive shift. And a discursive shift can be evidence of a cognitive shift. These two focus group interviews are distinctive in that the middle school group seemed to be progressing from Level 2 where students know facts and describe them, to Level 3 where students describe how these facts are connected to each other or to scientific principles. And the high school group spoke regularly about how things were related. An additional indicator in the word cloud might be the frequency of use by the high school group of "affects." Its use in the context of the interview was in linking between ideas, how one thing affects another. Related to this linking was the chunking of what they knew as "stuff" and how it affected other "stuff." A final indicator of more access to Level 3 ideas in the high school group was the repetition of the middle school group's use of "evaporate" and increased frequency of normative science discourse like "transpiration" and "permeable." While these speculations are made possible by visualizing the interviews using wordle, they are not in themselves results in the traditional sense. The word clouds have helped us in the research process in making decisions about how to continue in the next round of analysis.

Though less rich in verbal detail, we also generated the distribution across teachers of strategies we identified in the student interviews. Figure 11 gives the relative frequency of target instructional strategies according to student interview reports. To unpack that information a bit, we also offer Figure 12, which shows the distributions of relative frequency of coding for each target strategy for each of four focal teachers (in Figure 5 these same teachers are indicated by solid colored boxes in the same colors: blue, red, green, and purple).

We anticipated that use of strategies would vary across instructors and that was the case. It was also the case that the kind of variability resulting from analysis of student reports of their experience is similar to direct researcher analysis of classroom video in many ways but different in a few ways. In particular, student interview information offered little feedback on the two strategies that aligned with Anticipatory Thinking (Strategies 2 and 3 in Table 2). We suspect the absence of the strategies 2 and 3 in the interview coding is related to several factors. In particular, these are: (1) the fact that those two strategies are largely *planning* components for teachers that are unlikely to be noticed by non-teachers in a classroom environment and (2) the short protocol for the interview did not include prompts for probing deeply about these.

The teaching experiment materials were intended to include equally distributed supports for all eight strategies. The quantitative view in Figure 11 suggests that students experienced many of the target strategies in notable (to them) ways. However, for Strategy 8, encouraging students to engage in principle-based and/or evidence-based reasoning for making decisions, the low frequency may be an important hint about where teachers are facing the greatest challenges with learning progression-based instructional approaches.



Interview Snapshot - Distribution of Strategies in Student Experience

Figure 11. Relative frequency of target strategies coded in the 16 student focus group interviews.



*Figure 12.* Relative frequencies of target strategies coded in student focus group interviews of a sample of 4 teachers.

In Figure 12, notice that each teacher has a different profile of use for the strategies. Notably, the students of the Western Region focal teacher did not include any discussion of inquiry in recounting their experiences while only the students of the Mountain Region teacher mentioned experiences related to science-based decision-making. Implementing a curriculum with related professional development is a process with many moving parts. Between them, Figures 11 and 12 allow us to notice the big picture and some of the subtleties in that implementation process.

# **Context - Classroom Observation Preliminary Look**

Adding to the picture afforded by the images representing student experiences of the eight target teaching strategies, we have the researcher view of implementation through analysis of classroom video. The complete coding of 4 to 6 hours of classroom video for all 16 teachers is underway. To get a snapshot of teacher practices we reviewed one day of classroom video for each of the 16 teachers (Figure 13) and have completed analysis of all classroom video for four focal teachers (Figure 14) – these are the same four teachers referenced in Figure 12.



**Classroom Snapshot - Distribution of Strategies** 

*Figure 13.* Distribution of instructional strategies in a sample of mid-lesson classroom observations (1 class for each of the 16 teachers).



Figure 14. Frequency of strategy use across all recorded class meetings for four focal teachers.

The big-picture view in Figure 13, though sketchy because only one class meeting per teacher is included, indicates similar challenges but provides a different view of "authentic inquiry." There is a great variety in implementation across the group as well as some commonalities. As Figure 13 illustrates, the sampled videos included plenty of authentic inquiry but did not include much of either Strategy 7 – attention to local place and culture or Strategy 8 – work on evidence-based decision-making. Keep in mind that the reviewed classroom sessions all came from the midst of a set of lessons and may not be representative of the group. It is also worth noting that the *time scale* for implementing the practices in Strategies 7 and 8 (and possibly for Strategy 6 as well) may be much longer than a single class meeting. The fact that student focus group interview coding indicated a substantive experience of Strategies 6 and 7 is support for this conjecture. A next step will be to look across multiple class meetings.

Though limited to counts within class meetings, to illustrate the variety in teacher use of strategies, Figure 14 shows the distributions of frequency among the same four focal teachers whose student focus group results are shown in Figure 12. In comparing the results from student report in focus groups and researcher reports based on video analysis, we notice that student and reports and researcher coding are quite similar in some categories in Figures 12 and 14. Yet, some questions arises for us as researchers. Three strategies seem elusive: what does Strategy 2 look like in the classroom? How do we know Strategy 3 when we see it? What would have to happen for Strategy 8 to be identifiable? Our data gathering did not include debriefing teachers immediately after class meetings. The design-experiment grain size for the case study was at the level of the "teaching experiment" as unit of analysis, not daily class meetings. Future work will rely on information gathered from teachers during pre, interim, and post teaching experiment interviews.

#### Discussion

Student reports suggest that the challenges noted elsewhere in the literature remain significant for the project. The greatest variability in student reports of the instruction they experienced were in the areas of connecting science learning to life outside of school and making and defending claims based on scientific evidence. In addition to these two areas, student responses also indicated that experiences using scientific principles to explain observed phenomena were happening sometimes, but not enough. Among the questions that remain in the project's research and development space: How do we help ourselves as researchers, materials developers, and teachers to distinguish a learning progression informed implementation of the strategies from "just good pedagogy"?

In terms of PCK development, the set of eight strategies may be too large to be productive. Results suggest that Strategy 5 – Authentic Inquiry may need to be supported among middle school teachers differently than among high school teachers (e.g., in PD). Inquiry is an established paradigm in science teacher development. But, middle school scaffolding of students from Level 1 to Level 2 may be about getting students' hands dirty with field experiences where they get to "know" what things look like, while getting high school students from a Level 2 to a Level 3 (and beyond) relies more on abstracting and chunking that "stuff" to attend to "how" things "affect" each other. We posit that development from Level 3 to Level 4 involves fluency in the language of Level 3 (e.g., greater mastery of science vocabulary) as well as further abstraction across scales (from microscopic to macroscopic) and greater reliance on principles as opposed to personal experience with evidence. In this sense, S1, S4, S5, S7, and S8 may be especially generative for working with middle school students, developmentally. Strategies for supporting student development from Level 3 into 4 during high school may be S2 (because of the greater variation in student understandings once they reach high school), S3 (in order to deal with the greater variability in high school), a modified version of S4 (it may transform to supporting students to listen to and respond to *each other* rather than the teacher), and S6 (which focuses on moving away from evidence-based reasoning to principle-based reasoning).

Along those lines, we share a final wordle to illustrate an area of conjecture about language needs for making sense of and progressing along the developmental path to Level 4. The word cloud in Figure 15 is a researcher trimmed wordle from a middle school group. The fact that only 50 words are included is because only these 50 words were used substantively by students in the focus group interview.



*Figure 15*. Researcher trimmed wordle-50 from a Western Middle School Carbon Cycle group - note that only 50 words identified as core were used by students during the conversation.

Students in this particular focus group relied heavily on the interviewer uttering the science words – students responded by referencing "what you said" and "that thing" and "it" rather than voicing the words themselves. The use of "see" in describing their experiences was much greater than in the other focus groups. We wonder if a sense of having witnessed something in science is a precursor to taking it up as something that can be known, and linked to "how" relationships. Classroom video offers the opportunity to explore student discourse practices when they talk with the teacher and when they talk with each other (some class meeting videos are in the field as students engage in data gathering). More analysis of existing classroom video data with this conjecture in mind lies in our future.

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## Appendix

Focus Group Interview Summary [core questions asked in all interviews are in blue]

FGQ1: What do you think the teacher was trying to teach about X (biodiversity, carbon, water)?
FGQ2: How are the science ideas in these lessons connected to your everyday life?
<ul> <li>FGQ3: How did [process tool] play a part in helping you to learn about X?</li> <li>Potential related follow-up, depending on class:</li> <li>FGQ3b: Do you remember there being part where you were asked to make evidence- based arguments or explanations? (if yes) Describe or explain what took place. Was that helpful in learning about X?</li> </ul>
<ul> <li>FGQ4: Think of an instance during X when your teacher did <b>not</b> seem to understand what you or your classmates knew or that you were confused about a topic. How could you tell?</li> <li>Potential follow-up to Item 4, not a key interview question: FGQ5: What did you learn about X that your teacher never asked about? What more would you like to learn about X?</li> </ul>
FGQ6: I'd now like to move to questions about the teacher's use of Y. Think of an instance when your teacher seemed to understand what you and your classmates <b>did</b> know or get about topic Y. How could you tell? [Follow up to Item 4.]
FGQ7 [not a core interview question, may not have been asked in some FG interviews]: Does the phrase "principle-based reasoning" mean something for you? Did you learn about ideas you would call a BIG IDEA or basic principle in this unit? Can you explain one? How did it apply to the things you were studying?
FGClose: Before we end, what else you would like to tell me? What questions do you have?