Paper 1: Using Learning Progression Frameworks to Inform Instruction in Environmental Science: Teachers' Efforts to Move Their Students Up Levels

Problem: The purpose of this study is to explore science teachers' implementation of teaching strategies aligned with learning progressions (LP) to enhance their students' environmental science literacy. Learning progressions have been posed as frameworks that can support teachers in better eliciting and building from their students' ideas, for example, by engaging in formative assessments and by supporting principle- and evidence-based reasoning (NRC, 2007; 2012). However, we need to know more about how teachers use LPs to inform their classroom instruction (Furtak, 2012; Gunkel, Covitt, & Salinas, 2014).

In our study, we sought to understand how teachers implemented key teaching strategies to foster students' movement up learning progression levels. We focused on how teachers implemented two of these key strategies: (a) use of formative assessments and (b) engagement of students in principle- and/or evidence-based reasoning. We posed two research questions: (1) How did teachers implement these focal strategies in their classrooms? (2) How did the curriculum materials support (or not) teachers' use of these two focal strategies?

Conceptual Frame: Our conceptual framework is grounded in learning progressions (LP) – descriptions of increasingly scientifically based and coherent ways of thinking about a science practice, concept, or idea (NGSS Lead States, 2013; NRC, 2007, 2012). For learning progressions to help transform science education, they must be used to inform curriculum and instruction (Duschl, Maeng, & Sezen, 2011; NRC, 2007). The environmental science project studied here constructed LP frameworks for three strands: carbon cycling, water cycling, and biodiversity. The project then used these frameworks to develop three curricular units (Teaching Experiments, or TEs) and to identify teaching strategies aligned with the faithful implementation of the TEs. The eight key strategies included the two focal strategies mentioned above. Learning progression frameworks, teaching strategies, and curriculum materials were introduced to teachers in summer intensive and academic year follow-up professional development seminars on environmental science.

Design/Procedure: We collected data during 2012-2013, the fifth year of the project. We recruited 16 secondary science teachers to participate – approximately 10% of all teachers engaged in the larger project that academic year. Project staff identified these teachers as knowledgeable and skilled participants. Eight taught in high schools; eight, in middle schools. Four teachers implemented the carbon cycling teaching experiment (TE); six, the water cycling TE; and six, the biodiversity TE. The teachers were recruited by one of four research sites in the United State located on the west coast, in the mountain region, in the central region, and on the east coast. There were four teachers participating at each geographic site. Our qualitative analysis drew from four types of data: teacher interviews; video recordings of five consecutive days of classroom instruction; teacher written responses to several surveys (reflection questions, end-of-teaching-experiment surveys, and end-of-year surveys); and samples of student work (including pre-/post-TE content tests).

Analysis: To answer research question 1, on teachers' implementation of formative assessments and principle- and/or evidence-based reasoning, we conducted our first cycle of analysis. We began this cycle by analyzing video records of classroom instruction. We divided each teacher's five lessons into instructional segments, identified teacher-student discussions within a given lesson segment, and determined whether each discussion was *productive* or *unproductive* (Michaels & O'Connor, 2012). Next, for all instructional segments that included at least one productive discussion, we identified all instances of teachers' implementation of the two focal strategies. We defined the strategy use of formative assessment to be when teachers implemented part or all of any of the formative assessments explicitly labeled as such in the TEs. We defined the teaching strategy of engagement in principle- and/or evidence-based reasoning from previous work: engaging students in developing increasingly complex, principle-based and/or evidence-based accounts of environmental processes in socio-ecological systems.

We then constructed a second set of inductive descriptive codes to characterize teachers' use of these focal strategies. More specifically, for use of formative assessment, our inductive codes became emergent, transitional, and sophisticated. We considered a sophisticated implementation of this strategy as moving beyond *eliciting* student ideas to *engaging* students with these ideas. An emergent implementation of this strategy was categorized as teachers eliciting student ideas, but not discussing or addressing them, and a transitional use of this strategy comprised something in between. An example of sophisticated implementation came from Mr. J in Lesson 3: After introducing the Runoff Formative Assessment (FA) and providing students with time to complete it, Mr. J led a share out session during which student examples were presented anonymously to the rest of the class. During this session, Mr. J asked students to respond to the examples presented by supporting or refuting the claims made and by explaining the reasoning they used to do so. In this way, he used the FA to elicit student thinking, make that thinking public, and then engaged students in a discussion about the ideas that were expressed. We considered this an instance of sophisticated use of formative assessment because it involved not just eliciting ideas, but immediately and thoroughly addressing them as well. Divergent from the previous example is an example of emergent implementation from Ms. L, also in her third lesson: Ms. L provided an example of a less sophisticated use of formative assessment. In this case, the teacher introduced the FA, provided students time to answer the questions involved, and then had them share out their ideas in small groups. Finally, she asked a few students to share their ideas with the whole class. We considered this instance to be an emergent use of formative assessment because, while the teacher did elicit student ideas, she did not discuss or address them to any significant extent.

For instances of principle- and/or evidence-based reasoning, we also used the inductive codes of emergent, transitional, and sophisticated. We considered sophisticated implementation of this strategy as teachers explicitly asking students for reasoning based on principles and/or evidence through class discussion. We considered an emergent use of this strategy to be teachers using something like a process tool to engage students in principle- and/or evidence-based reasoning, but neither making this explicit to the students nor visibly engaging students in this reasoning. We decided if the teacher was doing most of the talking her or himself, it was an example of emergent implementation. If the teacher focused on asking probing questions, such as 'why do you think that?', it was transitional. And if the teacher focused on the probing questions and the students (rather than the teacher) displayed the reasoning, we considered that a sophisticated example.

As stated above, we defined this teaching strategy as engaging students in developing increasingly complex, principle-based and/or evidence-based accounts of environmental processes in socio-ecological systems. We chose to look at sophisticated instances of reasoning using an even finer grain size of analysis -- (a) to determine if instances were of evidence-based reasoning, of principle-based reasoning, or of both and (b) to search for patterns in the number or types of questions teachers posed. For instances of reasoning we deemed evidence-based, we looked for students discussing data and/or observable events. We asked, Are the students talking about a reason why based on something they actually observed? For principle-based instances, we looked for the principle they were using, such as gravity. Are the students talking about some driving force/principle – talking in generalities? Principles we identified for the carbon cycling TE included conservation of matter or mass, chemical bonding, photosynthesis (light and dark), respiration, and energy. Principles we identified for the water cycling TE included gravity, permeability, infiltration, conservation of mass, evaporation, and condensation. Principles for the biodiversity TE that we identified included food chains and food webs, classification (by feeding groups, like decomposers), and energy.

A sophisticated use of the teaching strategy of engaging students in principle- and/or evidence-based reasoning came from Ms. S, a middle school teacher teaching carbon cycling. She specifically asked students to provide evidence and reasoning for their ideas about what contributes to the mass of plants. She asked the students to consider if light was contributing to the mass of plants and to think about the "facts about light" they had learned in a previous lesson that would provide evidence for their reasoning. Ms. S elicited students' evidence and reasoning in a whole-class discussion and had students record the evidence and reasoning in their notebooks. In contrast, Ms. E, also a middle school teacher teaching carbon cycling, showed emergent use of engaging students in principle- and/or evidence-based reasoning. Ms. E asked students to work in groups to complete a process tool, a tool provided in the curriculum to support students' thinking and reasoning using visual cues. Although the process tool guided students in principle- and evidence-based reasoning, Ms. E did not make this reasoning explicit. After students finished the process tool, Ms. E provided an explanation to the class, rather than using class discussion to elicit students' ideas and reasoning.

To summarize, our purpose in undertaking this first cycle of analysis was to map both the frequency and the quality of strategies used by teachers as they productively engaged their students in talking and thinking about environmental science concepts. For reasoning, we delved further into sophisticated instances to better understand the types of reasoning teachers and students used as well as the types of questions teachers posed.

To answer research question 2, on the ways the curriculum supported (or not) teachers' implementation of focal strategies, we conducted a second cycle of analysis. We returned to all instances of these strategies found in the video records of classroom instruction. We decided to examine only the focal strategy of principle- and/or evidence-based reasoning, because it was much more common. We determined which TEs provided teachers opportunities to engage their students in this practice. For sophisticated instances, we also compared what teachers did in their classrooms to what was specified in the TEs themselves. Our purpose in undertaking this second cycle of analysis was to see if the three TEs provided teachers similar opportunities to engage their students in sophisticated reasoning.

Findings Set 1: To answer research question 1, we examined teachers' use of formative assessments and engagement of students in principle- and/or evidence-based reasoning.

Use of Formative Assessments: We observed limited use of the formative assessments recommended in the curricular materials (see Table 1). Only 7 of the 16 teachers, in two of the three curricular strands, carbon cycling and water cycling, implemented this strategy within instructional segments that included productive discussions. These formative assessment instances totaled 17 and ranged from 1 instance for Mr. A, who taught middle school carbon cycling, to 4 instances for Ms. E, who also taught middle school carbon cycling.

We also found that these seven teachers exhibited emergent to sophisticated use of this strategy. To remind readers, we considered a sophisticated use of formative assessment as moving beyond *eliciting* student ideas to substantively *engaging* students with these ideas. In total, 7 of the 17 instances of this strategy were deemed sophisticated. Five of the seven teachers had at least once sophisticated instance of this focal strategy.

Table 1

Instances of Teachers' Use of Formative Assessments

Teacher	Region	TE	Grade Band	Instances of use of formative assessment	Sophisticated	Transitional	Emergent
Ms. E	West	Carbon	MS	5	2	1	2
Mr. G	Central	Carbon	HS	3		1	2
Ms. P	East	Water	HS	3	2	1	
Ms. L	West	Water	MS	2	1	1	
Ms. S	Mountain	Carbon	MS	2	1		1
Mr. J	Mountain	Water	MS	1	1		
Mr. A	East	Carbon	HS	1		1	

Evidence- and Principle-Based Reasoning: Because we observed many more instances of engaging students in evidence- and/or principle-based reasoning, we focused in more detail on this strategy in our analysis. We found 57 instances of this strategy (see Table 2). These were fairly evenly divided between the teachers teaching the carbon cycling and water cycling Teaching Experiments (TEs), with 33 and 21 instances, respectively, and with an additional 3 instances observed from the teachers using the biodiversity TE. We observed instances of principle- and/or evidence-based reasoning within productive discussions for 12 of the 16 teacher participants. These instances ranged from one for Mr. D and Ms. M, who taught middle school water cycling and high school biodiversity, respectively, to 10 for Ms. E, who taught middle school carbon cycling. As with formative assessments, some teachers exhibited sophisticated use of this strategy while others showed emergent use; many teachers exhibited instances of two or three of these levels. From our inductive descriptive codes, we considered sophisticated use of this strategy as teachers explicitly asking students for reasoning based on principles and/or evidence through class discussion.

Table 2

Instances of Teachers' Use of Principle- and/or Evidence-Based Reasoning

Teacher	Region	TE	Grade Band	Instances of Principle- and/or Evidence-Based Reasoning	Sophisticated	S-Principle	S-Evidence	S-Both E&P	Transitional	Emergent
Ms. E	West	Carbon	MS	10	3	1		2	5	2
Mr. G	Central	Carbon	HS	8	1	1			3	4
Mr. A	East	Carbon	HS	8	3	2		1	4	1
Mr. J	Mountain	Water	MS	7	4		4		3	0
Ms. S	Mountain	Carbon	MS	7	6	2	3	1	0	1
Ms. V	Mountain	Water	HS	5	1			1	1	3
Mr. K	West	Water	MS	2	2	1	1		0	0
Ms. L	West	Water	MS	3	0				2	1
Ms. P	East	Water	HS	3	1		1		2	0
Ms. F	Central	Biodiversity	HS	2	0				1	1
Mr. D	Central	Water	MS	1	0				1	0
Ms. M	East	Biodiversity	HS	1	0				1	0

We saw varied contextual differences among these categories of emergent, transitional, and sophisticated for different teachers, TEs, and classroom activities. As can be seen by Table 2 above, most teachers who exhibited the teaching strategy of principle- and/or evidence-based reasoning did so at different levels of sophistication at different times. For example, Ms. E exhibited this teaching strategy 10 times, 3 at the sophisticated level, 5 at the transitional level, and 2 at the emergent level. Of the three sophisticated instances, one was specifically principle-based reasoning and the other two showed students' argumentation to include both principle-based and evidence-based reasoning.

Principle-Based Reasoning: A powerful illustration of principle-based reasoning came from Ms. S, who taught middle school carbon cycling in the mountain region. Students conducted experiments and had class conversations about mass versus weight gain. Of her seven instances of principle- and/or evidence-based reasoning, six were coded as sophisticated. Of the six sophisticated, two weres coded as principle-based reasoning, three as evidence-based, and one as both. One of the sophisticated principle-based reasoning instances occurred in Lesson 3: Teacher and students discussed the relationships among water, mass, and growth.

The other sophisticated principle-based reasoning example from Ms. S, in Lesson 7, occurred when the class was discussing the fact that they found water in baggies they had taped around the end of tree limbs. The evidence of the water in the bag started the conversation about transpiration. The students did not yet know it is called transpiration, but they were reasoning through where the water came from. The students discussed processes that could have led to water being in the bags. This was coded as only principle-based reasoning. If the teacher had asked, 'Does the plant transpire?' and the students had answered, 'Because there was water in the bag,' then it would have been coded as both. In short, in this case, a small piece of evidence was used to prompt students' principle-based reasoning about transpiration. Some of the probing questions Ms. S asked her students are listed below.

> Who looked in the bag? What did you see? Did anybody see anything in the bags besides the plant?
>
> What kind of moisture?
>
> What is happening here? Where did this water come from?
>
> What do you think? Where did it come from?
>
> Does photosynthesis make water? Where did this water come from? How did it get from the trunk to here? What does that mean? If there's water in the trunk, how did it get into this bag? A pump, and what did that pump look like?
>
> So the plant has some cells that have big molecules in them that has lots of energy and the plant is breaking those cells down and water is coming out of them. So the water is coming out of the plant?
>
> Any other ideas?
>
> Wait, water comes out of plant leaves? How can that happen?
>
> Where did that water vapor come from?
>
> Do you agree that it is coming from the leaves? From plant sweat?
>
> Where does it come out? What part of their leaves?
>
> What might it be letting out? Liquid? Drops?
>
> Do you remember learning about the water cycle?
>
> Does that make sense?
>
> What do you think is going to happen to it now?

To clarify, as made visible in the example of Ms. S above, the questions teachers posed seemed to be the difference between emergent and transitional levels of this teaching strategy. The teachers' use of those questions to prompt their students to engage in reasoning was the difference between transitional and sophisticated levels. Teachers' questions led us to want to know how the TEs supported opportunities for these principle- and/or evidence-based reasoning occurrences. This is explored in Finding Set 2 below.

Evidence-Based Reasoning: A straight-forward example of evidence-based reasoning by students came from Mr. J, teaching water cycling in a middle school in the mountain region. He began the water cycling TE by showing his students an aerial picture of their school grounds and by asking them when they thought the picture was taken. He did the same a little later in the lesson with a picture of the school obtained from Google Earth.

Instance 1:

Mr J: So if we look up here, our eyes are up here, we're looking at this. This is our school. And a little bit of foundational background is that this was taken, we have a sixth grade teacher, Ms. L is new to our school, her husband is an aerial photographer. And so just out of the blue, he was flying over on a route to do another job he was getting paid for, and he said he flew right over School Name so he snapped this photo. So we have a pretty good shot. Who would like to make an inference and say when was this picture taken. Student 1?

S1: Near the beginning of the year because they changed the sidewalk.

Mr. J: Oh, creative observation. Right here? [pointing to picture on screen].

S1: Yeah.

T: There had been some work done there. Anybody else want to make a guess, with some data to support their thinking? How colorful is the grass?

S2: I'd say not on a school day because there aren't that many cars.

Mr. J: That's a great observation.

S3: Maybe teacher work day.

Mr. J: OK, maybe actually - a few teachers, [pointing to picture]. Maybe it's -

S2: They're also, they're also aren't any like PE classes outside. Or anything outside which usually there are.

Mr. J: Nice observations. Another one?

S4: I'd say it would be closer to now [February] because some of the grass is dead. It isn't taken care of.

S5: Probably winter because they would cover over the sand for the long jump and they look covered.

Mr. J: Ah, that's a good observation. I didn't even think about that. Those are the long jump pits right?

Instance 2: 20 minutes later

Mr. J: Here's a different map of our campus. This one is complements of Google Earth. It's really cool that we got satellites and imagery taking pictures all the time. And before, we got an airplane at maybe thousand feet above the Earth, this is taken from hundreds if not thousands of miles above the Earth. Unbelievable pixelization. Ok. We could go outside and take a walking tour, and we'll be outside some, but maybe not today. Student 6, you had a question?

S6: Oh no, I was - I thought you were going to say when it was taken.

Mr. J: OK. We'll do the same observation. Observation is a great science skill. Student 6?

S6: I think it was taken after winter because all the grass is dead.

Mr. J: After winter. So, no snow on the ground, but no real sign of living grass. Could be. Yes sir, Student 7?

S7: I think it was spring or early summer, because there are not a whole lot of cars in the parking lot.

Mr. J: OK. Not a whole lot of activity around. Another one?
S8: Depending on what year, it could have been during the winter, or early spring.
Mr. J: Because?
S8: Well, we don't always get snow during Christmas break, so.
Mr. J: Ahh. So you're saying Christmas break, there is no cars, so you're thinking December time -
S8: Yeah

Across these two examples, we found that at least eight students were engaged in reasoning about the photographs and providing evidence for their reasoning. Also, we found that the teacher did not have to ask multiple probing questions; rather, the students frequently provided evidence with their answers on their own. We noticed this with one other teacher as well: Students provided reasoning without explicit and repeated prompting. Wewill talk more about this in the implications section below.

Both Types of Reasoning: We also found many instances where principle-based and evidence-based reasoning were intertwined, frequently one supporting the other. One such example came from Ms. E, teaching the carbon cycling TE in a middle school on the west coast. Ms. E started one lesson with the questions, “Why did CO2 levels increase in the dark? What process might be work here?” After watching a video of plants in the light and in the dark with a probe to measure CO2, Ms. E led a whole class discussion around the aforementioned questions. She followed up with the questions below.

What’s the process you’re thinking of here; do you know the name of it?
Does that increase the CO2 around the plant or does it decrease it?
Does the plant give it off or take it in?
What does it give off during photosynthesis?
During the light reaction, what was happening to the oxygen levels?
What about the level of CO2 in the light?
Did anybody else have a different idea?

These questions came from a modification of Lesson 7 from the carbon cycling TE. The teacher modified the lesson because her classroom probes were not working;the students were unable to do the experiment themselves. As an adaptation, the class watched a video of the experiment and then had to explain what happened. Both principle- and evidence-based reasoning were seen in student answers to the above questions from the teacher. Students observed (virtually) differences in CO2 and O2 levels in the light and in the dark, used that as evidence to describe a change, and then reasoned with principles to explain that change.

Findings Set 2: To answer research question 2, we examined the opportunities teachers provided their students to engage in principle- and/or evidence-based reasoning by TEs. As stated above, we focused our second cycle of analysis on reasoning as it was much more common than use of formative assessments. Overall, we found that the carbon cycling and water cycling TEs facilitated teachers' use of this teaching strategy more readily than the biodiversity TE. Of the 57 instances of principle- and/or evidence-based reasoning, 33 occurred during the carbon cycling TE, 21 during the water cycling TE, and only 3 occurred during the biodiversity TE.

We also found that the carbon cycling TE provided teachers with a wider range of opportunities to engage their students in sophisticated principle- and/or evidence-based reasoning than the other two TEs. Of the 57 instances of this teaching strategy, 21 were coded as sophisticated. Of these 21 sophisticated instances, 13 occurred during the carbon cycling TE and 8 during the water cycling TE. There were no examples of sophisticated reasoning from the biodiversity TE. More importantly, for the carbon cycling TE, the 13 sophisticated instances were spread over all 4 of the carbon cycling teachers and across seven of the 11 lessons in the TE. For the water cycling TE, the 8 sophisticated instances were spread over 4 of the 6 water teachers. However, all instances of sophisticated reasoning were found tied to the exploration piece of the first of the four lessons in the TE. For the water cycling TE, there were no instances of sophisticated reasoning beyond the first of its lessons.

Finally, we found that the carbon cycling and water cycling TEs provided teachers flexibility in how they engaged their students in sophisticated reasoning. These TEs provided this flexibility in three ways. One, teachers using these two TEs were able to use diverse activities to promote sophisticated reasoning. For the carbon cycling TE, sophisticated instances were spread across activities, readings, a quiz, the process tools, a warm up, and "evidence buckets**."** Similar to carbon cycling, instances for water cycling were spread across discussing the Formative Assessment Map, PowerPoint presentations, examining a map of an actual school campus, and an individual/small group/whole class activity that explored local rainfall data. Two, for both TEs, instances included both instruction specified in the TE and instruction that resonated with the TE but was designed by the teachers themselves. Three, again, for both TEs, instances spanned principle-based reasoning, evidence-based reasoning, and both.

In sum, we found that the carbon cycling TE, and to a lesser extent, the water cycling TE did indeed provide a resource for teachers to engage students in sophisticated principle- and/or evidence-based reasoning. These TEs also created a platform for teachers to build additional instructional contexts to engage their students in such reasoning. Additional exploration into the strengths and limitations of the biodiveristy TE in relation to reasoning is needed.

Implications and Future Research: We identified four implications of our study. One, we found a given teacher was not necessarily consistent in the quality of his or her implementation for our two focal strategies. Ms. E, for example, exhibited instances of reasoning that spanned emergent, transitional, and sophisticated levels. This finding that a teacher varied in the quality of her or his implementation of a strategy -- even within a given TE -- underscores the importance of observing teachers' practices across multiple lessons. One lesson appeared inadequate to determine the depth and quality of a teacher's use of a particular teaching strategy.

A second implication came from our examination of teachers' questioning to prompt principle- and/or evidence-based reasoning. Our examination of the questions teachers used to facilitate sophisticated instances of reasoning did not yield any identifiable patterns in number or types of questions posed. A possible future direction is to compare teachers' questions posed in emergent vs transitional vs sophisticated instances. Is there a difference in the kinds of questions teachers ask (Roach & Yestness, 2009), or is it difficult to predict the quality of a discussion by just looking at the teachers' questions?

A third, related implication was suggested by our examination of Mr. J and Ms. S. As discussed above, the students in Mr. J's class provided evidence with their answers without needing additional prompting from the teacher. Similarly, Ms. S's consistent use of "evidence buckets" appeared to facilitate her students' use of sophisticated reasoning. In other words, these two teachers had science norms established in their classes that helped students engage in reasoning. Perhaps these more concrete norms/practices could be suggested to teachers – to provide teachers with specific tools beyond just encouraging them to engage their students in reasoning.

A fourth implication emerged from our examination of the mis/connections between reasoning instances and TEs. Even though all three TEs were designed using a learning progression framework and all three encouraged teachers to engage students in principle- and/or evidence-based reasoning, the carbon cycling TE appeared better able to support teachers in using this reasoning strategy than either the water cycling or biodiveristy TE. This finding suggests that carefully developed curriculum materials can indeed support teachers in effectively implementing strategies aligned with learning progression frameworks. However, further research is needed to determine which aspects of the carbon cycling TE were most integral to teachers' sophisticated implementation.

Conclusion: In this paper, we discussed what drives and challenges teachers' implementation of LP-based teaching strategies, particularly their implementation of formative assessments and efforts to engage students in principle- and/or evidence-based reasoning. We identified both evidence of promise and areas in need of additional exploration. More specifically, we found that teachers were able to implement these two focal strategies in their classrooms -- sometimes in sophisticated ways. This finding suggests that teachers should be encouraged to use strategies aligned with learning progressions in their teaching. We also found, however, that teachers more frequently engaged their students in principle- and/or evidence-based reasoning than in formative assessments and that teachers who implemented the carbon cycling TE were better able to engage their students in sophisticated reasoning than teachers who implemented the water cycling or biodiversity TEs. These latter findings suggest that future research is needed to better understand reasons for such disparities and to better determine if such disparities are indeed instructionally important. These future directions are needed to inform teachers' own learning about learning progression frameworks and teaching strategies, as well as their practices for enhancing students' learning outcomes in environmental science.

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