Paper presented at the annual meeting of the National Association for Research in Science Teaching, Rio Grande, Puerto Rico (April 6, 2013)

Student Learning Progressions and Teaching Practices in Carbon-Transforming Process

Jiwon Kim, Li Zhan, Jennifer Doherty, and Charles W. Anderson
Michigan State University

In our project, we have been exploring student learning progressions, focusing on how students develop understanding of carbon-transforming process at multiple scales such as photosynthesis, biosynthesis, cellular respiration, combustion, and decomposition (Jin & Anderson, 2013; Mohan, Chen, & Anderson, 2009). The studies on learning progressions have revealed the increased levels of sophistication in students' understanding from naïve force-dynamic reasoning to sophisticated scientific reasoning.

We have supported students' learning progressions by engaging them in both inquiry and accounts practices. Each curriculum unit has reflected the tenet by including two core activity sequences, one focusing on investigation and the other focusing on accounts (Figure 1). Inquiry practices aims to build scientific explanations and make claims by engaging in both measurements and reasoning through evidence. The inquiry cycles in each unit are supported by a PEOE (predict-explain-observe-explain) structure. In comparison, accounts cycles focus on helping students apply scientific principles to various phenomena of carbon-transforming processes. This sequence scaffolds student learning by providing a series of chances to realize unanswered questions that come from the investigations (establishing problem), to observe how teachers are engaging in the scientific accounts activity (modeling), to do practice the activity with supports from either teachers or peers (coaching), to engage in the activity independently with less supports (fading), and to apply the activity to different situations in other units (maintaining) (Dauer, Miller, & Anderson, in press).

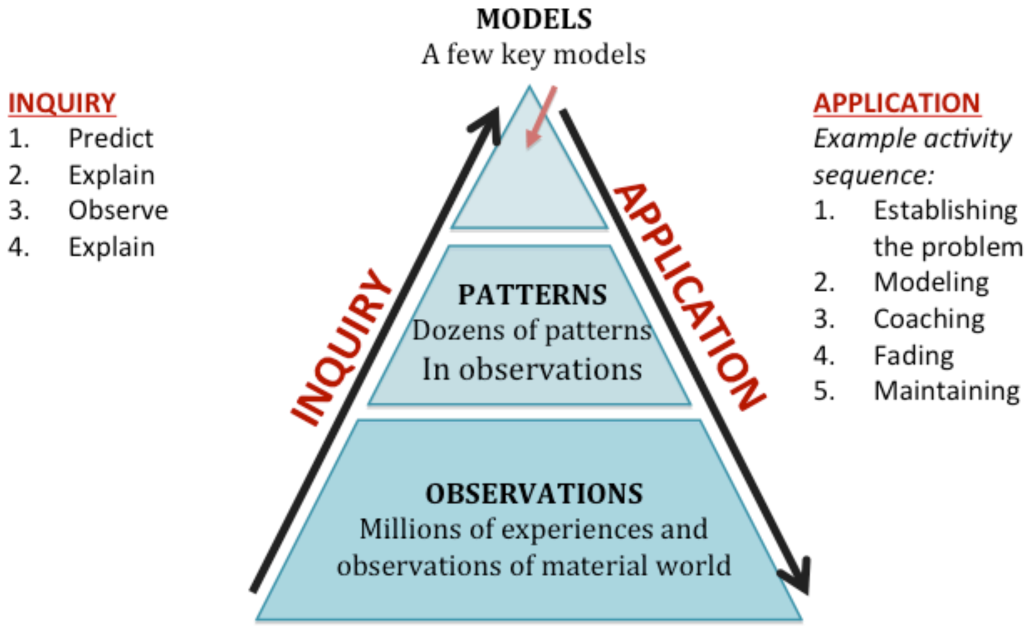

Figure 1. Inquiry and accounts activity sequences

Although we have developed learning progression-based teaching units, teachers are the ones who actually mediate between students and curriculum. Teachers work with students in classrooms by employing inquiry and accounts activity sequences. In this sense, teachers are expected to play a crucial role in supporting students to make transitions among levels. It appears consistent with the literature that has identified teachers as a main factor affecting student achievement (Darling-Hammond & Youngs, 2002; Rivkin, Hanushek, & Kain, 2005).

In consideration of teachers' role in student learning, one of our previous studies examined the relation between teachers' understandings and reported uses of curriculum materials and students' learning gain on carbon-transforming processes (Zhan, Cisterna, & Anderson, 2012). Based on student pre- and post-assessments and the interviews with teachers, this study revealed that teachers who have students with high learning gain showed deeper understanding of connections among different levels of teaching units, which are tools, activities, lessons, and unit. For example, teachers with high learning gain classrooms tended to connect individual activities with broader learning goals of the teaching unit. Although this study shed light on the possible effect of teachers' understanding and instructional practices on student learning, there is a limitation that teacher interviews based on self-report and stimulated recall may not fully reflect the actual instructional practices that the teachers did in classrooms.

Therefore, in the current research, we specifically focus on actual classroom instruction and learning events in which teachers implement the teaching materials. We attempt to explore how teachers' instructional practices support student learning in ways that enable students to make meaningful progress through learning progressions (Figure 2). There are two research questions we pose in the current study:

1. How do student learning gains differ among teachers?
2. How are differences in teachers' implementation of the curriculum related to student learning?

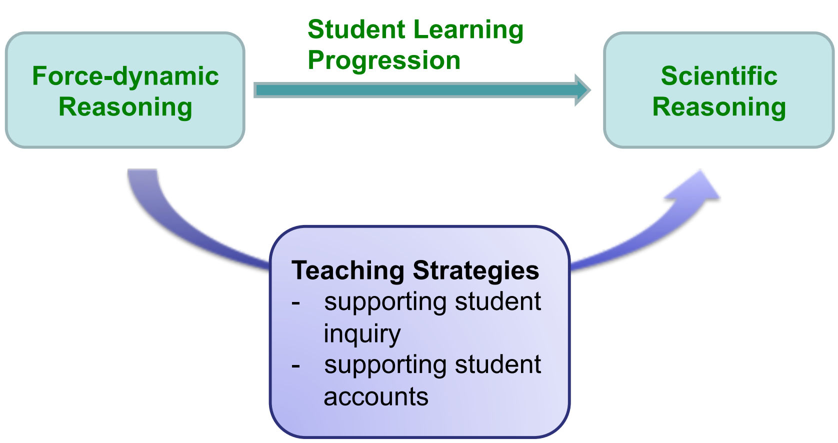

Figure 2. Teaching strategies to support student learning progressions

Methods

In the current study, we focus on seventeen teachers and their students who participated in Carbon TIME project during the 2011-12 academic year. Among seventeen teachers, three of them were middle school science teachers; the others taught in high schools. As part of a broader project context, student pre- and post-written assessments, student interviews, and student classroom work were collected for understanding student learning over the year. In order for understanding teachers' knowledge and their curriculum implementation, teachers' content and pedagogical content knowledge assessments, classroom videos, and teacher unit feedback were collected.

As an exploratory study, in the current research, we particularly focus on student written assessments and classroom videos. Student pre- and post- written assessments were analyzed to calculate student learning gains by teacher. We analyzed 464 students' matched written responses (82 are middle school and 382 are high school students) from the seventeen teachers' classrooms.

In order to see how teachers' implementation of the curriculum might be related to student learning preformance, we analyzed classroom videos of teachers who have different learning gains. The teachers participated in the project were asked to teach at least three curriculum units out of six during the school year and to video record one activity from each unit they taught. We provided the information of which activity teachers need to video tape for each curriculum, which means that teachers who implemented the same unit video recorded same activity.

In order to choose teachers for analyzing classroom videos, first, we identified two groups of teachers whose student learning gains were significantly different based on student written assessments analysis (Figure 4, in Findings below). From those two groups of teachers, we chose two pairs of teachers who taught the same unit within the same school level. At middle school level, we identified a pair of teachers who taught the same Systems and Scale unit, recording the required activity, but having significantly different student learning gains. In the same manner, we chose a pair of teachers who taught the Plants unit at high school level.

In middle school comparison, we analyzed classroom videos of the Burning Ethanol: Claim, Evidence, Reasoning (CER) activity from the Systems and Scale unit. The Burning Ethanol activity is located in the last "Explain" part of the inquiry sequence (Figure 3). Before this activity, students finished the investigation of burning ethanol, focusing on BTB color change and mass change in soda lime and ethanol. In the current activity, now students were trying to explain what they observed and revisit their initial prediction and explanation, which were the first two parts of the inquiry sequence.

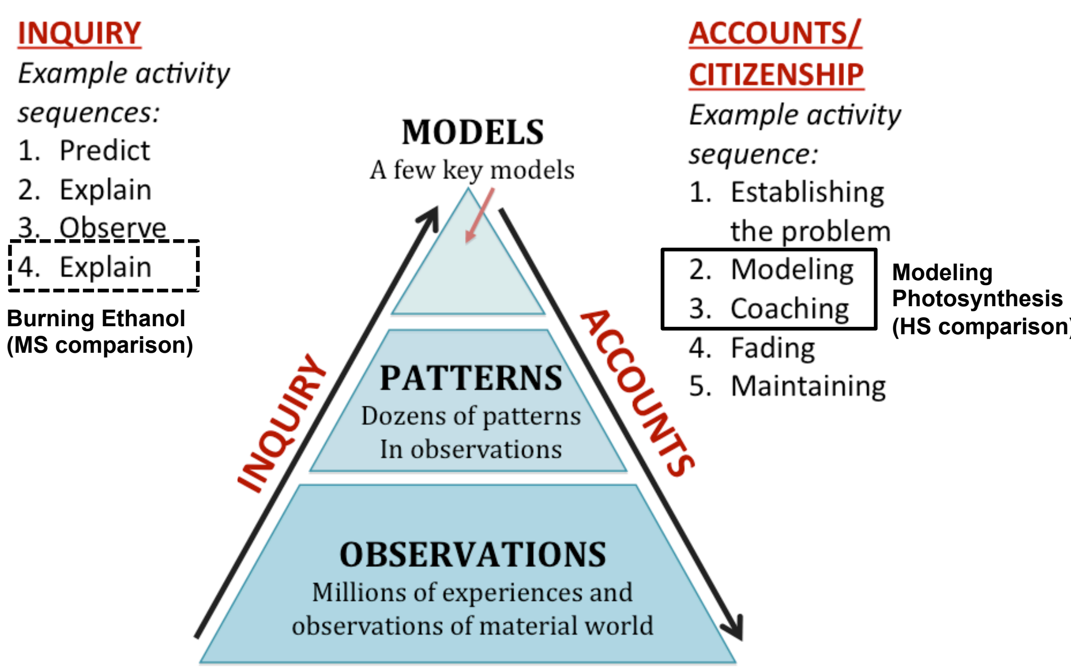

Figure 3. Location of focus lessons in the instructional sequences.

In high school comparison, we analyzed classroom videos of the Modeling Photosynthesis activity from the Plants unit. This activity includes both “Modeling” and “Coaching” parts in the application sequence (Figure 3). In this activity, teachers explain photosynthesis process at the macro, micro, and atomic molecular levels. Then, students build molecular models to understand the photosynthesis process at atomic molecular level, and teachers are coaching student molecular building activity.

We conducted our video analysis using “constant comparison” (Corbin & Strauss, 2008). We cataloged videos and measured time spent in each identified event. Then, we constantly looked for similarities and differences in classroom videos of different teachers. We also compared classroom videos to the written curriculum, looking for whether teachers implemented the activity as the curriculum developers intended and what similarities or differences existed among teachers in implementing curriculum. In both “teacher to teacher” and “teacher to curriculum” comparisons, we attempted to identify (a) what types of content, formative assessment, inquiry/accounts activities, and classroom discussion were employed (b) in which ways (c) for how long/many times. This analysis consisted of cumulative cycles of interpretive process in which we continued to (re)construct and test our understanding of how teachers actually work in classroom with students on carbon-transforming processes.

Findings

Finding 1. Different student learning gain by teachers

From the student pre-and post-assessment, we found different student learning gains by teachers. The graph (Figure 4) shows student learning gain between pre and post assessment by teachers. The horizontal axis represents Cohort 1 (2011-12 year) teachers’ IDs, and the vertical axis represents student learning gain measured in logit scale. Each dot represents the mean of student learning for each teacher, and the error bar represent the 95 % confidence interval around the mean. Thus, if two teachers' ranges of logit scores do not overlap, we believe that there is significant difference in student learning gains between these two teachers.

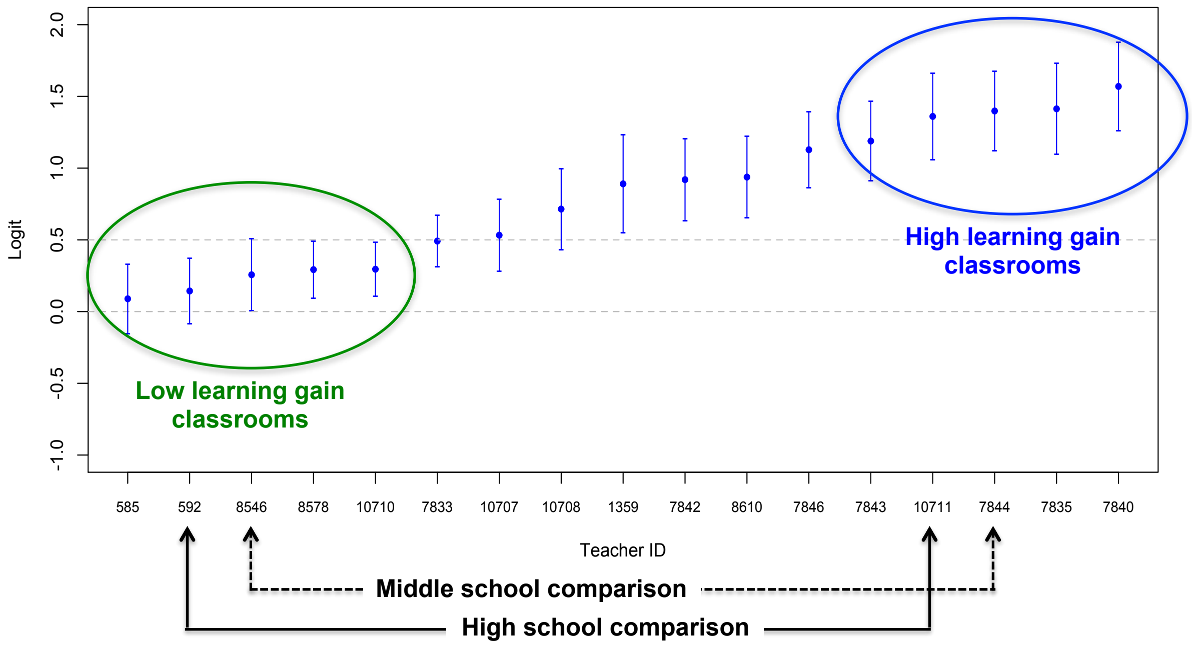

Figure 4. Comparison of teachers' mean learning gains (same student pre-post differences). Error bars represent 95% confidence intervals.

According to this graph, this line 0 means that the mean student proficiency (measured using a logit scale based on a Rasch-model analysis) did not change between pre and post assessment. As the graph shows, there are different learning gains in different classrooms. On one hand, there are several teachers whose students made bare improvement between pre and post. We grouped them as "Low Learning Gain" (Low-LG) classrooms. On the other hand, the most successful teachers showed much higher learning gains, above 1.0 logits. We named these classrooms as "High-Learning Gain" (High-LG) classrooms.

Finding 2. Differences in teachers' curriculum implementations and teaching practices

We used these results to compare the teaching practices of high and low learning gain teachers, focusing on ways in which teachers from those two groups implemented the curriculum in classrooms. As the Figure 4 shows, we compare between teachers' teaching practices in the Low- and High-LG groups within same school level. At the middle school level, we chose teachers 592 and 10711 respectively from the Low- and High-LG classrooms; both teachers taught the *Systems and Scale* unit. At the high school level, we chose teachers 8546 and 7844 from each group, focusing on how they taught the *Plants* unit. The Table 1 summarizes the information of school level, unit taught, teacher IDs, and identification of Low/High-LG for the four teachers.

Table 1. Classroom video analysis information

School level	Unit/Activity	Teacher IDs	Student learning gain
Middle school	Systems and Scale/ Burning Ethanol	592	Low-LG
		10711	High-LG
High school	Plants/ Modeling Photosynthesis	8546	Low-LG
		7844	High-LG

Teachers' unit feedback and classroom videos showed little difference among teachers in their content coverage. Both Low- and High-LG teachers appeared to implement the curriculum materials relatively faithfully. A closer look at the ways teachers implemented curriculum, however, revealed three dimensions of difference between two groups of teachers: (a) how content is discussed, (b) how teachers scaffold student learning, and (c) how teachers provide students with opportunities for getting feedback. In the next section, we discuss how these differences were found in both middle and high school classrooms.

<u>Middle school comparison</u>

Our comparison of the two middle school lessons is organized around the three dimensions of difference listed above.

How content was discussed. The Low-LG teacher tended to talk mostly to identify the reactants and products in combustion while the High-LG teacher discussed big ideas and principles underlying the process. For example, when students wrote their claim, evidence, and reasoning for explaining burning ethanol investigation, the High-LG teacher asked students to refer to five practices, which are principles and big ideas to follow. The teacher emphasized, “Do your explanation fit those rules? If you talk about energy, is there conservation of energy? If you talk about mass, is there conservation of mass?”

In addition, the Low-LG teacher discussed matter and energy without clear distinction between them while a clear distinction was made in High-LG teacher’s classroom. For example, the High-LG teacher used the Matter and Energy Process Tool (Figure 5) to help students distinguish between matter and energy. While students worked on filling out reactants and products in the process tool, the High-LG teacher emphasized using a box to identify matter and a start burst to identify energy. By highlighting the importance of using different figures for matter and energy, the High-LG teacher helped students to distinguish between changes in matter and transformation of energy when ethanol burns. Also, the teacher emphasized that matter has mass while energy does not. In contrast, there was little focus on differentiating between matter and energy in the Low-LG classroom.

How teachers scaffolded student learning. In burning ethanol activity, students were asked to explain burning ethanol using framework of claim, evidence, and reasoning. Students needed to make their claims based on the evidence that they observed from the investigation such as BTB color change and mass change in soda lime and ethanol. In this activity, the Low-LG teacher introduced claim, evidence, and reasoning as separate questions on the worksheet. In this classroom, students followed claim, evidence, and reasoning step by step, and discussed each of

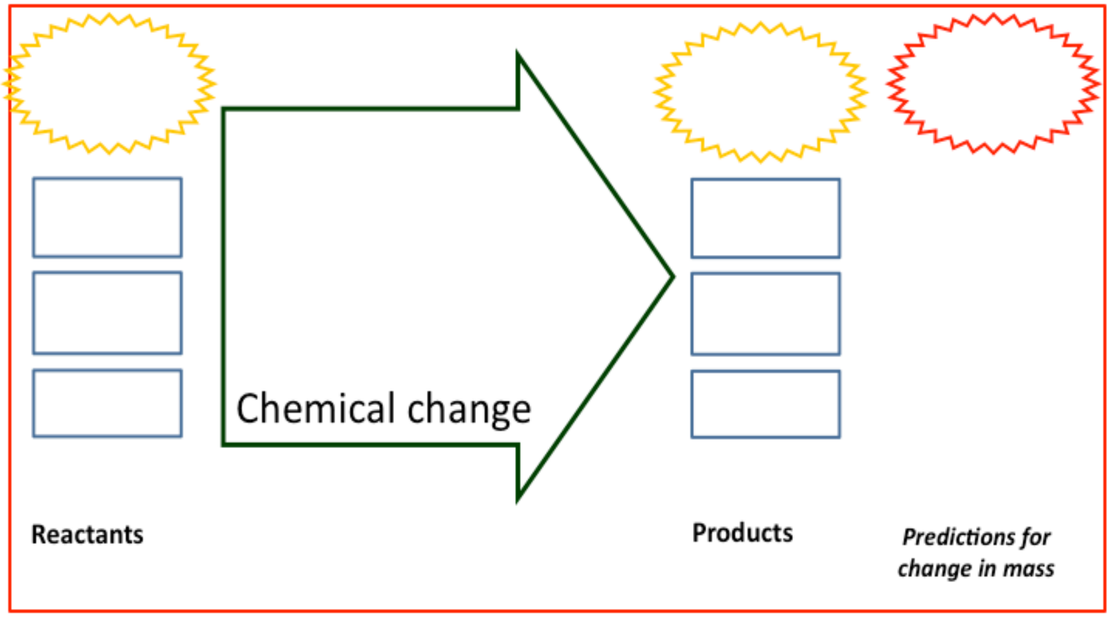

Figure 5. Matter and Energy Process Tool

them separately. In contrast, the High-LG teacher had students work on making claims with close connections to evidence bridged by reasoning. The teacher had students work on claims, evidence, and reasoning at the same time, guiding students to look at CER as a whole explanation. In summary, the Low-LG teacher had students work on making claims separately from evidence and reasoning while students in the High-LG classroom constructed coherent arguments with close connections among claims, evidence, and reasoning.

Students' opportunities to share their ideas and get feedback. Students in the High-LG classroom had more chances to share their ideas and get feedback from both peers and teacher in comparison to those in the Low-LG classroom. The Low-LG teacher had students work individually and selected a few individual students to report their answers and responded to them. The High-LG teacher, on the other hand, had students work in groups to share their ideas with peers; then as a whole class every group reported and the teacher gave feedback to all groups.

For example, the Low-LG teacher had students individually think and write their CER for a short period of time (less then 10 minutes in total, 2-3 minutes for writing claim, evidence, and reasoning respectively) and called out three or four students to report what they wrote for CER. In contrast, the High-LG teacher had students work in groups and encouraged them to share their ideas with peers. The High-LG teacher emphasized, “Don’t write until everybody shares ideas and agree on. Speak and share first.” This teacher also allocated 20 minutes for group discussion, a larger time commitment than the Low-LG teacher. After the small group conversations, the High-LG teacher asked every group to report their groups’ CER writing, and her gave feedback to each group. After listening from all the groups, as a whole class, the High-LG teacher gave his overall comments about students’ CER practices. Thus, in summary, the Low-LG teacher provided selected individuals with opportunities to get feedback on their ideas while the High-LG teacher provided all students with chances to share their ideas and get feedback from peer and teacher through group work activity.

Table 2 below summarizes the three differences we found from comparing Low- and High-LG middle school classrooms.

Table 2. Middle school Low- and High-LG classrooms comparison on explanations of Burning Ethanol in the *Systems and Scale* unit

	Low-LG classroom (Teacher 592)	**High-LG classroom** (Teacher 10711)
Content	- Reactants/Products - Matter/Energy not clear	- Principle-based - Matter/Energy clear distinction
Scaffold Student Learning	- Separate claim, evidence, reasoning	- Coherent argument
Opportunities for Feedback	- Few individual - Teacher-to-student	- All groups - Peer/teacher feedback

<u>High school comparison</u>

We also found similar differences in ways that high school teachers implemented curriculum, Modeling Photosynthesis activity.

How content was discussed. In high school classrooms we found similar patterns to those we saw in middle school comparison. The Low-LG teacher mostly talked about the reactants and products in photosynthesis process, and there was little discussion of photosynthesis at the atomic-molecular scale in this classroom. The Low-LG teacher showed a short video clip of photosynthesis at the atomic-molecular scale, which shows how atoms are rearranged, but there was no teacher's follow-up explanation of the video and students moved onto building the molecular models of photosynthesis. Also, matter and energy were discussed without either clear distinction or relation between them in this classroom.

In contrast, the High-LG teacher appeared to do principle-based teaching by focusing on conservation laws of matter and energy. Also, the High-LG teacher discussed the process of photosynthesis at the atomic-molecular scale by not only identifying reactants and products but also by discussing how atoms are rearranged, tracing individual atoms through the process. In addition, the teacher distinguished energy from matter by highlighting that energy cannot become matter and chemical energy is stored in C-C, C-H bonds.

How teachers scaffolded student learning. There were different ways found in which the teachers allocated time between conceptual understanding and technical procedures in the classroom activity. In the Low-LG classroom, each group of students moved at their own pace and focused more on following the procedures while students in the High-LG classroom discussed both procedures and big ideas and moved as a whole class. The Low-LG teacher had students build molecules using the modeling kit in a procedural manner, but there were few scaffolds for students to understand the substantive meaning of the activity. The students in the Low-LG classroom spent two class periods just building the molecular models, and there was no whole class discussion of what is the purpose of the molecular building activity and what each step represents in photosynthesis. In contrast, a clear purpose of molecular building activity was evident in the High-LG classroom. The High-LG teacher discussed how to build molecular models and clearly reminded students of what they are building in each step. Also, whole class moved together through each step. Overall, students in the High-LG classroom spent more time thinking about atoms' rearrangement while spending less time on building molecules.

Students' opportunities to share ideas and get feedback. In the Low-LG classroom, none of the students got personal feedback from the teacher. Although students made the molecules and filled out the Process Tools in their small groups, there was no follow up discussion on that. Also, in most cases, the teacher was only person who responded to student questions. However, in the High-LG classroom, students filled out their Process Tools individually, then they had chance to share their answers and discuss in class. Also, students in this classroom had opportunities to get "mediated peer-to-peer" feedback, which happened when the questions are raised by students and other students have opportunities to give feedback before the teacher responds.

Table 3 below summarizes the three differences we found from high school low and high learning classrooms.

Table 3. High school Low- and High-LG classrooms comparison on Modeling Photosynthesis activity in the *Plants* unit

	Low-LG classroom (Teacher 8546)	**High-LG classroom** (Teacher 7844)
Content	- Reactants/Products - Matter/Energy not clear	- Principle-based - Matter/Energy clear distinction
Scaffold Student Learning	- Individuals following procedures	- Whole class discussing procedures and big idea
Opportunities for Feedback	- None of the groups - Teacher-to-student feedback	- Some of the individuals - Mediated peer-to-peer feedback

Discussion

In summary, we found that although there was little difference in teachers' content coverage, there were important differences in the ways that teachers used the curriculum. The Low-LG teachers appeared to focus on identifying reactants and products in the carbon-transforming process, provided less scaffolding for student performance, and provided fewer chances for students to get feedback. In contrast, the High-LG teachers appeared to more focus on principle-based reasoning with clear distinctions between matter and energy, provided clear learning goals and better scaffolding for students, and provided more chances for students to share their ideas and get feedback from both peer and teacher.

The differences in implementing curriculum among the teachers may be associated with how they interpret and understand curriculum (Pintó, 2005; Schneider & Krajcik, 2002). The Low-LG groups of teachers appeared to have procedural understanding of curriculum. They seemed to use the curriculum as it is written and focus on following procedures step by step. In contrast, the High-LG teachers appeared to have conceptual interpretation of curriculum. This group of teachers seemed to understand the rationale behind the curriculum and focus on the overall learning goals and big ideas that students might be able to successfully achieve across the individual parts of curriculum in meaningful, coherent ways. Although the current study does not include the data of how teachers interpret the curriculum, our previous study that shows teachers who have higher student learning gains tended to see the relationships among individual pieces of curriculum (Zhan, Cisterna, & Anderson, 2012) provides some insights.

This exploratory study has a couple of limitations. First, it is based on a limited number of both teachers and data sources. These preliminary findings should be validated with a more comprehensive, systematic analysis across different data sets collected from more classrooms.

Second, there may be other factors that affected students' learning gains – such as school demographic. The High-LG classrooms tend had lower percentages of students on free and reduced lunches and were located in more prosperous suburban in West neighborhoods while the Low-LG classrooms were from rural Midwest schools with relatively higher percentages of students on free and reduced lunches.

The current study holds implications for future direction. First, this study helped us to develop and revise the curriculum that is most helpful for student learning. Second, it helps us to design our professional development workshops for teachers. Finally, it guides us to build more systemic ways for more complete data collection.

References

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research* (3rd ed.). Thousand Oaks, CA: Sage.

Darling-Hammond, L., & Youngs, P. (2002). Defining "Highly qualified teachers": What does "Scientifically-based research" actually tell us? *Educational Researcher*, *31(9),* 13–25.

Dauer, J., Miller, H., & Anderson, C. W. (in press). Conservation of energy: An analytical tool for student accounts of carbon-transforming processes. In R. Chen, A. Eisenkraft, D. Fortus, J. Krajcik, K. Neumann & A. Scheff (Eds.), *Teaching and Learning of Energy in K-12 Education*. New York: Springer.

Eisenhart, M., Borko, H., Underhill, R., Brown, C., Jones, D., & Agard, P. (1993). Conceptual knowledge falls through the cracks: Complexities of learning to teach mathematics for understanding. *Journal for Research in Mathematics Education*, *24(1)*, 8-40.

Jin, H. & Anderson, C. W. (2012). A learning progression for energy in socio-ecological systems. *Journal of Research in Science Teaching*, *49(9),* 1149-1180.

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

Pintó, R. (2005). Introducing curriculum innovations in science: Identifying teachers' transformations and the design of related teacher education. *Science Education, 89(1)*, 1 – 12.

Rivkin, S. G., Hanushek, E. A., & Kain, J. F. (2005). Teachers, schools, and academic achievement, *Econometrica, 73(2),* 417-458.

Schneider, R., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Science Teacher Education, 13(3)*, 221 – 245.

Zhan, L., Cisterna, D., Anderson, C.W. (2012, March). *Students' learning performance on carbon-transforming processes and its relationship to teaching practice*. Paper to be presented at the annual meeting of the National Association for Research in Science Teaching, Indianapolis, IN.