Paper 4: Carbon TIME Classroom Discourse and Its Connections to Student Learning

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Introduction

This paper reports data from *Carbon: Transformations in Matter and Energy* (*Carbon TIME*, http://carbontime.bscs.org/), a design-based implementation research (DBIR) project for middle and high school classrooms focusing on carbon cycling at multiple scales. This project builds on science educators' broad consensus around the *Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards (NGSS)*, including the framework of three-dimensional science learning in those documents.

Analyses of student learning results show that while almost all students improved their performance on *Carbon TIME* assessments from pretest to posttest, there were significant differences in average student learning for different classrooms. In this paper, we use *Carbon TIME* data, with an emphasis on classroom video, to characterize classroom discourse in five teachers' classrooms and identify patterns of discourse that are alike and different. We also examine plausible relationships between classroom discourse and student learning. The research questions we address include the following:

1. What qualities and patterns of discourse are apparent in *Carbon TIME* teachers' classrooms? How are they alike and different?
2. How do these qualities and patterns of discourse relate to student learning outcomes?

Methods

Design and Analysis Frame. This paper draws on data from five contrasting *Carbon TIME* teachers' classrooms to examine classroom discourse and its relationship to student learning outcomes. We use a discourse routine framework that comprises a set of lesson discourse elements. The discourse elements include (1) whole class introduction, (2) whole class middle of lesson discussion, (3) whole class conclusion, (4) group work, and (5) individual writing and accountability. The first three elements of the discourse routine occur roughly, though not strictly, in sequential time. Discourse routines reflect the engagement of both the teachers and the students during a lesson. Taken together, these five elements comprise a generalizable lesson discourse routine that serves as the unit of analysis for this paper.

We utilize the discourse routine in both generic and normative ways. In the generic sense, the discourse routine is intended to be general enough to be suited to classify most learning-focused episodes within any given lesson. Even if teachers are not strictly following the *Carbon TIME* curriculum activities, most learning-focused lesson activities may be classified as one of the five discourse routine elements. In the normative sense, the elements of the discourse routine may be viewed as progress variables for classroom discourse. Each of the elements may be enacted in the classroom by the teacher and students in ways that we hypothesize are more or less conducive to supporting productive disciplinary engagement.

Data Sources and Analysis. To address research question one, we analyzed three lessons from each of five *Carbon TIME* teachers' classrooms (Table 1). Data included classroom lesson video, student work samples, and video of student focus groups. Video of each classroom lesson was transcribed and divided into episodes, with each episode characterized as representing a lesson element type from the discourse routine. Each lesson might have multiple episodes (or in some cases no episodes, e.g., for group work) classified as each of the five discourse routine elements.

Table 1. Five Carbon TIME case study teachers

Teacher*	**Case Year**	**Grade Level**	**School %FRL**	**Notes**
Ms. Barton	2015-16	Middle	23%	
Ms. Callahan	2016-17	High	1%	Science center high school
Ms. Eaton	2016-17	Middle	13%	
Mr. Gilbert	2016-17	High	56%	English language students from around the world
Mr. Harris	2015-16	High	15%	

*Pseudonyms

When a lesson included multiple episodes representative of a discourse routine element, the episodes were considered together as a whole to characterize and provide a lesson code for that discourse element. Each discourse routine element consisted of multiple attributes (Table 2) with indicators of low, medium, or high values for enactment (full coding scheme in Appendix I). Coders considered all attributes together to provide each discourse element type in each lesson a code of low, low/medium, medium, medium/high, high, or not present. Mixed (e.g., low/medium) codes were assigned when the codes for different attributes within the discourse element were mixed. Coders coded the five discourse routine elements separately and then came to consensus through discussion of codes for each lesson.

Table 2. Discourse routine elements and attributes

Whole Class Introduction	A. Foregrounding connections to previous lessons
	B. Foregrounding meaning of target performance
	C. Providing advance scaffolding for target performance
	D. Engaging students to prepare for activity
Whole Class Middle of Lesson Discussion	A. Sharing ideas or data
	B. Teacher taking ideas seriously
	C. Students taking up ideas and data
	D. Public writing
Whole Class Conclusion	A. Concluding discussions
	B. “Taking-as-shared” conclusions
	C. Public writing
	D. Connecting to future lessons
Group Work	A. Equitable participating
	B. Acting as critical friends
	C. Progressing toward target performance
	D. Teacher monitoring
	E. Groups being held accountable
Individual Writing and Accountability	A. Scaffolding individual student writing
	B. Opportunities for self-assessing and revising
	C. Individuals being held accountable
	D. Producing quality individual student work

In addressing research question one, we present results for classrooms of five *Carbon TIME* teachers. For each teacher, we share a lesson vignette that characterizes what discourse looks like in this classroom and then discuss how the teacher’s classroom discourse is representative of either one-dimensional or three-dimensional characteristics of doing school. Given the complexity of classroom discourse, we have chosen one focus for the results that we hypothesize to be an important facet for connecting classroom discourse with student learning. In particular, we focus on student writing, discussing how teachers assess and scaffold student writing and, consequently, what types of writing and revision students complete in these classrooms.

Research question two was answered through examining test results for the students of the five case teachers. We examine student learning for each of the five teachers' students during the school year in which the case study for that teacher was collected. Analyses draw on the value-added models presented in Paper 3 (Lin et al., 2020) to examine student learning performance in light of patterns and characteristics of discourse evident in the five case teachers' classrooms.

In a future paper, evidence from all seventeen *Carbon TIME* case studies will be used to examine classroom discourse and the relationship between classroom discourse and student learning with a larger sample – providing further evidence concerning prevalence of types of discourse in multiple classrooms and the relationship between discourse type and student learning outcomes.

Results

Research Question One: What qualities and patterns of discourse are apparent in *Carbon TIME* teachers' classrooms? How are they alike and different?

General Patterns: How Teachers are Alike and Different

Carbon TIME teachers are like most science teachers across the United States in sharing some basic priorities associated with their work. These priorities, in turn, can influence what teachers and students do in the classroom (i.e., what classroom discourse looks like). Some of the most basic priorities that science teachers must fulfill involve making sure that what Windschitl has defined as "doing school" gets done in the classroom. Windschitl proposes that facets of doing school involve teacher control, curricular coverage, consumption of knowledge, and individualism in learning (2019, p. 8).

While Windschitl implies a pejorative evaluation, another way to look at doing school is as a baseline or floor for the least that needs to get done in a functioning (as opposed to a dysfunctional) science classroom. Doing school may not lead to three-dimensional learning for all or even many students, but it can be understood as articulating a baseline for what needs to happen in a science classroom, including having a controlled setting with minimal chaos, covering some designated curriculum for science learning, and providing an environment where students - including each individual student - can gain some knowledge.

In each of the five teachers' classrooms that we observed, the teacher and students had worked out a way to do school together, accomplishing the basic purposes of science class. In some classrooms, students were engaged primarily in one-dimensional activities, learning facts and skills; we characterize the discourse in these classrooms as *1D doing school.* In other classrooms students showed deeper patterns of three-dimensional engagement with phenomena; we characterize the discourse in these classrooms as *3D doing school.* General patterns that we observed in each type of classroom are summarized below.

1D doing school. Classrooms where 1D doing school is happening can be thought of as successful classrooms in some meaningful ways. For example, in 1D doing school classrooms, teachers and students generally have positive relationships and those positive relationships provide a foundation for classroom environments where the activities of science class are carried out every school day with little fuss or ado. In these classes, expectations are generally set at a level where most students can be successful in the performance for grade exchange (Doyle, 1983). That is, students do what is expected of them, demonstrate some evidence of learning (which may be one-dimensional in nature), and receive satisfactory grades. Furthermore, in many 1D doing school classrooms, teachers and students perceive the experience of science class as interesting, engaging, and worthwhile. While what students learn may represent one rather than three-dimensional performance expectations, there is still evidence that something is being achieved by students and because of that, it is often the case that teachers and students who are just doing school can feel satisfied that science class is a successful experience (Doyle, 1983; Smith, 1996).

3D doing school. In some science classrooms, discourse reflects more than just 1D doing school. While the basics of doing school are still happening, other things are happening as well. In classrooms where discourse involves more than just the basics, the types of student engagement, responsiveness, and rigor that are evident may be more consistent with supporting students in achieving three-dimensional science learning.

As we examined discourse in *Carbon TIME* classrooms, we assumed at the most basic level that what students did in class would affect what they learned. Because 1D doing school does not generally engage students in 3D performances, learning in these classrooms may fall short of three-dimensional goals. That said, some learning – including meaningful learning – may still occur. In contrast, in classrooms that also encompass disciplinary engagement or productive disciplinary engagement (Engle and Conant, 2002), students are working toward capacity for personally meaningful, conventionally correct 3D performances.

In Table 3, we summarize patterns of discourse representative of a spectrum from low to high classroom engagement, expectations, and motivation. We suggest that classroom discourse representative of 1D doing school likely falls in the intermediate column of the table. In identifying 1D doing school as intermediate along a spectrum, it is possible to see how this type of classroom discourse may be viewed as a meaningful accomplishment for teachers and students. In contrast with the low column, we see that in these classrooms, familiar and traditionally valued activities are occurring, and some goals for what school should accomplish are likely to be met.

Table 3. Patterns of classroom discourse

	Low	**Intermediate**	**High**
Student Engagement	• Disengaged • Procedural display	• Doing school around 1D performance	• Engagement w/phenomena (Productive) disciplinary engagement
Rigor	• Low expectations • Making tests/tasks easier • Students don't do work	• Covering content • Grading for completion	• Standards, coaching & accountability for 3D performance
Responsiveness	Accepting students' • Limited abilities • Lack of motivation to meet high standards	• Eliciting but not engaging students' ideas • Quick and snappy • Motivation w/novelty	• 3D assessment • Sticky probing (eliciting & working w/students' ideas) • Motivation to learn

Cases of Five Individual Classrooms

For the most part, in the *Carbon TIME* classrooms we have observed, teachers and students are at least accomplishing the doing of school. And, in some classrooms, more and sometimes much more than 1D doing school is happening. We examined the five cases described below to see how different teachers accomplished their purposes and how their students responded. We began with Ms. Barton, whose classroom typifies patterns of discourse at the lower and intermediate levels of the spectrum shown in Table 3 and proceeded through the cases to end with Ms. Eaton and Ms. Callahan, whose classrooms both exemplify patterns of discourse at the higher end of the spectrum.

Ms. Barton

Ms. Barton teaches eighth grade students in a rural middle school that also includes a scientific research station. She uses *Carbon TIME* materials for a version of doing school that emphasizes student talk and sharing ideas and devalues writing and mastery.

Vignette: Explaining Cow Digestion

We visit Ms. Barton as her class is working on the *Animals Unit* and engaging in a lesson in which students complete an Explanations Tool for Cow Digestion. The target performance involves students explaining in writing how matter moves and changes and how energy changes during cow digestion. As the lesson video begins, Ms. Barton is speaking about how the year is going for everyone, and about the importance of being yourself and not dwelling on comparing yourself with others.

Whole class introduction. The lesson moves into whole class introduction as Ms. Barton passes out the Explanations Tools and reminds students that they completed an interactive and previewed a PowerPoint yesterday. She tells the students that they'll reshow the PowerPoint and look more at digestion, how digestion is just like the ethanol burning that they had studied previously, and how digestion involves rearranging of atoms because atoms last forever.

The *Carbon TIME* lesson calls for the teacher to introduce the Explanations Tool, then for students to work on it individually, then to discuss their responses in a small group, and finally for the class to discuss and come to consensus on their written answers. The sequence in Ms. Barton's class is different. She mentions pair talk, saying, "you guys will talk about it in your pairs or whatever." However, pair talk is skipped during the lesson enactment.

Whole class middle of lesson discussion. The class moves through the PowerPoint with some reading of slides (by the teacher and students), some discussion, and some attention to answering the Explanations Tool questions. As the class reviews the slides, the teacher poses questions to check students' understanding related to the target performance. For example, here Ms. Barton checks understanding of where chemical energy might reside after digestion.

> Ms. Barton: And then some of the outputs [from the cow are] carbon dioxide, urine, and feces. Do you think that any of the cow's outputs have chemical energy?
>
> Student: Um. Yes.
>
> Ms. Barton: Ok. Which one if you were choosing between feces, urine, and carbon dioxide, which one do you think would have chemical energy?
>
> Student: Um, the carbon dioxide?
>
> Ms. Barton: Ok, so I'm talking about which one is like the organic material. Which one is going to have those high energy bonds?
>
> Student: Feces?
>
> Ms. Barton: Yes, feces.

At one point, a student asks, "Are we supposed to be writing this down?" Ms. Barton responds, "No, you're supposed to be taking it in and thinking about it."

Whole class conclusion: At the end of the Explanations Tool, the directions instruct students to write a paragraph explaining cow digestion in a way that answers three key questions. Ms. Barton substitutes a different assessment that she put together after reading some questions students had posed after doing their investigation of mealworms eating. She says, "I just kind of retyped what some peoples' questions were and joined together some peoples' questions… so you're going to choose one of those questions… [and] you're going to do those eight things about that one question." Students begin this assignment as class comes to a close.

What patterns of student engagement, rigor, and responsiveness do we see in Ms. Barton's classroom discourse?

For the most part, discourse in Ms. Barton's class is accomplishing the doing of school with one-dimensional focus. This is particularly true for written performances, which Ms. Barton de-emphasizes in favor of spoken performances. For example, in the lesson vignette, Ms. Barton wants students to think about the questions on the Explanations Tool, but not necessarily to write down answers. Also, noticeably, she substitutes a different written assessment (that does not address the target performance) for the challenging last question on the Explanations Tool, which asks students to write out their explanations for cow digestion in paragraph form (a three-dimensional performance that asks students to use the practice of explaining core disciplinary ideas for digestion while following the rules set forth by crosscutting concepts related to tracing matter and energy in a system).

While practicing the target performance is not always undertaken in Ms. Barton's class, other commonly valued school science activities do occur with regularity. For example, consistent with her focus on talk, Ms. Barton often asks students to share their ideas related to the science content that is being covered. In the cow digestion lesson, students are given the opportunity to share their ideas about what it means for something to be organic. This dialogue between Ms. Barton and a student is representative.

Ms. Barton: I think the word organic is like a struggle. A struggle. Yes?

Student: I could see how organic food wise and organic high energy bond wise are alike because usually when there are high energy bonds. There are high energy bonds in stuff that's natural. Nothing's really happened to it. Like carbon and oxygen and CO_2. And organic since its usually Non-GMO food wise. Nothing's been modified to it. So, it's still natural.

Ms. Barton responds to the student by agreeing with him and then providing an alternative definition of organic that is canonical, but that does not address the student's idea that things are organic when they are natural. In other words, students' ideas are often elicited, but rarely engaged in Ms. Barton's class.

Table 4. Discourse in Ms. Barton's classroom

	Low	**Intermediate**	**High**
Student Engagement	• Disengaged • Procedural display	• Doing school around 1D performance	• Engagement w/phenomena (Productive) disciplinary engagement
Rigor	• Low expectations • Making tests/tasks easier • Students don't do work	• Covering content • Grading for completion	• Standards, coaching & accountability for 3D performance
Responsiveness	Accepting students' • Limited abilities • Lack of motivation to meet high standards	• Eliciting but not engaging students' ideas • Quick and snappy • Motivation w/novelty	• 3D assessment • Sticky probing (eliciting & working w/students' ideas) • Motivation to learn

Mr. Harris

Mr. Harris teaches ninth-grade biology in a suburban high school. He prioritizes traditional science investigations and procedures while also recognizing problems with these one-dimensional approaches to doing school.

Vignette: Evidence-Based Arguments for Ethanol Burning

When we visit, Mr. Harris's class is working on an Evidence-Based Arguments (EBA) Tool for the ethanol burning activity within the *Systems and Scale Unit*. This lesson is within the first of three *Carbon TIME* units the class will complete. In the same lesson period, the class also moves to the next activity, which involves molecular modeling of ethanol burning. The target performance for the EBA Tool activity involves students using data from their ethanol burning investigations to develop evidence-based arguments about matter movements and matter changes when ethanol burns. They are also asked to identify unanswered questions about matter movement and matter change that their investigation data are insufficient to answer.

Whole class introduction followed by individual writing. As class begins, Mr. Harris asks students to write down new entries in their science class tables of contents. Next Mr. Harris directs the students to the Observing Ethanol Burning Worksheets they had completed during the ethanol burning investigation, which immediately precedes this activity. He asks them to add the class data to their own worksheets and to describe the patterns for the class. Mr. Harris leads the students through recording class data, noting data errors, and identifying patterns. In examining the class data, Mr. Harris emphasizes procedural concerns that affect the quality of recorded data. Noting an error, he says, "just always remember when you go back to your scale, look, does it say 'g' next to it? Make sure it's not saying ounces or something else. But we can still see there is a decrease." Mr. Harris also states aloud the overall pattern in the data from all of the investigation groups combined.

Next Mr. Harris introduces the Evidence-Based Arguments Tool for Ethanol Burning. He provides directions for how students should complete the Tool. Mr. Harris directs students about which column on the Tool they should complete first and how they should draw on their evidence and thinking. However, Mr. Harris does not mention either ethanol or burning in his initial introduction to the Tool. Students work individually for about nine minutes with Mr. Harris offering some additional directions during this time.

Group (partner) work and whole class poll. Mr. Harris then ask students to talk with a partner – directing them to discuss what they "feel rock solid on" and what they "feel less confident about." After pair sharing, Mr. Harris alters the whole class discussion about the students' answers to the EBA Tool suggested by *Carbon TIME* and instead conducts a poll. Students put their heads down so they cannot see other students and respond to the following questions by raising their hands. Mr. Harris asks, "Did you mention the word BTB?" and "Anywhere in your writing did you use the words mass or weight in talking about your evidence?" and "Which of the three questions, first, second, or third, was most challenging?" There is no whole class discussion about students' responses to the EBA Tool after the poll and the class moves on to the next activity, molecular modeling of ethanol burning.

What patterns of student engagement, rigor, and responsiveness do we see in Mr. Harris's classroom discourse?

In Mr. Harris's class, we see a lot of emphasis on doing school science through a focus on science class procedures. With regard to assessing and scaffolding writing, unlike Ms. Barton – who has students write less and does not assess students' writing - we see Mr. Harris conscientiously checking that students have correct answers to procedural questions (e.g., written data and patterns from their ethanol burning investigation). In the lesson vignette above, Mr. Harris also asks students to undertake writing aimed at the target performance – that is, they complete individual writing on their Evidence-Based Arguments Tools. Though writing occurs, scaffolding toward conventionally correct performances on the Evidence-Based Argument Tool does not. Mr. Harris directs pair discussion toward what students feel more and less confident about, rather than sharing and revising their ideas about evidence, conclusions, and unanswered questions. Also, whole class discussion – a time for ideas to be shared and engaged and for the class to come to consensus – is omitted, and Mr. Harris instead asks students to answer a few questions in a heads-down, hands-up poll.

As with Ms. Barton's classroom, we see that Mr. Harris's classroom is a place where content is being covered, students are engaged in relevant performances, students willingly go along with the lesson activities, and students have opportunities to share their ideas - but they are not engaged in practicing or learning the complete target performance. By moving to the molecular modeling activity after taking the poll, Mr. Harris leaves students in a space where their written performances (i.e., their Evidence Based-Arguments Tools for Ethanol Burning) stop at the point of personal performance without the opportunity to discuss, revise, or come to consensus through whole classroom discourse. Thus, students completed the

Evidence Based-Arguments Tool without scaffolding or accountability for three-dimensional writing performances.

Table 5. Discourse in Mr. Harris's classroom

	Low	Intermediate	High
Student Engagement	• Disengaged • Procedural display	• Doing school around 1D performance	• Engagement w/phenomena (Productive) disciplinary engagement
Rigor	• Low expectations • Making tests/tasks easier • Students don't do work	• Covering content • Grading for completion	• Standards, coaching & accountability for 3D performance
Responsiveness	Accepting students' • Limited abilities • Lack of motivation to meet high standards	• Eliciting but not engaging students' ideas • Quick and snappy • Motivation w/novelty	• 3D assessment • Sticky probing (eliciting & working w/students' ideas) • Motivation to learn

Mr. Gilbert

Mr. Gilbert teaches biology to tenth-grade students in an urban school. His class includes students who are learning English as a second language and students new to the district. He helps students use science in the English language for personal sense-making and supports their classroom participation through teacher-mediated talk and writing.

Vignette: Finishing Molecular Models and Working on Explanations for Soda Water Fizzing

Mr. Gilbert's class is finishing up molecular modeling of soda water fizzing as the lesson begins. After, students work on the Explanations Tools for Soda Water Fizzing. The target performance involves students explaining how matter moves and changes when soda water loses its fizz.

Whole Class Introduction. This lesson begins with a review of accounting for atoms and molecules on the soda water fizzing molecular modeling worksheet. Mr. Gilbert directs students to complete the "check yourself" part of the worksheet through working and talking with others. He talks with students about their ideas and banters with students as they work. Because this a class of students who have recently arrived from different places around the world, we hear snippets of multiple languages as students work and talk.

Whole class discussion. Next the class reviews responses to the worksheet together. Mr. Gilbert is aware that both the English language and common ideas from science are new to his students, so he focuses on explaining ideas and practices in ways he thinks his students will understand. For example, after finding that only one student has worked with chemical equations, he explains that, "chemical equations are very similar to math equations. So, if I took a math equation and said that two equals one plus one that would be correct, right? Okay, but notice I can't say that two equals one plus four, right? Those two are not equal. The same thing has to happen on either side of the arrow in this type of equation." Mr. Gilbert proceeds to work through the equation verbally querying students about atoms.

Mr. Gilbert: How many carbons?

Student: One.

Mr. Gilbert: One. How many oxygens?

Student: Three. One, two, three.

Mr. Gilbert: Three. Right.

Whole Class Introduction. Next Mr. Gilbert introduces the Explanations Tool for Soda Water Fizzing. He again scaffolds students in the English language by defining what an explanation is and notes that students will explain what happened when their soda water fizzed. Mr. Gilbert asks students to work on the Explanations Tool, either on their own or with their partners.

Individual and group work and whole class discussion. In Mr. Gilbert's class, there is no distinction between individual and group work; students are welcome to work on their own or to talk with others. The Explanations Tool has three questions. Mr. Gilbert has students work on one question at a time, coming back to whole group discussion before moving on. During individual and group work, he talks with students about what they are writing, scaffolding their work without directly answering the worksheet questions. For example:

Mr. Gilbert: You have to figure out where they [products and reactants] fit in the equation. So, did the CO_2 and H_2O produce carbonic acid? Or is it the other way around?

S: Oh. Maybe.

Mr. Gilbert: Think about that.

Whole class conclusion. In whole class discussion around answers to each of the questions, Mr. Gilbert does most of the talking. He calls on students to provide short answers to questions such as "what's moving out?" [CO_2]. Mr. Gilbert emphasizes that students should have the correct answers on their sheets. He says, "Now for the matter movement question, do you have a label showing carbonic acid in the soda water? And let me tell you, this is a right or wrong situation. You had to have these things in order for this to be correct."

The lesson nears its end as Mr. Gilbert scaffolds students toward writing explanations for soda water fizzing in sentences. He is explicit about what their explanations should include, saying, in part, "your ideas need to be something like this. Carbonic acid is in the soda water before it fizzes. Alright. Something like that. It breaks up into or changes into, or molecules are rearranged. That's a pretty big word. But molecules change, to carbon dioxide and water." After describing what the explanation should include, he says, "You need to be able to put some of this in your own words, okay?" Mr. Gilbert closes the lesson by telling students that in the next class they will answer, "What do we know now that we didn't know before the investigation?"

What patterns of student engagement, rigor, and responsiveness do we see in Mr. Gilbert's classroom discourse?

As in the previous classrooms we visited, Mr. Gilbert and his students are accomplishing the doing of school. While friendly banter is common, Mr. Gilbert is in control of the activities of the class, curricular material is being covered, and students are creating individual performances consistent with consumption of some science-related knowledge.

We argue, though, that what is happening in Mr. Gilbert's class also reflects or at least approaches 3D rather than 1D doing of school. While Mr. Gilbert does most of the talking in whole class episodes, he is also scaffolding and assessing students' written conventionally correct performances. He is clear that, while it should be written in students' own words, there is a standard for what counts as a correct explanation. In another lesson, Mr. Gilbert is clear that he is checking students' work to make sure they are moving toward correct performances - as he hands back a worksheet at the beginning of a lesson in the *Animals Unit* he says, "We are going to have those who fully understand this help those who did not fully understand this to finish it up and finish it up correctly… If you turned it in and did not get twenty, you can fix the things that are wrong with your paper and get full credit. Okay?"

While Mr. Gilbert understands that science class in the U.S. is difficult for his students as English language learners, he does not respond by simply lowering expectations and making class easy. Mr. Gilbert summarizes part of his approach in this dialogue from the same lesson as the vignette.

Student: This class makes me feel dizzy.

Mr. Gilbert: This class makes you feel dizzy? It's because of the amount of knowledge that's going into your mind so quickly.

Student: Your brain can't take it.

Mr. Gilbert: Your brain can't take it all at once. You have to break it down. It's like trying to eat your whole lunch in one bite, you have to cut up the food.

In Mr. Gilbert's whole-class discussions, where students do a little bit of talking and Mr. Gilbert does a lot of talking, we see classroom discourse that nevertheless engages students with phenomena in productive ways. His class also provides opportunities for students to put their ideas down in writing and discuss their ideas with their peers as helping friends, as well as opportunities for students to practice and revise target performances toward conventionally correct performances.

Table 6. Discourse in Mr. Gilbert's classroom

	Low	**Intermediate**	**High**
Student Engagement	• Disengaged • Procedural display	• Doing school around 1D performance	• Engagement w/phenomena (Productive) disciplinary engagement
Rigor	• Low expectations • Making tests/tasks easier • Students don't do work	• Covering content • Grading for completion	• Standards, coaching & accountability for 3D performance
Responsiveness	Accepting students' • Limited abilities • Lack of motivation to meet high standards	• Eliciting but not engaging students' ideas • Quick and snappy • Motivation w/novelty	• 3D assessment • Sticky probing (eliciting & working w/students' ideas) • Motivation to learn

Ms. Eaton

Ms. Eaton teaches seventh grade in a small city that includes a major university. She scaffolds her students' three-dimensional performances in ways that support them in writing conventionally correct explanations.

Vignette: Predictions for Ethanol Burning

We visit Ms. Eaton as her class completes a lesson in the first *Carbon TIME* unit in which the target performance involves students using *Carbon TIME* scaffolds such as The Three Questions sheet to help them make predictions for what will happen when ethanol burns.

Whole class introduction. Ms. Eaton opens with a warmup discussion about chemical compounds found in the human body. She calls on students to add ideas until the four compounds she wants to highlight have been offered. Next, Ms. Eaton directs students to briefly talk with a partner about their previously completed Expressing Ideas about Ethanol Burning Tools. Ms. Eaton specifies that, "if you have any things that you want to change on there will you just make sure that you are circling them so that we know what those are?" With this, Ms. Eaton scaffolds the students to keep track in writing of how they are revising their thinking over time.

Students' ideas are then shared in a whole class discussion as Ms. Eaton reads from publicly displayed sticky notes where students have written answers to two prompts, "Why ethanol burns" and "Your questions." She reads every sticky note aloud then asks students if they have other questions. Students offer a few more questions such as, "What chemicals in the ethanol make it turn blue?"

Next Ms. Eaton introduces the Predictions Tool for Ethanol Burning by saying that, just as they figured out what was happening with soda water fizzing, they are now going to figure out what's happening when ethanol burns. She leads the students through considering three key questions about ethanol burning, while querying the students about what they will need to look for during the investigation. For example, one of the three questions relates to where molecules are moving. Ms. Eaton draws students' attention to the rule that, "a change in mass shows that molecules are moving. So, we need to mass something." She follows by querying, "Any ideas about what we need to mass?"

Individual writing. Students next write responses to the Predictions Tool questions on their own. While students work, Ms. Eaton moves around talking with and questioning individual students to prompt their thinking and responding. For example, one student had written that atoms are what's moving in. Ms. Eaton asks, "There are atoms going in, but what do you think those atoms are? What kind of molecule is it?"

Group work and whole class conclusion. Next Ms. Eaton directs students to talk about their Predictions Tool responses with a partner and she moves around the room to talk with the different pairs. The lesson closes with a whole class discussion of responses that includes opportunities both for individual students to share their ideas and for checking how many students agree with ideas that are expressed. For example, when one student says that ethanol is going to lose mass, Ms. Eaton responds, "You think the ethanol is going to lose mass? Did anyone come up with anything different? You all think that the ethanol is going to lose some mass? Okay." This whole class discussion continues until the end of the lesson.

What patterns of student engagement, rigor, and responsiveness do we see in Ms. Eaton's classroom discourse?

Ms. Eaton and her students are involved in 3D doing school. Ms. Eaton is actually a quite controlling teacher; she frequently instructs her students to do things like clear their desks of everything but a pen, use certain colored pens for certain kinds of work, and to follow very specific guidelines and rubrics for what should be included in their answers (beyond the guidelines provided by the *Carbon TIME* curricular materials). The curriculum is being covered and individual students in Ms. Eaton's class are consuming science knowledge.

In addition, though, students in Ms. Eaton's class are engaging in deep and productive activities and discussions concerning science phenomena. They are writing, discussing, and carefully revising their writing in sustained activities that extend over multiple class periods and move very intentionally toward all students producing conventionally correct performances. Student writing that is both public (such as the sticky notes) and private (such as individual students' tools) are saved, organized, revisited, and revised through individual writing, teacher assessment, and group and whole class discussion.

Ms. Eaton actively engages in what Hess and Azuma (1991) describe as sticky probing – digging into students' ideas through discussion in ways that help the whole class move toward conventional science understanding. We see evidence of sticky probing in the following dialogue, also from the lesson in the above vignette, in which students are making predictions for what happens when ethanol burns:

> Student: I was just going to say like the main reason that we're finding out the mass is to see if when it burnt it lost molecules.
>
> Ms. Eaton: Whether it lost molecules or whether or not molecules moved into it, right? So, when you're talking about burning up, what does that mean? Because when I envision burning up that means that it goes away.
>
> Student: Catching fire.
>
> Ms. Eaton: So, if I light a molecule on fire, like ethanol, right, is it going to burn up and disappear and go away forever?
>
> Students: No... lose mass or gain mass. [multiple speak at once.]
>
> Ms. Eaton: Okay. Somebody raise your hand and tell me what you're saying.
>
> Student: So, what I mean by burn up is there wouldn't be ethanol in the container anymore and the ethanol would become different molecules slash atoms. So, it would go into the air and, um, what would go into the fire.

Ms. Eaton: So, there's going to be a chemical change, right? It's going to turn into something different and we just want to figure out what it's changing into and if it goes into the air, it's no longer in the ethanol, right? So, we can look for that. What else are we going to look for?

In talk and particularly in writing, Ms. Eaton provides very pointed scaffolds that support her middle school students in refining and revising as they move toward conventionally correct performances.

Table 7. Discourse in Ms. Eaton's classroom

	Low	**Intermediate**	**High**
Student Engagement	• Disengaged • Procedural display	• Doing school around 1D performance	• Engagement w/phenomena (Productive) disciplinary engagement
Rigor	• Low expectations • Making tests/tasks easier • Students don't do work	• Covering content • Grading for completion	• Standards, coaching & accountability for 3D performance
Responsiveness	Accepting students' • Limited abilities • Lack of motivation to meet high standards	• Eliciting but not engaging students' ideas • Quick and snappy • Motivation w/novelty	• 3D assessment • Sticky probing (eliciting & working w/students' ideas) • Motivation to learn

Ms. Callahan

Ms. Callahan teaches ninth-grade biology in a science center that serves a small city and surrounding rural communities. She coaches conventionally correct, three-dimensional performances while encouraging her students' personal interests and collective sense-making.

Vignette: Explaining Cellular Respiration

We visit Ms. Callahan's ninth grade biology class. She works with her students to develop explanations of how matter moves and changes and how energy changes during cellular respiration in a cow's cells (connecting macroscopic observations with atomic-molecular models and using principles of conservation of matter and energy).

Whole Class Introduction. Ms. Callahan begins with reminders about what the class has been working on (mealworm investigation data, molecular modeling) and asks if everyone is feeling confident. She says that at the end of the unit she wants students to be able to, "say not only for school, but for life, this is exactly what happens when the organism moves. We're going to actually figure out what's going on in these cow muscle cells. Get ready to explain."

Individual writing. The students work on an Explanations Tool, which combines a graphic organizer for tracing matter and energy with a paragraph that students write giving an overall explanation of the process. Ms. Callahan sets students to their personal writing by saying, "Alright, so now it's your turn to sort of solo artist figure out some explanations for this. I want you to be specific. Use your evidence. Use your thoughts. Start putting all these things together." Students work for ten minutes.

Group (partner) work. Next the students work in pairs. Ms. Callahan instructs her students, "don't just throw your paper at them and have them look at it. Talk to them. Communicate and work your way through. Get out a different colored pen or pencil. I want you to circle any areas that you have in common and then if you want to add items in that's fine. You have a lot more in common but maybe still some differences, which could be interesting."

Whole class middle of lesson discussion. The class then comes together for a discussion that is sometimes very specific to the Explanations Tool, and at other times related, but delving into content students were curious about (e.g., tracing water through urine and milk in the body; functions of organs including kidneys, gall bladder, and pancreas; discussing why urine is yellow; and ATP). Ms. Callahan uses talk moves to scaffold students in figuring out. Sometimes she solicits short responses, but often she asks for extended explanations.

Whole class conclusion and individual accountability. The close of discussion scaffolds students in checking whether they have written good explanations. Ms. Callahan queries students about confidence and consensus.

> Ms. Callahan: Good. Good. Note this is a pretty solid answer. They're saying glucose is going into the cell. Pretty important. Do you have an arrow showing oxygen or O_2 going into the cow's cells?
> Students: Yes.
> Ms. Callahan: Is that pretty universally confident? You're good with that?
> Students: Yes.
> Ms. Callahan: Excellent. Alright. Coming out do you have CO_2? Did you make it very clear that you're separating the ideas of matter and energy?
> Students: Yes.
> Ms. Callahan: At no point did you say glucose was converted into energy?
> Students: No.
> Ms. Callahan: Good! I'm pretty excited about some of the common ground we have. That you're all in agreement on things that are going in and out after your molecular modeling kits. Which is great. So, we're good. We're good.

What patterns of student engagement, rigor, and responsiveness do we see in Ms. Callahan's classroom discourse?

As in all of the other classrooms that we have visited, doing school is getting done in Ms. Callahan's classroom. However, perhaps related to the fact that Ms. Callahan teaches in a science center that requires application and recommendations for students to attend, Ms. Callahan is able to, at times, dial down control in her classroom and allow students some free rein to share and discuss their ideas. As a result, classroom discourse in Ms. Callahan's class ranges beyond the coverage of *Carbon TIME* materials as students discuss ideas about tracing water through urine and milk in the body; functions of organs including kidneys, gall bladder, and pancreas; why urine is yellow; and ATP.

This is not to say, however, that Ms. Callahan allows students to direct the lesson. She is very explicit both in providing direction for activities and highlighting consensus ideas during class. For example, as she sets students to group work, she emphasizes student metacognition around revising their ideas by instructing students to, "Get out a different colored pen and pencil. I want you to circle any areas that you have in common and then if you want to add items in that's fine. Just do it in a different color pen or pencil."

Further, during consensus discussion, Ms. Callahan asks all the students to check that they have the correct answers written on their Explanation Tools. Students may have gone far afield in discussing urine, milk, and the roles of various organs in the body along the way, but at the end of the discussion we see Ms. Callahan very explicitly making sure that students understand what comprises the conventionally correct target performance.

While Ms. Callahan is fortunate to have students who come to class motivated to learn, and while she is able to give rein to students' tangential ideas related to cellular respiration, we see that she is also carefully attending to scaffolding her students toward conventionally correct written and spoken performances.

Table 8. Discourse in Ms. Callahan's classroom

	Low	Intermediate	High
Student Engagement	• Disengaged • Procedural display	• Doing school around 1D performance	• Engagement w/phenomena (Productive) disciplinary engagement
Rigor	• Low expectations • Making tests/tasks easier • Students don't do work	• Covering content • Grading for completion	• Standards, coaching & accountability for 3D performance
Responsiveness	Accepting students' • Limited abilities • Lack of motivation to meet high standards	• Eliciting but not engaging students' ideas • Quick and snappy • Motivation w/novelty	• 3D assessment • Sticky probing (eliciting & working w/students' ideas) • Motivation to learn

Research Question Two: How do qualities and patterns of discourse relate to student learning outcomes?

Analyses of student learning data included calculations of value-added models for individual classrooms to examine how students' posttest performances differed from what would be predicted on the basis of their pretest performances and school factors (including percentage of free and reduced lunch and percentage of marginalized students of color). Figure 1 below (from Lin et al., 2020) shows the results of these analyses for the five case study teachers – with results from case study years circled in red. We can see in Figure 1, that, as we hypothesized, learning results for each teacher correspond to our analyses of classroom discourse patterns we see in the different teachers' classrooms. Ms. Barton's students and Mr. Harris's students have relatively lower learning gains compared with other *Carbon TIME* teachers. Mr. Gilbert's students' learning gains were in the middle compared with those of other teachers. And, Ms. Eaton's and Ms. Callahan's students demonstrated relatively higher learning gains.

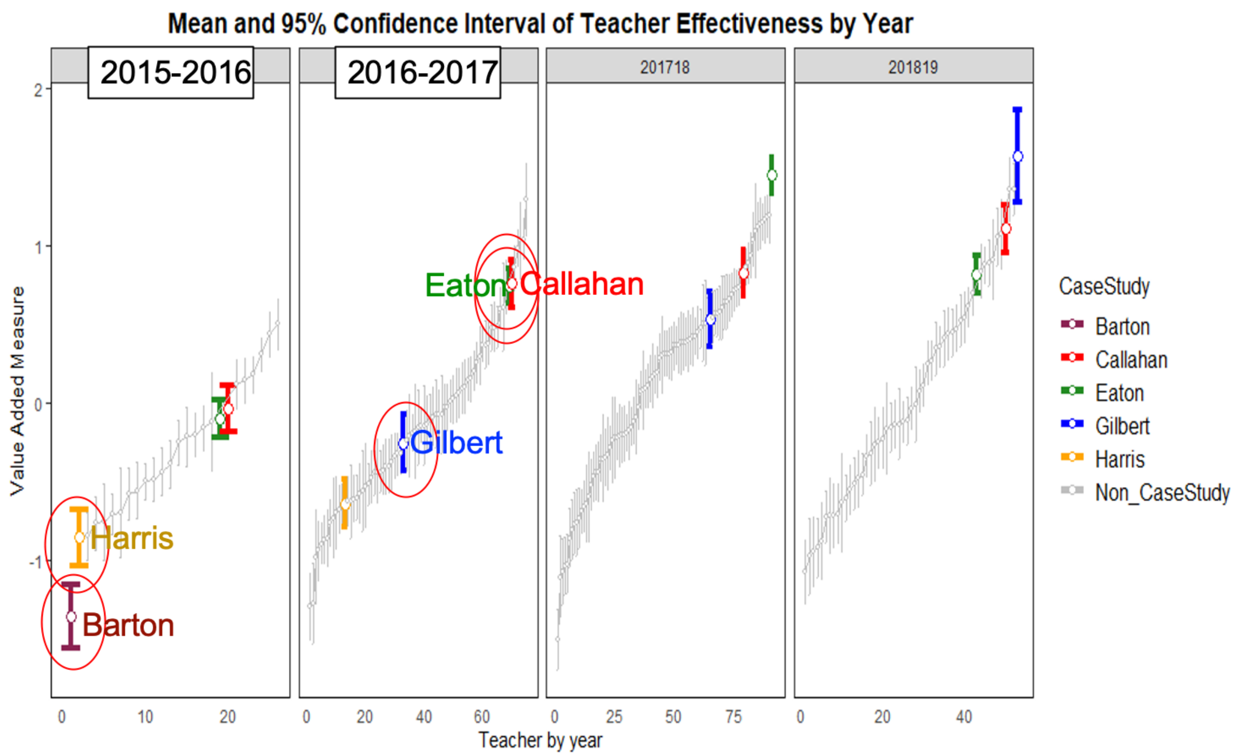

Figure 1. Value added results for case study teachers. Circled cases show student learning results for the five case study teachers for the year of case study data examined in this paper.

In their paper Lin, et al. (2020), discuss the important limitations of these value-added measures. These limitations remind us that multiple factors, not just classroom discourse, influence student learning gains by teacher, and that we need to be cautious about making any causal claims at this point with our small data set of five teachers. For example, Ms. Barton's very low learning gains seem to be due in part to anomalously high performance by her students on the pretest. Similarly, note how the rankings of Mr. Gilbert, Ms. Eaton, and Ms. Callahan changed across the years of the project. Some of these changes may reflect shifts in classroom discourse as teachers gain experience, but some change may reflect advances over time in the effectiveness of *Carbon TIME* curriculum materials and coordinated professional learning. Nevertheless, the pattern of student learning results for cases we examined are consistent with our hypothesis concerning how facets of classroom discourse including students' engagement and teachers' rigor and responsiveness may influence student learning outcomes.

Returning to our focus in this paper on teachers' assessing and scaffolding student writing and students engaging in writing and revision, a pattern of differences in discourse emerges in our five case study teachers that illustrates the mechanisms that may underly differences in student learning across the cases.

In classrooms where the discourse reflects 1D doing school, individual student writing was generally less frequent – very infrequent in Ms. Barton's class, a bit more in Mr. Harris's class. When individual writing does occur in 1D doing school classrooms, it is likely to involve students expressing their own ideas in writing without opportunities to revise initial ideas toward conventionally correct written target performances. Writing may either not be assessed, or may be assessed for completion, rather than being assessed for evidence of the conventionally correct target performance. Sometimes in 1D doing school classrooms, emphasis is placed on correctness in procedural rather than conceptual aspects of writing (e.g., having data recorded correctly rather than having a correct explanation). In other cases, writing assignments get altered to elicit easier performances. Since students in these classrooms do not practice three-dimensional writing performances in class, it is not surprising to us that they have difficulty producing conventionally correct performances on *Carbon TIME* posttests or in post-instruction student interviews.

In contrast, what we see in 3D doing school classrooms with respect to individual student writing and accountability for writing is very different. In 3D doing school classrooms, students are asked to engage in complex writing performances; they are also expected to revise those written performances until they are conventionally correct. Often in 3D doing school classrooms, students are scaffolded to keep track in writing of how their ideas are changing (e.g., writing new ideas in a different color or circling ideas that have changed). In 3D doing school classrooms, teachers make sure that the standards for correct written performance are clear to students and that students are accountable for meeting those standards. This occurs in different ways. In some classrooms, students check their written answers as the class reviews the correct performance (this generally happens later in a learning sequence – after students have had opportunities to express, discuss, and revise from initial ideas). In other classrooms, teachers provide tools such as detailed rubrics for what needs to go into a correct performance. Students use these rubrics to check their own answers and make sure they have done things like followed important rules (e.g., atoms last forever in living systems) and included all the necessary parts of a good performance.

Comparing 1D doing school and 3D doing school classrooms with respect to individual student writing and accountability, one difference that emerges is a focus on cognitive apprenticeship (Collins, Brown, & Newman, 1989) that is clearly evident in 3D doing school classrooms, but not in 1D doing school classrooms.

- In 3D doing school classrooms, the conventionally correct performance is *modeled* by the teacher – that is, the teacher makes sure that the students have a clear picture of what the conventionally correct performance should look like and include. This often occurs through classroom discussion. One example comes from Mr. Gilbert's class, when he tells his students, "your ideas need to be something like this. Carbonic acid is in the soda water before it fizzes. Alright. Something like that. It breaks up into or changes into, or molecules are rearranged. That's a pretty big word. But molecules change, to carbon dioxide and water."
- In 3D doing school classrooms, teachers also *coach* students in moving toward conventionally correct performances. This happens in various ways such as through whole class discussion that involves self-checking, or through grading with feedback, or through use of detailed rubrics.
- Finally, in 3D doing school classes, teachers also use *Carbon TIME* materials in ways that, to differing degrees, begin to *fade* performance scaffolds. Ms. Callahan, who has highly motivated students, expects her students to be able to write explanations on their Explanations Tools because they've written other similar explanations before during their *Carbon TIME* learning. In contrast, Ms. Eaton continues to scaffold students with extra supports like writing rubrics, which she believes are necessary for her middle school students.

For all *Carbon TIME* students, whether they are ready or not, the unit written assessments serve as less scaffolded (i.e., faded support) opportunities to demonstrate their capacity for producing target performances. We have begun, but not completed, analyses of student work, student interviews, and student-focused videos for selected focus students in each class. We anticipate that those analyses will enable us to more robustly trace causal connections among classroom discourse, student engagement, and students' posttest performances.

Discussion

As noted above, all five teachers in our cases were successfully doing school in ways that reflected their experience and teaching skill and that fostered positive relationships with their students and their colleagues. (Mr. Harris and Ms. Barton, for example, had both served as chairs of their departments.) But the differences in how they did school were real and consequential.

An implication that we infer from both our examination of classroom discourse as well as from our extended and extensive interactions with *Carbon TIME* teachers is that classroom discourse in each teacher's classroom tends to make sense and work (i.e., be perceived as at least satisfactory and effective) given the circumstances that teachers and classrooms reside within, and given the types and depth of resources that teachers have access to. Our representation of this inference is shown in the final three rows of Table 9, relating to low and high resource approaches to doing school, performance for grade exchange, and engaging student interest. We emphasize again that, even in classrooms with relatively fewer resources, doing school is getting done – the classroom is a controlled setting with minimal chaos, some designated curriculum for science learning is being covered, and students – including each individual student - are gaining some knowledge.

Table 9. Different Approaches to Basic Needs and Obligations of Science Teaching

Basic need	**Low resource approach**	**High resource approach**
Professional identity (including efficacy, relationships with students and colleagues)	Separate public discourse with colleagues from private discourse with students	Discourse with colleagues about assessing and scaffolding students' 3D engagement
"**Doing school** is not just a set of enactments; it is a frame that emphasizes teacher control, curricular coverage, consumption of knowledge, and individualism in learning." (Windschitl, 2019, p. 8)	• Control with clear rules, effective management • Coverage of 1D facts and skills • Consuming knowledge to get a grade • Individual work and accountability	• Control through student agency & engagement • Coverage of 3D performances • Consuming knowledge to act as informed citizens • Accountability for participation in classroom discourse
Performance for grade exchange	Student success through clear, low expectations	Student success through productive disciplinary engagement
Engaging student interest	Quick and snappy: Keep up pace and novelty	Sticky probing: Intrinsic rewards of 3D learning

In this paper we have described differences between generally lower-resourced classrooms that are 1D doing school and higher-resourced classrooms that are 3D doing school and discussed the consequences of these different approaches for student learning. Figure 2 shows how the questions addressed in this paper relate to the questions that are examined in several other papers in the set including Paper 5 (Morrison Thomas et al., 2020) and Paper 3 (Lin et al., 2020).

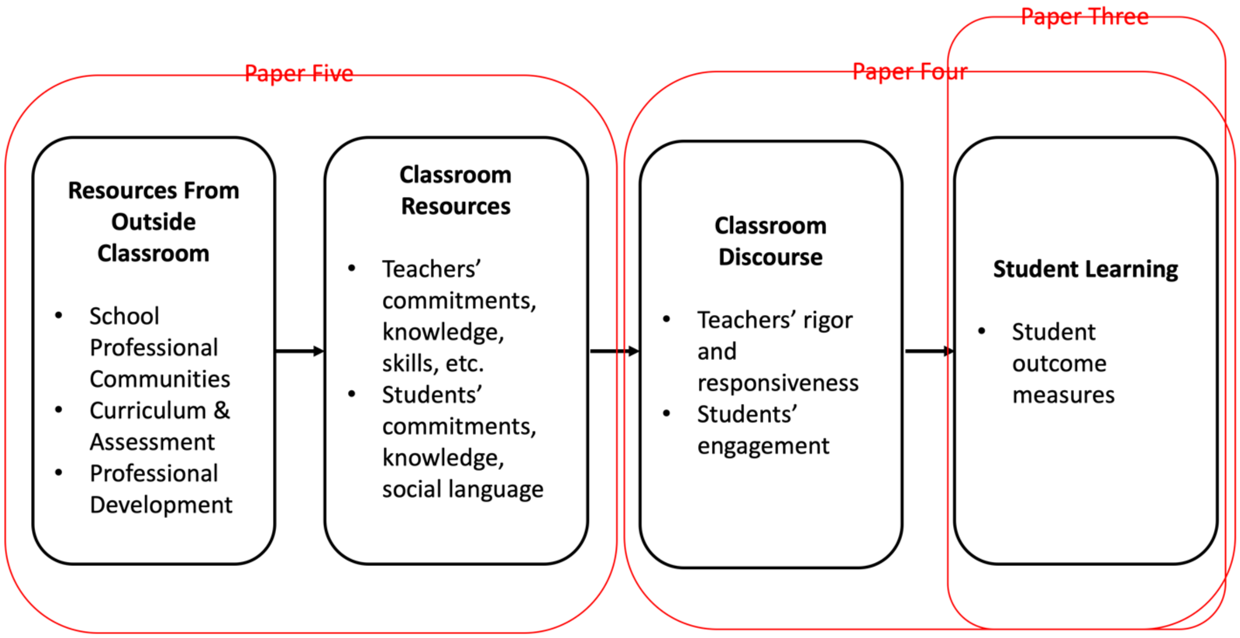

Figure 2. *Carbon TIME* Logic Model

The *Carbon TIME* logic model helps us consider both how the three papers relate to one another and potential implications for building systems that support three-dimensional student learning at scale. Paper 5 (Morrison Thomas et al., 2020), discusses interviews with the teachers and what they tell us about plausible causes for the differences we see in classroom discourse (this paper), including teachers' professional identities and commitments, resources that teachers and students brought to their classrooms, and support that teachers perceived from their school professional communities. In turn, this paper (Paper 4) provides insights concerning the likely consequences of classroom discourse on the student learning outcomes that are examined in depth in Paper 3 (Lin et al., 2020). In our future work we will dig more deeply into the causal mechanisms that connect classroom resources, classroom discourse, and student learning. We will also examine how resources from outside the classroom such as research-practice partnerships, can support 3D classroom discourse in a wider range of classrooms.

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Appendix I: Progress Variables for Classroom Discourse in *Carbon TIME*

1. Whole class introduction: Connecting to ongoing storylines and establishing the problem for the lesson

Definition: Introductions include:

- Either the first whole-class episode in a lesson or the first whole-class episode at the beginning of a new activity (which could be after the beginning of a lesson)
- Episodes where the main purpose is to prepare students for individual or group work can go both here and with individual or group work or whole class discussion coding. For intro we're coding more on how T conveys general purpose. For individual work, more emphasis on how T conveys specific procedures.

Successful teachers use a variety of strategies to make sure that students see a purpose for each lesson beyond completing the task at hand. In particular, we see two qualities in successful lessons: connections to student learning storylines and establishing the problem for the target performance.

Conceptual connections to student learning storylines. The most effective lesson introductions connect the activity to the ongoing story of *students' learning in the unit.* The connections are not just procedural (e.g., "today we will be working on the Evidence-based Argument Tool); they don't just connect to the general unit storyline (e.g., yesterday we learned how digestion breaks large organic molecules into small organic molecules. Today we will learn how cells use the small organic molecules to grow."). Instead, they review students' ideas and conclusions from previous lessons, how those ideas have changed, and how the upcoming lesson will address questions that students still haven't answered.

Establishing the problem for the target performance. The Teacher's Guides include a target performance for every activity—what students should be able to do by the end of the activity. Successful lesson introductions prepare students for active learning where they will be figuring out the target performance with support from the teacher and tools. In particular:

- Successful introductions help students to see how the target performance will be personally meaningful to them, answering questions that they are interested in.
- Successful introductions help students remember relevant ideas that they already have and tools that can help them achieve the target performance.

Indicators based on progress variable description

Attributes	Values
A. Connections to previous lessons (VAC 12, 19)	**H:** Connections to student learning storyline from previous lessons: making sense of focus phenomena (including phenomena relevant to students' interests) **M:** Content or practice connections (to content storyline or place in instructional model) **L:** Few connections to previous lessons; connections are superficial and/or procedural
B. Meaning of target performance (VAC 13,14)	**H:** T identifies target performance and explains/suggests why 3D mastery might be interesting, worthwhile; T builds on Ss' expressed relevant interests **M:** includes some connection to phenomenon under study; but fails to meet 3D **L:** T identifies 1D goal and/or describes lesson activities in procedural terms (no mention of learning goal)
C. Advance scaffolding for target performance (VAC 15, 16)	**H:** T models target performance and scaffolds Ss' use of CTIME tools to enact 3D performance **M:** T identifies relevant tools and models or scaffolds 1D performance **L:** T may identify relevant tools but does not model or scaffold target performance

Attributes	Values
D. Student engagement (VAC 1, 4)	**H:** Ss ask conceptual questions or verbalize in ways that show active sense making (any LP level) **M:** Ss verbalize relevant ideas that suggest responding to teacher query rather than personal sense-making; (S engagement does not go beyond responding to teacher query rather than actively making sense themselves). (Ss trying to make sense of what Ss think teacher wants rather than trying to make sense of target performance). **L:** S engagement is procedural and/or very shallow (e.g., one-word answers to cloze type questions from teachers). Ss may show indicators of disengagement (apathy, irrelevant comments)

2. *Whole class middle of lesson discussion: Sharing ideas and data through class discussions with public writing*

Definition: Any whole-class episodes that occur between introductions and conclusions (even if what's happening isn't public sharing of ideas).

Individual and group work produces *private writing*—writing that is seen and shared by individual students or small groups. A key part of the *Carbon TIME* discourse routine involves sharing ideas, questions and results from that private writing, comparing and questioning ideas from different students or groups, and recording some of them as *public writing.*

Whole-class discussions can and should be both *responsive and rigorous.* In the case of whole-class discussions this means responsive dialogue (discussed in this section) leading to rigorous conclusions (discussed below). In responsive dialogue students' ideas and results are *both respected and taken seriously.*

Sharing and respecting students' ideas. Sharing ideas is a logistical challenge; every student should have a voice, but there often isn't time to give every student an individual turn to speak. *Carbon TIME* teachers have addressed this challenge in many ways, some of which are incorporated into the tools for sharing ideas and data presented in the box. We note two kinds of strategies in particular:

- Sharing results of pair or group discussions: Students talk in pairs (Think-Pair-Share) or small groups, then had the pairs or groups share their ideas, with or without support from whiteboards and posters.
- Sharing through Post-it notes: Students can also use Post-it notes to display and organize ideas, as discussed in the box above.

Taking students' ideas seriously. Taking students' ideas seriously requires more than encouraging them to talk or write. "It's fine to say whatever you are thinking of" conveys a different message from "Your ideas are important, and we will discuss them seriously." Some teachers use talk moves such as those discussed in the Talk Science Primer that encouraged students to compare and organize ideas, looking for similarities and differences, using those differences to articulate unanswered questions.

Taking ideas seriously involves encouraging students to articulate them clearly and explain them fully, as opposed to accepting one-word answers or irrelevant comments. Teachers also encourage students to evaluate their ideas with respect to criteria such as those in the Three Questions or to evaluate anomalous data for possible mistakes.

Public writing also plays an important role in taking students' ideas seriously. Through public writing, such as writing on posters, PowerPoint slides, or the Driving Question Board, teachers select and preserve important ideas and questions that the class can return to later.

Investigation results: Carbon TIME investigations are organized around the idea that scientific investigations are designed to find *patterns in data.* This means that individual groups need to share their results and look for patterns. Sometimes this might involve questioning anomalous results (e.g., when groups have made procedural or measurement mistakes).

Indicators based on progress variable description

Attributes	Values
A. Sharing ideas or data (VAC 1, 4, 6, 8, 9, 18, 19)	**H:** T & Ss engage with phenomena or data together; questions and responses promote broad student participation (e.g., think-pair share, patterned turns) in 3D sensemaking **M:** T makes 3D sense, Ss learn about 3D science; T to S talk (IRE) T & Ss develop a collection of ideas w/out evaluation or uptake. **L:** T tells & Ss learn about science facts (lecture); S talk is procedural display only or very short response to cloze type queries from T (no S sense-making of phenomenon)
B. Teacher taking ideas seriously (VAC 8)	**H:** T takes up S idea with: talk move; productive re-voicing; productive redirecting; building across S voices **M:** T takes up S idea with: Correcting or explicitly evaluating response at inappropriate time in DR; writing some S responses but not others w/no stated rationale **L:** Redirecting away from S response; No substantive uptake; No response to S idea; Public denigration of S idea
C. Student uptake on ideas or data (VAC 4, 6)	**H:** Ss verbalize in ways that show active sense making based on ideas previously expressed by teacher or other students **M:** Ss verbalize relevant ideas and questions, but mostly individually, without reference to previous discussion **L:** Ss verbalize non-science related ideas, procedural questions, or shallow science facts without principles
D. Public writing	**H:** Class uses ways to share and display ideas or data from multiple students or groups (Post-it notes, data posters, Driving Question Board, etc.) **M:** Ss verbalize relevant ideas and questions, but they are not preserved in public written form **L:** No public display of student ideas or writing

3. Whole class conclusion: Consensus-seeking discussions and writing; connections to future lessons

Definition: Conclusions include:

- Either the last whole-class episode in a lesson or the last whole-class episode at the end of a CTIME activity (which could be before the end of a lesson)
- Other episodes where the main purpose is to reach cloture or consensus

Class discussions need to be consensus-seeking as well as sharing ideas. The ideas that students initially share usually fall short of the target performances for the activities. It is hard to manage consensus-seeking (or convergent) discussions that is both responsive and rigorous, but both qualities are essential. Responsive discussions engage students in personal sense-making rather than leaving them as passive listeners. Rigorous discussions help students make progress toward target performances.

Rigorous conclusions: achieving target performances by using tools and principles. The Classroom Discourse Routine Educator Resource shows how the goals for consensus-seeking discussions change through the course of each unit:

- *Students as questioners:* At the beginning of each unit (including the Expressing Ideas and Questions Tool) the consensus-seeking goals focus on *questions* rather than ideas. Students can share or discuss their ideas about answers to the unit driving question without achieving consensus, but it is important for the class to agree on some key questions that they want to answer during the unit.

- *Students as investigators:* During investigations (including the Predictions and Planning Tool, data sharing and discussion activities, and the Evidence-based Arguments Tool) students need to reach consensus on (a) plans for the investigations, (b) patterns in their data, (c) conclusions based on patterns in data, and (d) unanswered questions that are not fully answered by the data.
- *Students as explainers:* When students are explaining processes, students need to reach consensus on explanations that answer the Three Questions, including the checklist on the Three Questions handout.

Responsive conclusions: building on student data and ideas. We have seen *Carbon TIME* teachers using two kinds of strategies to conduct consensus-seeking discussions in responsive and rigorous ways.

Talk moves. Teacher language is an important part of responsive and rigorous science discussions. During *Carbon TIME* discourse routines, we recommend:

- Using the Three Questions: Point out ways that student ideas are potential answers to the Three Questions or fall short of following the rules in the second and third columns.
- Comparing student contributions: Comment on students' ideas and questions that are similar or potentially in conflict, identifying emerging consensus or issues to be resolved.
- Revoicing: Revoice student ideas and questions that help move the discussion toward consensus outcomes.

The Talk Science Primer describes a variety of additional talk moves that teachers can use to support consensus-seeking discussions.

Connecting to future lessons through public and private writing. Successful consensus-seeking discussions are accompanied by public and private writing that (a) identifies the key questions or conclusions and (b) saves those conclusions so that the class can return to them later. All of the tools mentioned in the box for starting lessons above—the Driving Question Board, Exit Tickets, the Learning Tracking Tool, and the Matter Tracing Tool—are useful for this public and private writing. They are the tools that teachers use to connect lessons to one another, and to the ongoing student learning storyline.

Investigation results: Successful teachers use tools such as the posters and spreadsheets to support consensus-seeking discussions about patterns in data. If the data are really bad, then the investigation videos and PowerPoint slides suggest patterns that other classes have found.

Indicators based on progress variable description

Attributes	Values
A. Concluding discussions (VAC 4, 5, 6, 8, 9, 15, 18)	**H:** T & Ss make 3D sense together, leading to target performance **M:** T makes 3D sense, Ss learn about 3D science; OR • T to S talk (IRE, cloze type): OR • T & Ss develop a collection of ideas w/out consensus **L:** T tells & Ss learn about science facts (lecture); S talk is procedural display only (no S sense-making of phenomenon)
B. Taken-as-shared conclusions (VAC 5, 7, 13, 15, 16)	**H:** Students enact target performance and teacher validates **M:** Teacher models target performance OR class ends with 1D or incomplete performance **L:** Activity ends without clear conclusion OR with incorrect conclusion
C. Public writing	**H:** Public display of class consensus including student input (data posters, Driving Question Board, etc.) **M:** Public display of conclusions not based on student input (e.g., PPT slides) OR public display of student input without clear consensus **L:** No public display of student ideas or writing or class conclusions

Attributes	Values
D. Connections to future lessons (VAC 6, 14, 19)	**H:** Explicit discussion of how consensus conclusions or questions will be saved and used in future lessons **M:** Lesson is connected to general CTIME storyline without reference to lesson-specific conclusions **L:** No discussion or procedural discussion of future lessons

4. Group work

Definition: Episodes where students are expected to be talking with one another and/or working together toward a common product, including most preparation and data collection for investigations.

Some of the most important times for student learning occur when students are working in small groups. This is when students can be active learners, personally figuring out how to engage in target performances. During successful group work, students are individual contributors and critical friends and teachers are actively monitoring and coaching students.

Students are individual contributors and critical friends. Students' participation in successful groups has three key qualities:

- *Equitable and meaningful participation:* All students participate in equitable ways (as opposed to some students doing work while others watch or copy), showing evidence that they find their work meaningful and worth their individual efforts. They take care to record their personal ideas and questions and to make use of the resources available. They share their ideas with partners and group members, rather than waiting to write down what someone else says. They consider others' ideas, sometimes editing what they have written in response.
- *Acting as critical friends:* Students in successful classrooms also serve as *critical friends* to others in their groups, listening to others' ideas, comparing them with their own, and analyzing differences. So, they act as peer coaches and help groups to reach consensus about the best ideas and questions.
- *Progress toward target performance:* Finally, students in successful groups are focus their work and talk on the key questions or goals for the day, make effective use of tools, and other resources, and help one another make progress toward the target performance.

Teachers are actively monitoring and coaching students. Teachers in successful classrooms play active roles in setting up and monitoring students' individual and group work. In part, they take care to establish the problem for the students' work, as discussed above. They make sure that the work is meaningful, and that procedures and expectations are clear.

Teachers in successful classrooms are also active while students are doing individual and group work, circulating around the classroom and working purposefully with different students and groups. Successful teachers generally have an agenda for their interactions with groups, with planned initial questions (back pocket questions) that provide ways of checking the group's progress quickly (e.g., looking at a drawing or a key conclusion). They provide active coaching for students or groups that are struggling while taking care to reach all the groups in a class.

Accountability for group results. Group work is also consequential in some way. Typically, groups share their results with the whole class, through contributions to class data for investigations, white boards, posters, etc. Jigsaw activities also make groups responsible for preparing all their members to become experts who can help members of other groups.

Relevant evidence for group work variable. We will probably find that the student-focused videos and examples of student work provide better evidence for the indicators below than the teacher-focused videos. We will definitely want to look at them for case study analyses. For quantitative analyses, we will need to consider the value added by looking at additional data sources and whether we have the time to do that.

Indicators based on progress variable description

Attributes	Values
A. Equitable participation (VAC 2, 3, 4, 6)	**H:** Ss all participate in active sense making (any LP level) **M:** Some Ss participate in active sense-making; others are silent, off-task,or offer 1D science ideas **L:** Ss verbalize non-science related ideas (e.g., I'm going to the game tomorrow) or S verbalizations provide evidence that Ss are not sense-making (Do you want full sentences?, I don't know.), or everyone is only focused on 1D science or hearing an answer from other Ss engaging with ideas.
B. Acting as critical friends (VAC 1, 4, 6)	**H:** Productive disciplinary engagement: Ss help one another engage meaningfully in the target performance **M:** Non-rigorous engagement: Ss support one another in uncritical ways **L:** Lack of engagement: Ss do not respond to other group members' work or ideas or respond in shallow ways (e.g., focus only on procedure or having an answer)
C. Progress toward target performance (VAC 5, 6)	**H:** S is performing or contributing to the target performance meaningfully. **M:** Ss verbalize in ways that fall short of the target performance, but relevant OR Ss engage in rote version of target performance **L:** S verbalizations not contributing to or related to the target performance.
D. Teacher monitoring (VAC 7, 8, 9, 13, 16, 17)	**H:** T engages with most groups and supports target performance with questions and scaffolding **M:** T visits most groups with questions or comments that do not scaffold students toward full target performance as appropriate **L:** T does not actively monitor or engage with students during group work or monitors on completion rather than sense making
E. Group accountability	**H:** Products of group work are evaluated by teacher or shared with other students (white boards, posters, jigsaw, etc.) and evaluated **M:** Groups generate products that are shared, but that are not clearly evaluated **L:** Group work does not lead to defined products or leads to products that are not shared

5. Individual writing and individual accountability

Definition: Episodes where students are writing individually, self-assessing their own writing, revising their own writing, or assessing/scoring writing of individual peers.

If there is one quick way to identify the classrooms with the largest learning gains on the posttests, it is to look at samples of student work. In the most successful classrooms, it is clear that students put sustained effort into completing and revising their process tools, and that teachers held students accountable for what they wrote. Classroom videos and interviews with teachers and students show several strategies that teachers use to scaffold students' writing and hold them accountable, both during lessons and after the lessons are over.

Scaffolding, accountability, and revisions during lessons. Successful teachers find ways to scaffold and assess students' work that are both responsive and rigorous. They encourage students to write down their ideas and take them seriously. They help students to see how the work is meaningful and their ideas and experiences are relevant. At the same time, they remind students of criteria for successful performance such as those on the Three Questions checklist; they provide opportunities for students to assess their work; they sometimes provide model responses; they encourage revisions, sometimes in a different color pen from the students' original work.

Accountability after lessons are over. Accountability takes different forms at different times in the unit. In the initial parts of a unit (e.g., the Expressing Ideas and Questions Tool and the Predictions and Planning Tool) successful teachers do not formally grade students' ideas and questions. They do, however, discuss and critique them and save them to return to later in the unit—conveying that the work is significant even if if is not formally graded.

Later in the unit, especially for the Explanation Tools and posttests, successful teachers do formally grade students' work according to established criteria. Sometimes they engage students in evaluating and revising their own work or in acting as "critical friends," critiquing the work of partners or group members and suggesting improvements. Successful teachers also sometimes collect students' work and assign formal grades, making the criteria for their grades clear. Again, they signal to students that their work is significant and that quality matters.

Student motivation and accomplishment. Successful students show a commitment to "figuring out" rather than just "learning about." They work conscientiously throughout the lesson to put their ideas in writing and assess the quality of their own writing, rather than waiting to copy or follow the ideas of other students and the teacher. They also show commitment to "finishing the job," taking advantage of opportunities to revise and improve their work, so that their final drafts are close to the target performance for the activity.

Relevant evidence for individual work variable. We will probably find that the student-focused videos and examples of student work provide better evidence for the indicators below than the teacher-focused videos. Some ideas:

- We might want to assess examples of student writing separately from the videos, since we often have videos without writing and sometimes writing without videos.
- We might also look to the focus student interviews as a source for this variable. They often provide relevant evidence about how the students approached their work—whether they were actively "figuring out" or waiting to write what the teacher says
- Sometimes there are clear differences among focus students in the same classroom. We will need to figure out how to record and analyze those differences.

Indicators based on progress variable description

Attributes	Values
A. Scaffolding individual student writing (VAC 7, 10, 16)	**H:** T uses a variety of strategies to scaffold students' individual writing, including CTIME tools and rubrics and specific guidance about expectations for the task **M:** T uses written or stated non-CTIME standards or rubrics OR provides vague and/or insufficient scaffolding with CTIME tools **L:** Students do not write individually or write without scaffolding from the teacher
B. Opportunities for self-assessment and revision (VAC 10, 11)	**H:** Ss use standards or rubrics to assess and conceptually revise own work **M:** S procedural self-assessment and revision (e.g., follow along w/T) of own work **L:** No opportunity for revision anywhere in activity
C. Individual accountability (VAC 7, 10, 11)	**H:** Products of individual work are evaluated by teacher or self-assessed using 3D standards OR saved and used later **M:** Students share their writing without standards-based evaluation or self-assessment **L:** Students are not held accountable for the quality of their individual writing; writing does not have consequentiality – explicit message/understanding that writing matters, has purpose, and will be used.
D. Quality of individual student work (VAC 3, 6)	**H:** Students produce writing that is their own work and achieves target performance **M:** Students produce their own work that falls short of target performance OR copy target performance from teacher or other students **L:** Students do not produce their own writing or produce writing whose purpose does not involve the target performance