SUPPORTING THREE-DIMENSIONAL SCIENCE LEARNING: THE ROLE OF CURIOSITY-DRIVEN CLASSROOM DISCOURSE

By

Wendy Renae Johnson

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Curriculum, Instruction, and Teacher Education—Doctor of Philosophy
Ecology, Evolutionary Biology and Behavior—Dual Major

2017

ABSTRACT

SUPPORTING THREE-DIMENSIONAL SCIENCE LEARNING:
THE ROLE OF CURIOSITY-DRIVEN CLASSROOM DISCOURSE

By

Wendy Renae Johnson

The National Research Council's *Framework for K-12 Science Education* (2011) presents a new vision for science education that calls for the integration of the three dimensions of science learning: science and engineering practices, crosscutting concepts, and disciplinary core ideas. Unlike previous conceptions of science learning that separated content and process goals, in the *Framework,* "learning is defined as the combination of both knowledge and practice" (2011, p. 254). *The Next Generation Science Standards* (2013) operationalized the *Framework's* vision by developing learning standards that integrate science and engineering practices, crosscutting concepts, and disciplinary core ideas into three-dimensional performance expectations. The *Framework* and NGSS supporting documents emphasize that three-dimensional learning requires instruction that centers on explaining natural phenomena.

Instruction aimed at figuring out phenomena requires that questions about the natural world and a shared drive to answer those questions are at the core of classroom discourse. I call this *curiosity-driven discourse* because it is motivated by the desire to explain natural phenomena. It differs from typical classroom discourse aimed at procedural display, which I call *task-driven* discourse, primarily in the purposes that are established for learning activities. Curiosity-driven discourse is focused on figuring out phenomena by engaging in scientific practices and applying disciplinary core ideas and crosscutting concepts. Classrooms engaged in task-driven discourse may engage in many of the same activities, but their purposes for doing so

are limited to completing the task at hand, generally with the intention of acquiring some discrete knowledge or skill.

Through classroom discourse, teachers and students negotiate the purposes of their activities which orients students toward particular types of learning. My dissertation aims to describe how a taken-as-shared frame for understanding "What are we doing here?" emerges through discourse in science classrooms, and how it positions students in terms of developing and using knowledge. Using a mixed methods approach, I carried out three interrelated studies within the context of the *Carbon Transformations in Matter and Energy* (*Carbon TIME*) project. I analyzed videotaped lessons and a student survey collected in classrooms that were implementing an *NGSS*-aligned curriculum designed to support students' three-dimensional learning about carbon-transforming processes in high school biology.

My dissertation advances both theory and practice by conceptualizing curiosity about the natural world as the driver of productive science classroom discourse that fosters three-dimensional learning. Drawing on rich descriptions from diverse high school classrooms, I describe how curiosity-driven discourse positions students as epistemic agents responsible for figuring out phenomena as well as how task-driven discourse orients students toward learning about authoritative science knowledge. My analysis demonstrates the importance of clearly establishing driving questions about natural phenomena to anchor an instructional unit and describes teaching practices that scaffold students' sensemaking and position them as epistemic agents. My dissertation also uncovers key challenges that teachers face in establishing and maintaining curiosity-driven discourse. These insights can benefit practitioners, teacher educators, and researchers as they work to create classroom communities that promote three-dimensional science learning.

This dissertation is dedicated to my family.
Kevin, thank you for making it possible for me to have it all.
Clara & Hollis, thank you for inspiring me with your curiosity.

ACKNOWLEDGEMENTS

I am deeply grateful for the many people who have supported me throughout the PhD program. My dissertation chair, Andy Anderson, made this dissertation possible by allowing me to pursue my interest in scientific curiosity in classrooms within the *Carbon TIME* project. Carrying out my research within this larger project allowed me to ask questions and collect data that I never would have been able to do on my own. I learned so much about teaching and learning that will help me become the kind of science teacher I aspire to be. Thank you, Andy, for pushing me to become a better teacher, writer, and researcher!

I am also thankful for my advisor, Gail Richmond, who guided me through the PhD program. Her listening ear and wise counsel were invaluable to me as I navigated coursework and my dissertation. In addition to Andy and Gail, I was fortunate to also have Bethany Wilinksi and Tom Getty on my dissertation committee. I appreciate their time, encouragement, and feedback throughout the dissertation process.

Thank you to the entire *Carbon TIME* team, especially Hannah Miller, Christie Morrison Thomas, MaryMargaret Welch, Jenny Newell, Elizabeth de los Santos, and Sam Baruah. I am grateful for the expertise and insight you have shared and the support you have offered. It has been a pleasure getting to know you!

Finally, I am thankful for the many friends and family members who have encouraged and supported me. My parents, David and Donna Schroeder, have encouraged my curiosity and sacrificed to help me reach my goals my entire life. My husband, Kevin, and my daughters, Clara and Hollis put up with a lot of busy days and late nights as I have pursued my interests and are my biggest cheerleaders. I love you!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION TO DISSERTATION

The discourse in most high school science classrooms traditionally has focused on *learning about* science topics. However, the vision for three-dimensional learning put forth in the National Research Council's (NRC) *Framework for K-12 Science Education* (NRC, 2011) contends that more productive science learning is aimed at *figuring out* natural phenomena. Three-dimensional learning requires experiences that engage students in developing and using all three dimensions of science—practices, crosscutting concepts, and disciplinary core ideas—to explain observable natural phenomena. The *Next Generation Science Standards* (*NGSS*; NGSS Lead States, 2013) integrates the three dimensions into performance expectations and asserts that, "learning to explain phenomena and solve problems is the central reason students engage in the three dimensions" (NGSS Website, 2016). Therefore, the *NGSS* represent not just a new way to package content and process goals for science education, but a new paradigm for science learning that positions students as epistemic agents who engage in science practices, apply crosscutting concepts, and develop and use disciplinary core ideas to explain phenomena in science classrooms.

If figuring out phenomena is central to three-dimensional learning, it raises the question, how can classroom discourse orient students toward figuring out phenomena rather than simply learning about science topics? Instruction aimed at figuring out phenomena requires that questions about the natural world and a shared drive to answer those questions are at the core of classroom discourse. I call this *curiosity-driven discourse* because it is motivated by the desire to explain natural phenomena. It differs from typical classroom discourse, which I call *task-driven* discourse, aimed at procedural display (Bloome, Puro, & Theodorou, 1989) primarily in the purposes that are established for learning activities. Curiosity-driven discourse is focused on figuring out phenomena by engaging in scientific practices and applying disciplinary core ideas and crosscutting concepts. Classrooms engaged in procedural display may engage in many of the same activities, but their purposes for doing so are limited to completing the task at hand, generally with the intention of acquiring some discrete knowledge or skill.

Through classroom discourse, teachers and students negotiate the purposes of their activities which orients students toward particular types of learning. My dissertation aims to describe how a taken-as-shared frame for understanding "What are we doing here?" in science classrooms emerges through classroom discourse, and how it positions students in terms of figuring out phenomena or learning about science topics. Each of the three studies I present were carried out within the context of the *Carbon Transformations in Matter and Energy* (*Carbon TIME*) project. *Carbon TIME* is an example of design-based implementation research (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013), which brings together researchers and practitioners to address and study issues related to implementation of new pedagogical approaches. The classrooms in this study were implementing an *NGSS*-aligned curriculum designed to support students' three-dimensional learning about carbon-transforming processes in high school biology. Thus, my research is aimed both at advancing theory and informing practice around productive discourse in science classrooms.

The first paper, *Supporting Three-Dimensional Learning Through Curiosity-Driven Classroom Discourse*, is aimed at a practitioner audience. It introduces my conceptualization of curiosity-driven discourse and how it fosters three-dimensional learning. In this study, I analyzed classroom videos to compare the discourse in two classrooms that demonstrated the highest and lowest learning gains on *Carbon TIME* assessments during the 2012-2013 school year. This was a pilot study in which I developed the coding framework for curiosity driven-discourse through grounded theory methods (Glaser & Strauss, 1967). Rather than describe the coding framework in detail in this paper, I used the results to develop a storyline that contrasted what the students were doing in the two different classrooms and what the teachers did that lead to those differences. Thus, this paper illustrates the differences between classroom discourse aimed at figuring out phenomena (in the high learning gains classroom) and learning about science (in the low learning gains classroom).

The second paper, *Framing Classroom Activities as Figuring Out Phenomena Versus Learning About Science: The Role of Curiosity-Driven Discourse in Three-Dimensional Science Learning*, is the centerpiece of my dissertation. In this study I applied and refined the coding framework developed in the first study to compare the discourse in five high school classrooms during the 2015-2016 school year. I was able to dig deeper into classroom discourse by analyzing three videos recorded during the first *Carbon TIME* instructional unit from five case study classrooms. I attended specifically to the purposes that teachers' and students' talk and actions conveyed for *Carbon TIME* activities throughout the unit, and how those resulted in a curiosity-driven or task-driven taken-as-shared frame for classroom discourse.

In the second study I conceptualized teachers' practices related to establishing the purposes for classroom activities and supporting students in framing activities as a way to figure out phenomena as an important form of scaffolding in science classroom discourse. In addition, I conceptualized students' purposes for classroom activities through the questions that they asked during lessons. I used students' questions along with how the teachers' practices positioned students with respect to developing and using knowledge to describe students' epistemic agency in each classroom. This reflects the notion that student agency is both a product of their own actions as well as the context within which they act (Bandura, 1997). Thus, in the second study describes in detail specific features of classroom discourse and how these orient students either toward figuring out phenomena or learning about science.

I found that only one of the five case study classrooms achieved curiosity-driven discourse aimed at figuring out phenomena. This supports the notion that sustaining curiosity-driven discourse in science classrooms is complex and challenging and speaks to why it is presently relatively uncommon. This study contributes rich descriptions of curiosity-driven and task-driven discourse in well-managed classrooms lead by competent teachers who faithfully enacted the *Carbon TIME* curriculum. My analysis demonstrates that *NGSS*-aligned curriculum is not sufficient to ensure three-dimensional learning aimed at figuring out phenomena. The study suggests key practices that teachers engage in to support curiosity-driven discourse and illuminates some of the challenges associated with establishing and maintaining it.

The third paper, *How Do Students Perceive the Discourse in Their Science Classrooms?* represents my foray into the educational psychology literature to better conceptualize curiosity-driven classroom discourse and its influence on students' motivation to learn science. The paper describes how my theoretical framework for curiosity-driven classroom discourse relates to key constructs in the educational psychology literature and the student survey that I developed to measure these constructs. The survey consisted of multiple scales and was administered to the students in each of the five case study classrooms (from study 2) when they had finished implementing the *Carbon TIME* curriculum. I had two main goals in developing, administering, and analyzing the survey: (1) compare students' perceptions of classroom discourse across the case study classrooms to my findings from the video analysis, and (2) determine whether students' responses on the survey could be used in place of more time-intensive observations of classroom discourse.

My analysis of the student survey yielded somewhat surprising results. First, I found that the mean scores for each scale revealed the same pattern across the classrooms. This suggests that the scales were not measuring discrete variables as described in the educational psychology literature, but rather that each of the scales are measuring aspects of the same construct. In addition, analysis of the survey total scores indicated that students' perception of the discourse in their classrooms did not align with my conclusions about which classrooms were more curiosity-driven and which were more task-driven. These differences are likely due to the fact that students' perceptions of classroom discourse are primarily influenced by their other classroom experiences. Thus, the results of this study raise serious concerns about the legitimacy of claims made by studies that rely only on student surveys. While I was not able to clearly link classroom discourse with students' perceptions and their motivation to learn, developing the survey was helpful for conceptualizing the affective dimensions of curiosity and how curiosity-driven discourse influences student motivation. In addition, the results suggest that, as a whole, students in all five *Carbon TIME* classrooms were motivated to learn and had positive perceptions of the discourse in their classrooms.

Overall my dissertation advances both theory and practice by conceptualizing curiosity about the natural world as the driver of productive science classroom discourse that fosters three-dimensional learning. Drawing on rich descriptions from diverse high school classrooms, I describe how curiosity-driven discourse positions students as epistemic agents responsible for figuring out phenomena as well as how task-driven discourse orients students toward learning about authoritative science knowledge. My analysis demonstrates the importance of clearly establishing driving questions about a phenomenon to anchor an instructional unit and describes teaching practices that scaffold students' sensemaking and position them as epistemic agents.

My dissertation also uncovers key challenges that teachers face in establishing and maintaining curiosity-driven discourse. These insights can benefit practitioners, teacher educators, and researchers as they work to create classroom communities that promote three-dimensional science learning.

REFERENCES

REFERENCES

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York: W.H. Freeman and Company.

Bloome, D., Puro, P., & Theodorou, E. (1989). Procedural display and classroom lessons. *Curriculum Inquiry, 19*(3), 265-291.

Fishman, B. J., Penuel, W. R., Allen, A.-R., Cheng, B. H., & Sabelli, N. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *National Society for the Study of Education, 112*(2), 136-156.

Glaser, B. G. & Strauss, A. L. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. London: Wiedenfeld and Nicholson.

National Research Council (NRC). (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Retrieved from https://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Retrieved from https://www.nextgenscience.org

NGSS Website (September, 2016). Using phenomena in NGSS-designed lessons and units. Retreived from http://nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf

STUDY ONE

How Curiosity-Driven Classroom Discourse Supports Three-Dimensional Learning

INTRODUCTION

The National Research Council's (NRC) *Framework for K-12 Science Education* (2011) and the resulting *Next Generation Science Standards* (*NGSS*; NGSS Lead States, 2013) call for the integration of science practices, crosscutting concepts, and disciplinary core ideas into three-dimensional learning experiences to prepare scientifically literate citizens. Therefore, the NRC *Framework* and the *NGSS* advocate curricula and instruction in which the main goal is to help students develop scientific explanations of natural phenomena. Students should engage in the work of scientists (scientific practices) while applying scientific habits of mind (crosscutting concepts) to develop and use scientific knowledge (disciplinary core ideas). This contrasts with the science instruction typical in most classrooms which "emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done" (NRC, 2012, p. 1). Thus, the *NGSS* represent more than just a new set of standards, but a new paradigm for science teaching and learning that reorients classroom discourse from "learning about a topic to figuring out why or how something happens" (NGSS Website, 2016).

The notion of three-dimensional learning is supported by research from the learning sciences and from science studies, which seeks to understand of the work of scientists through social, historical, and philosophical lenses. Three-dimensional learning reflects the aim that Duschl (2008) refers to as "harmonizing conceptual, epistemological, and social learning goals" (p. 269). As Duschl points out, this represents "a shift from teaching about *what* to teaching about *how* and *why*" (p. 270). Emphasizing how and why science is done requires attention to what counts as knowledge and how it is validated as well as to how people work together to address scientific questions and negotiate meaning. Therefore, in order for three-dimensional learning to occur, classrooms must become communities of practice in which students are making sense of the natural world.

Curiosity About the Natural World Drives Three-Dimensional Learning

An underlying assumption of phenomena-driven, three-dimensional learning is that the work of scientists is driven by curiosity about the natural world and that students are also inherently curious about the world around them. The NRC *Framework* asserts that, "many scientific studies, such as the search for the planets orbiting distant stars, are driven by curiosity and undertaken with the aim of answering a question about the world or understanding an observed pattern" (p. 47). In addition to emphasizing the role of curiosity in the work of scientists, the NRC *Framework* contends that children are innately curious about the world. The *Framework* suggests that building on their curiosity provides intrinsic motivation to learn science because "The actual doing of science or engineering can pique students' curiosity, capture their interest, and motivate their continued study" (p. 43). Thus, curiosity about the natural world is at the root of three-dimensional learning, both because it reflects the aims of scientific inquiry and because of its role in motivating students' science learning.

When I say that curiosity drives three-dimensional learning, I have a specific meaning in mind. Instead of thinking of curiosity as an individual personality trait or mental state, I am using curiosity as a description of the motivation for particular activities in a community of practice (e.g. a classroom or a group of scientists). So, in this sense, curiosity about the natural world motivates the group to ask questions about natural phenomena and engage in scientific practices in order to develop answers to those questions. Therefore, if students are to engage in three-dimensional learning, classroom activities must scaffold their personal and collective curiosity about natural phenomena as well as their use of each of the three dimensions to develop personally meaningful answers to their questions.

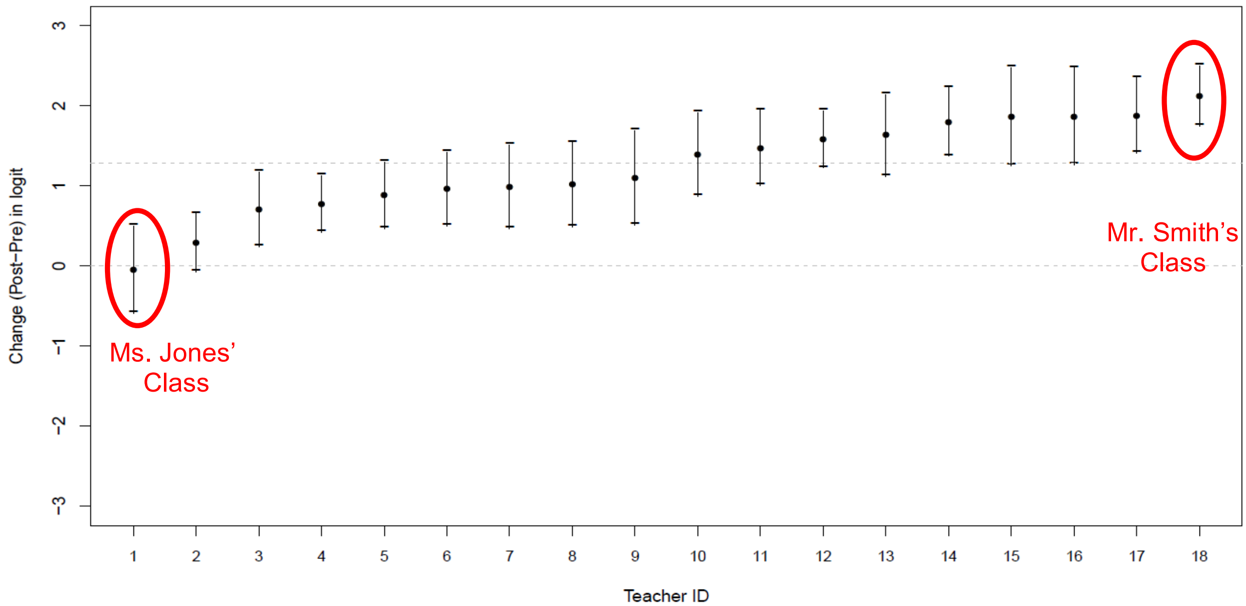
Curiosity-driven three-dimensional learning as I have defined it above happens through classroom talk and activities (which I summarize with the term, "discourse") that orient the work of students towards figuring out phenomena. In this study I compared the discourse in two classrooms that were alike in some important ways—both were well-managed and engaged in the same lessons from the same NGSS-aligned curriculum—but very different in terms of students' three-dimensional learning. My findings point to curiosity—a shared drive among members of the classroom community to make sense of the phenomena that the lessons focused on—as a key difference between the classrooms. In this article I describe the differences in the discourse of the classrooms, and what the teachers did that led to those differences. While there are many potential reasons for the differences in classroom discourse including the prior experiences and knowledge of the teachers and students, here I focus on describing how the discourse differed and its effects on students' opportunities to learn.

CONTEXT AND METHODS

The *Carbon Transformations in Matter and Energy* (*Carbon TIME*) project is a collaboration between researchers and teachers that began in 2010 and has been funded by the National Science Foundation. *Carbon TIME* is an example of design-based implementation research (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013), which brings together researchers and practitioners to address and study issues related to implementation of new pedagogical approaches. A key piece of the project has been developing and refining a three-dimensional curriculum for teaching about processes that transform matter and energy in organisms, ecosystems, and global systems including: combustion, photosynthesis, cellular respiration, digestion, and biosynthesis. The *Carbon TIME* curriculum (freely available online at http://carbontime.bscs.org) consists of six phenomena-based units in which students learn about carbon-transforming processes in order to explain the functioning of plants, animals and decomposers as well as ecological and global carbon cycling. In addition to curriculum development, the development and validation of three-dimensional assessments of students' understanding of carbon-transforming processes has been a central component of the *Carbon TIME* project (Mohan, Chen, & Anderson, 2009; Jin & Anderson, 2012).

Assessment data indicates that the *Carbon TIME* curriculum substantially increases students' understanding of carbon-transforming processes. However, we have also found that student learning gains differ significantly among classrooms implementing the curriculum. Figure 1.1 shows the learning gains (change in score from pre to post test) on the overall *Carbon TIME* assessment for one cohort of classrooms during 2012-2013 school year. The confidence intervals for the two teachers whose classrooms I investigated are circled on Figure 1.1. I have given them the pseudonyms of Ms. Jones (Teacher #1) and Mr. Smith (Teacher #18).

Figure 1.1. Student learning gains in *Carbon TIME* classrooms. Error bars represent 95% confidence intervals. Dashed lines represent (a) no learning and (b) average learning gain for all teachers.



Each of the participating teachers videotaped one lesson from each of three different *Carbon TIME* units. In this article I report on a comparison of the videotaped lessons from Ms. Jones' and Mr. Smith's classrooms—the teachers whose students demonstrated the lowest and highest learning gains.

Ms. Jones and Mr. Smith provided videotapes of the same lessons from three different *Carbon TIME* units: the burning ethanol investigation (*Systems and Scale* unit), the digestion and biosynthesis modeling activity (*Animals* unit), and the photosynthesis modeling activity (*Plants* unit). The videos from Mr. Smith's classroom were between 40 and 60 minutes in length. Ms. Jones' videos were 20 – 40 minutes in length due to shorter class periods at her school as well as the fact that she recorded only the specific *Carbon TIME* activities rather than the entire class period. In the videos both teachers faithfully enacted the *Carbon TIME* curriculum and ran well-managed classrooms. The students in both classrooms appeared attentive and engaged in the activities. In addition, the videos from both classrooms demonstrate much more teacher-talk than student-talk. Both teachers engaged students in whole class-discussions primarily through a call-and-response format in which the teacher posed a question and the students provided words or phrases in response.

The teachers and students also differed in important ways. Mr. Smith had used the *Carbon TIME* curriculum previously, while Ms. Jones had not. In addition, Mr. Smith and Ms. Jones taught at different schools which differed in their demographics. Mr. Smith taught a suburban high school serving approximately 1,700 students in Washington state, while Ms. Jones taught a rural high school serving approximately 1,000 students in California. While both classrooms were introductory biology courses, Mr. Smith's students were primarily 9th graders, while Ms. Jones' students were primarily 10th graders. Both schools had significant minority populations, but Mr. Smith's school had notably fewer economically disadvantaged students than Ms. Jones' school.

Although these differences between the teachers and the students likely contributed to the differences in classroom discourse and student learning outcomes, there is real value in looking closely at how the talk and actions differed in these two classrooms and how these created opportunities for different types of learning. To characterize differences in discourse—the purpose and substance of the conversation for the participants—I analyzed the videos through an iterative process of coding the talk and actions of the teachers and students (Miles, Huberman, and Saldana, 2014). Using StudioCode software I marked specific instances of teacher and student talk and actions, producing a corresponding timeline for the lesson. After coding the classroom discourse in the six videos, I used the timelines to compare and contrast the discourse in Mr. Smith's and Ms. Jones' classrooms.

RESULTS

My comparison of the discourse in Mr. Smith's and Ms. Jones' classrooms includes three key parts:

1. **What students were doing:** The learning gains scores show that students' learning was very different in the two classrooms. I think that these results can be explained by looking at what the students were doing. I looked in particular at the kinds of questions the students were answering, the kinds of questions that students were asking, and the roles that they played as learners in the classroom.
2. **What the teacher was doing:** What students do in the classroom is largely the result of the expectations set by the teacher. I looked in particular at how teachers framed the purposes for activities in their classrooms, how they scaffolded students' talk and work, and the sources of authority they appealed to support knowledge claims.
3. **Comparing classroom learning communities:** I conclude by putting it all together, describing how teachers and students together constructed two very different kinds of classroom communities while studying the same content and using the same teaching materials. One classroom constructed a curiosity-driven community focused on *figuring out* phenomena, while the other constructed an task-driven community focused on *learning about* scientific information.

What Students Were Doing

In both Mr. Smith's and Ms. Jones' classrooms there were two main structures for students' participation: whole-class discussions and small-group work. Because the cameras were positioned in one location in the room, whole-class discussions were better captured than small group work. So, while my analysis of what students were doing draws on both, I have more evidence about the discourse during whole-group discussions. In particular, I noted how students answered their teacher's questions as well as the questions that they posed. Whole-class discussions in both classrooms were structured similarly in that the teacher asked a series of questions to which the students responded, typically by calling out words or phrases. At first glance, these whole-class discussions looked very similar. However, upon a closer look it became clear that the role of the students differed in the two classrooms. In Ms. Jones' classroom the students were positioned as receivers of knowledge as they *learned about* scientific topics, while in Mr. Smith's classroom the students were positioned as developers and users of knowledge as they *figured out* phenomena.

For example, in both classrooms the photosynthesis modeling activity was preceded by a whole class discussion in which the students called out answers to the teachers' questions. One part of this discussion involved identifying where the elements that make up organic compounds in a plant come from. In Ms. Jones' class she used the *Carbon TIME* PowerPoint slides to ask a series of questions about the elements making up glucose:

> **Ms. Jones:** A question that we want to think about is, where does the sugar come from? So, just think about that for a second. Where does the sugar come from?
> **Female student:** [immediately raises her hand and teacher indicates that she can respond] the carbon and light energy
> **Ms. Jones:** The carbon and light energy and probably what is the third thing?
> **Students:** Water
> **Ms. Jones:** Water, because a sugar has what three elements in it?
> **Student:** Glucose
> **Ms. Jones:** Glucose is the name of the sugar, but what are the atoms?
> **Male student:** carbon, hydrogen, and oxygen
> **Ms. Jones:** Carbon, hydrogen, and oxygen. So carbon dioxide has what?
> **Students:** carbon and oxygen
> **Ms. Jones:** Carbon and oxygen. So is that enough to make a sugar?
> **Students:** No
> **Ms. Jones:** No. So it has to get that hydrogen from somewhere else, right? It is important to try to figure out. We will get to it, just think about it. [moves on to discuss organic versus inorganic]

At the end of this exchange Ms. Jones indicated that it is important to figure out where the hydrogen in glucose comes from. However, she immediately followed that statement with, "We will get to it, just think about it." and then moved on to a different line of questioning. Thus, the question of where the hydrogen in glucose comes from was a rhetorical one, and not something that the students were responsible for figuring out. Rather, their job was to learn scientific information when it was presented to them. Although it had already been established that carbon dioxide, water, and light were necessary to make glucose, and that glucose is made up of carbon, oxygen, and hydrogen, the teacher did not ask students to reconcile these two facts. The class did not come back to the question of where the hydrogen in glucose comes from during the rest of the lesson.

After discussing the reactants and products of the photosynthesis reaction as a class, Ms. Jones said:

> So, overall process is… we have water going from the roots into the plant up to the leaves, because leaves are where photosynthesis is taking place, right? And carbon dioxide from air to leaves. It goes into the tree and then we have sugar that is created and oxygen that is released. Now you guys are going to model that process with the actual molecular compounds. So, I'm going to give you your modeling poster and your kits.

The students followed the instructions on the printed handout to build the reactants and products of photosynthesis with molecular modeling kits. Thus, their role in the modeling activity was to follow directions and practice naming the reactants and products of the reaction. In both of the other videos of lessons in Ms. Jones' classroom the role of the students was the same: to follow directions and complete tasks that allowed them to learn scientific information that was already known.

In Mr. Smith's class a similar discussion about where the atoms in organic molecules come from occurred before the photosynthesis modeling activity. However, Mr. Smith used a children's book (which was not part of the *Carbon TIME* curriculum) to contextualize the process using the phenomenon of a tree growing:

> **Mr. Smith:** So they [trees] are made out of carbohydrates, proteins, and fats. But where does that stuff… where do the atoms come from in order to make those things?
> **Students:** air
> **Mr. Smith:** Yeah, from the air right? Somewhere in this book there is a nice little breakdown. If you separated a 4,000 pound tree into atoms, you would find [writing on board]… 1760 pounds of carbon. The same number, 1760 pounds of oxygen. Where did that oxygen come from?
> **Students:** Carbon dioxide
> **Mr. Smith:** Yeah, carbon dioxide… maybe… where is the other source it could come from?
> **Students:** water
> **Mr. Smith:** It could have come from water. So we haven't really identified the exact source of it [oxygen]. But, how much do you think is hydrogen?
> **Students**: less
> **Mr. Smith:** 240 pounds of hydrogen. What else do I need to add to the mix here? I've got carbons, oxygens, hydrogens… what else do we need?
> **Students:** nitrogen, phosphorus, sulfur [students calling out, teacher repeats each as he hears them]
> **Mr. Smith:** As it turns out about 240 pounds of the tree are these other things. We can call these other things minerals. Where do those minerals come from?
> **Students:** Soil
> **Mr. Smith:** Yeah… from the soil, right. We saw that when those plants increased in mass, they did take something from the soil. So it must be that, that mineral stuff. What are they using the nitrogen for? [Silence for 7 seconds] What molecule are they incorporating nitrogen into?
> **Students:** proteins
> **Mr. Smith:** Yeah, into proteins right. If you look at this protein here [pointing to a picture on the board] it has nitrogen present in it.

Although the students in Mr. Smith's class were supplying words or phrases to answer the teacher's questions just as in Ms. Jones' classroom, the discourse in Mr. Smith's class differed in a number of important ways. First, the conversation was broader in that it focused not just on the atoms in glucose, but the atoms in carbohydrates, fats, and proteins that make up a tree. It was therefore connected to a larger phenomenon—plant growth— that gave the discussion meaning. Second, the students were responsible for figuring out where the atoms making up the tree come from. Mr. Smith's questions built on each other to carefully scaffold their responses, but the sense is that students were figuring out where the mass of the tree comes from by answering his questions. Mr. Smith fostered this focus on sensemaking by pointing out uncertainty and asking students to make predictions. For example, when students said that the oxygen in a tree comes from carbon dioxide he agreed, but also asked for other possibilities. When students suggested that the oxygen could also come from water pointed out that, "We haven't really identified the exact source of it" and then asked students to make a prediction about the relative amount of hydrogen in the tree.

After the whole-class discussion of the reactants and products in the photosynthesis reaction, Mr. Smith said, "So, how do we get from carbon dioxide and water to glucose and oxygen? Your job is to show me how it's done." Thus, the students were expected to use the molecular model kits to figure out what was happening to the reactants and products on an atomic-molecular scale that resulted in the production of glucose (and eventually other organic molecules) in a tree. In both of the other lessons in Mr. Smith's classroom the role of the students was the same: to figure out the hidden mechanisms responsible for a particular phenomenon.

The differing roles that students played in the examples above are representative of the broader pattern of discourse in these classrooms, summarized in Table 1.1 below. In Mr. Smith's classroom nearly all of the instances of teacher questioning (19 out of 23 total) positioned students as making sense of phenomena. However, in Ms. Jones classroom the students' role in most instances of teacher questioning (13 out of 15 total) was to supply correct answers to the teacher's questions. In addition, the students' own questions demonstrate a similar pattern. In Mr. Smith's classroom the students asked 13 questions across the three lessons, 11 of which were conceptual in nature. In Ms. Jones' classroom the students asked nine questions total, two of which were conceptual in nature, while the rest were procedural or fact-based. Conceptual questions indicate that students are trying to make sense of phenomena or scientific models, while procedural questions indicate that students are focused on using correct vocabulary or following directions. To distinguish conceptual questions from other types I used the context in which the question was asked, the words the student used, and the teacher's response to understand the meaning that the question conveyed within the classroom community.

In summary, the students played very different roles in these two classrooms. In Ms. Jones' classroom the students' role was to follow directions and learn scientific information. Thus, their questions focused on facts and procedures. In Mr. Smith's classroom the students were collectively curious, working with the teacher to figure out phenomena and asking conceptual questions to help make sense of what they were learning. The students' posttest performances suggest that these differences had consequences for three-dimensional science learning. In the next part we look at how differences in the students' roles were connected with differences in how the teachers framed and scaffolded the activities.

Table 1.1. Student Questions in Mr. Smith's and Ms. Jones' Classrooms. Conceptual questions indicated by +.

Lesson	Mr. Smith's Classroom	Ms. Jones' Classroom
Burning ethanol investigation	+ Why is the H to the right of the oxygen? [asking about OH group in molecular formula of ethanol] + What chemical is in the fire extinguisher? – Do we put the glass on top [of the burning ethanol]? + Wouldn't this be H-6 [asking why ethanol was written as C_2H_5OH]? + Do we take this apart [molecular model] and put it back together again? + Do the extra bonds form light and heat energy? + What happened to the hydrogen?	+ Won't putting the lid on put out the ethanol?
Digestion & biosynthesis modeling activity	– Does this look good [asking teacher to check model]? + Isn't it poisonous to breathe in CO_2?	– Is diffusion from polymers to monomers [clarifying vocabulary terms]?
Photosynthesis modeling activity	+ Why can't plants get nitrogen from the air? + Do [real] molecules fall apart that easy [as our models do]? + If we burn glucose, what will happen… because it is organic? + So can you actually burn it [glucose]?	+ Wouldn't carbon-hydrogen bonds be a little lower energy [than carbon-carbon bonds]? Students asked the following questions while modeling the reaction. The teacher responded with procedural information. – What color is oxygen [in the molecular modeling kit]? – Do we put these all together [the atoms in the glucose molecule]? – What do you mean oxygen gas? – How many oxygens are we supposed to need? – How many atoms do you begin with? – Do you need to make this bigger or smaller [to balance the equation]?

What The Teacher Was Doing

The students in Ms. Jones' and Mr. Smith's classrooms carried out different roles because the teachers established different purposes for the activities and supported students in different ways. The main difference was how the teachers framed the purpose of the activities in which students engaged. Although both classrooms carried out the same activities, the teachers indicated different purposes for these activities in the way that they introduced them and in how they shared the procedures with students. Mr. Smith framed each activity as a way to answer a driving question about a phenomenon and expected the students to use empirical evidence and scientific models to figure out a scientific answer to that question. In contrast, an explicit purpose was never stated for activities in Ms. Jones' classroom. Instead, the implicit purpose conveyed for each activity was to learn complete the activity to learn scientific information.

Mr. Smith explicitly identified the purpose of each lesson by stating a question about a specific observable phenomenon within the first 10 minutes of the class period. In addition, he reiterated this driving question at key points during the lesson. For example, Mr. Smith started the ethanol investigation by explaining that students were going to apply what they learned about changes in matter in the previous investigation of soda water losing its fizz to answer the question, "What happens when ethanol burns?" He restated this question at two other key points in the lesson. One was when a student asked whether they should place a container over the burning ethanol. Mr. Smith confirmed that they should cover the dish of burning ethanol and then said, "We are interested in knowing what is happening to the ethanol right? Otherwise, whatever is happening to it will just go up into the air." Mr. Smith chose not to give students the *Carbon TIME* handout with the procedure for the investigation, but instead lead a discussion of how they could adapt the procedure they had used to study soda water losing its fizz to answer their new question about ethanol burning. The students recognized that they needed to record the mass of ethanol before and after burning it and that they could use bromothymol blue (BTB) to test for the presence of carbon dioxide.

While the students waited for the results of the ethanol investigation they began to build molecular models of the reactants in the combustion of ethanol. Mr. Smith related the modeling activity back to the same driving question for the investigation by saying, “There may be some things that we are not seeing that may be useful to us in terms of being able to explain what happens to ethanol when it burns.” He explained that using the molecular models would help them better understand what was happening to the ethanol at a scale too small to see. In addition to making this conceptual connection, Mr. Smith framed the modeling activity as a way to figure out an unknown product of the combustion of ethanol. After the students built the reactants (ethanol and oxygen molecules), he asked them to observe what was happening in the container in which they had placed the burning ethanol. When a student stated that the BTB was turning yellow, Mr. Smith asked a series of questions that helped establish that carbon dioxide was being produced as ethanol burned.

After establishing that carbon dioxide was one of the products of the reaction, Mr. Smith told students to use their molecular models to determine “how many carbon dioxides are formed and what is this other molecule that is forming and give me a number too. Use your models to tell me.” Thus, Mr. Smith framed the investigation as a way to collect empirical evidence to help answer the question “What happens to ethanol when it burns?” then used the modeling activity to figure out the unknown product (water). Mr. Smith positioned the students to figure out what happens when ethanol burns by clearly stating the driving question, “What happens to ethanol when it burns?” multiple times during the lesson. In addition, he established the source of authority for answering that question as empirical evidence and scientific models. Mr. Smith's conceptual questioning throughout the lesson helped students to clearly connect the procedures to the driving question and scaffolded their sensemaking about the empirical evidence they collected and the models they were using. This pattern of clearly stating a question about a phenomenon, relating the procedures for the activity to that question, and emphasizing the role of empirical evidence and scientific models in answering the question was also evident in the other two videos from Mr. Smith's class.

In Ms. Jones' classroom an explicit purpose for each lesson was not captured in the videos. Instead, facts and procedures were emphasized. For example, after students wrote predictions for the ethanol burning investigation, the teacher turned on the camera and said, "Go ahead and turn your paper over from the predictions side. On the back side are the procedures to follow for actually doing the burning ethanol investigation." It was clear that students had written their predictions on the worksheet, but it is not clear whether or not they discussed their predictions. The driving question suggested in the *Carbon TIME* Teacher's Guide, "What happens when ethanol burns?" was never stated during the recorded portion of the lesson, nor was there any reference to the students' predictions. Instead, the teacher emphasized following the procedure on the handout. She read the procedure aloud to students and asked a series of questions to check that students knew what they were expected to do.

Like Mr. Smith, Ms. Jones chose to move on to the modeling activity while students waited for the results of the burning ethanol investigation, but for Ms. Jones this seemed to be purely a logistical decision. She told the students to return to their seats for the modeling activity once they had set up the investigation. Unfortunately, I don't have any information about the discourse during the modeling activity because she turned off the camera once the students had set up the investigation. However, when the video camera was turned back on while students collected their data from the burning ethanol investigation, there was no mention of the modeling activity that they had been engaging in while the camera was off. (Ms. Jones likely turned the camera off during the modeling activity because she did not view it as part of the investigation, which we had asked teachers to record.)

Although Ms. Jones followed the directions in the *Carbon TIME* Teacher's Guide, she did not help students connect the procedures for the activities to the phenomena they were learning about. In addition, Ms. Jones placed a strong emphasis on following directions. She relied heavily on the printed directions for activities, and when students seemed to be struggling her first response was to remind them to read the directions. This emphasis on following directions, coupled with Ms. Jones' fact-based questioning positioned the curriculum materials as the source of authority in the classroom and established role of the students as receivers of scientific information. Although they were expected to be actively engaged in the discussions and activities, their role was to complete activities to *learn about* scientific ideas rather than to *figure out* scientific phenomena.

Comparing Classroom Learning Communities

Ms. Jones' and Mr. Smith's classroom discourse provide concrete examples of the differences between *learning about* scientific topics and *figuring out* phenomena. Ms. Jones' classroom discourse established a task-driven community that made learning scientific facts the main purpose for each activity, invoked the curriculum materials as the source of authority, and positioned the students as responsible for following directions and reciting scientific information. In contrast, Mr. Smith's classroom discourse established a curiosity-driven community that made answering questions about the natural world the main purpose for each activity, invoked empirical evidence and scientific models as the source of authority, and positioned students as responsible for figuring out an answer to the driving question.

The presence of a clear driving question about phenomena appears to be the key difference between Mrs. Smith and Ms. Jones' classrooms. By establishing a driving question about a phenomenon as the purpose of each learning activity, Mr. Smith engaged students' curiosity and framed activities as a means for answering scientific questions. Thus, in Mr. Smith's classroom students were positioned as developers and users of scientific information responsible for figuring out phenomena. In contrast, in the absence of a driving question in Ms. Jones' classroom, students were positioned as receivers of scientific information responsible for completing tasks and learning about science.

While establishing a driving question for lessons is essential, it would be a mistake to conclude that simply stating a driving question would significantly alter classroom discourse. It is important to recognize that Mr. Smith did a number of things that continually emphasized the driving question and supported students in figuring out the answer. He clearly connected the procedures for activities back to the driving question, established empirical evidence and scientific models as the source of authority for answering the driving question, and scaffolded student thinking through carefully sequenced questions that lead them to important conceptual connections. Students responded with interest and a sense of collective curiosity, as indicated by how they contributed their own conceptual questions to class discussions.

The fact that students in Mr. Smith's classroom achieved significantly higher learning gains on the three-dimensional *Carbon TIME* assessment is not surprising given that these students were engaged in three-dimensional reasoning about phenomena during classroom instruction. While Ms. Jones' students also learned content knowledge, their assessment results suggest that they were less prepared to apply their knowledge to new situations and had a less robust understanding of the principles of matter and energy that underlie carbon-transforming processes. The fact that Mr. Smith's students achieved significantly higher learning gains than Ms. Jones' students suggests that the curiosity-driven discourse established in his classroom better fosters three-dimensional learning.

CONCLUSION

Most teachers want their students to be curious about the science they are studying, and to engage in figuring out rather than learning about science. This close look at two teachers' classrooms shows us some key teaching strategies that helped Mr. Smith to achieve this goal. In Mr. Smith's classroom, the discourse established a curiosity-driven community that started with questions about phenomena and positioned students as active inquirers and explainers. Although both teachers were implementing the same NGSS-aligned curriculum, Mr. Smith organized each class around an explicit driving question about phenomena and emphasized the role of empirical evidence and scientific models in answering those questions. Thus, his students were able to apply what they learned to explain similar phenomena on the *Carbon TIME* post-test. The absence of a driving question in Ms. Jones' classroom and a corresponding emphasis on facts and procedures positioned her students in a way that lead to a different type of learning. Students learned facts and procedures, but were not well prepared to apply the principles of matter and energy to explain phenomena.

With many states and districts shifting to NGSS, much attention is given to the need for curriculum materials that are aligned to these new goals. However, as Mr. Smith's and Ms. Jones' classrooms demonstrate, aligned curriculum is not sufficient for ensuring three-dimensional learning. The shift from learning about science to figuring out phenomena requires creating a curiosity-driven classroom community that engages students in developing their own answers to scientific questions and emphasizes the role of empirical evidence and scientific models as the source of authority. Table 1.2 describes the recommendations for instruction based on the findings of this study and the goals of NGSS. The recommendations are drawn from the results of this study (How column), while the rationale (Why column) references the NGSS supporting document titled "Using Phenomena in NGSS-Designed Units and Lessons" (NGSS Website, 2016).

Table 1.2. Recommendations for practice.

What	How	Why
Engaging with specific phenomena	Teacher clearly identifies a specific phenomenon and gives students the opportunity to observe and discuss it. Teachers must guide students toward what to look at, what to look for, and what a scientific explanation would include.	"Anchoring the development of general science ideas in investigations of phenomena helps students build more usable and generative knowledge" (p. 3).
Explicit driving questions articulated and emphasized	While students may be involved in formulating questions about the phenomenon, the teacher clearly articulates which question(s) are being addressed in each activity.	"There could potentially be many different lines of inquiry about the same phenomenon… Teacher guidance may be needed to help students reformulate questions so they can lead to grade- appropriate investigations of important science ideas" (p. 2).
Authority for claims comes from empirical evidence & scientific models	The teacher clearly articulates how empirical evidence and scientific models support scientific claims. The teacher scaffolds students in collecting and analyzing evidence and developing and using models to answer driving questions about phenomena. The teacher presses students to support claims with evidence and relate scientific models to observations of phenomena.	Students develop an appreciation for how scientific knowledge is developed and used. "The goal of building knowledge in science is to develop general ideas, based on evidence, that can explain and predict phenomena" (p. 1).
Students positioned as sensemakers	1. Teacher states the driving question multiple times during a lesson and frames activities as a means for answering those questions. 2. Questions posed to students are carefully sequenced to scaffold students' thinking rather than to evaluate their knowledge. 3. Students are given opportunities to discuss their ideas in small and large group discussions and encouraged to ask conceptual questions. 4. Teachers respond to students' questions by scaffolding their sensemaking rather than simply stating facts.	"Students who come to see how science ideas can help explain and model phenomena related to compelling real world situations learn to appreciate the social relevance of science. They get interested in and identify with science as a way of understanding and improving real world contexts" (p. 1).

REFERENCES

REFERENCES

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268-291.

Fishman, B. J., Penuel, W. R., Allen, A.-R., Cheng, B. H., & Sabelli, N. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *National Society for the Study of Education, 112*(2), 136-156.

Miles M.B., Huberman, A.M, & Saldaña, J. (2014). *Qualitative Data Analysis: A Methods Sourcebook, Third Edition*. Thousand Oaks, CA: SAGE Publications.

National Research Council (NRC). (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Retrieved from https://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Retrieved from https://www.nextgenscience.org

NGSS Website (September, 2016). Using phenomena in NGSS-designed lessons and units. Retreived from http://nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf

STUDY TWO

Epistemic Framing: Figuring Out Phenomena Versus Learning About Science

INTRODUCTION

The National Research Council's (NRC; 2011) *Framework for K-12 Science Education* lays out a new vision for science education that calls for the integration of the three dimensions of science learning: science and engineering practices, crosscutting concepts, and disciplinary core ideas. Unlike previous conceptions of science learning that separated content and process goals, in the NRC *Framework,* "learning is defined as the combination of both knowledge and practice" (p. 254). *The Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) operationalized the NRC *Framework's* vision by creating learning standards that integrate science and engineering practices, crosscutting concepts, and disciplinary core ideas into three-dimensional performance expectations. The NRC *Framework* and NGSS supporting documents emphasize that three-dimensional learning requires instruction that centers on explaining natural phenomena.

The word phenomena, and its singular form, phenomenon, occur 114 times in the NRC *Framework*. Phenomena are defined as "observable events that occur in the universe and that we can use our science knowledge to explain or predict" (Achieve, 2016). The emphasis on explaining phenomena in science classrooms reflects that the goal of scientists is to use empirical evidence to explain and predict phenomena. NGSS supporting documents make the connection between three-dimensional learning and explaining natural phenomena explicit by asserting that, "Learning to explain phenomena and solve problems is the central reason students engage in the three dimensions of the NGSS" (Achieve, 2016).

Thus, the defining feature of three-dimensional science instruction is that students engage in the three dimensions to explain a phenomenon or solve a problem. "Engineering involves designing solutions to problems that arise from phenomena, and using explanations of phenomena to design solutions." Therefore, engineering can provide a context for science learning and help students to develop an appreciation for the connections among science, technology, and society. Centering instruction around investigating and explaining natural phenomena shifts the purpose in science classrooms *from learning about* science ideas to engaging in scientific ways of thinking to *figure out* phenomena. NGSS supporting documents explain that "By centering science education on phenomena that students are motivated to explain, the focus of learning shifts from learning about a topic to figuring out why or how something happens" (NGSS, 2016).

Scientific Curiosity

I suggest that curiosity is at the heart of the distinction between learning about science and figuring out phenomena, and explains why the latter is more effective in terms of both affective and cognitive outcomes. Curiosity is commonly defined as "the desire to learn or know" (Dictionary.com), and has been described as a key factor in intrinsic motivation to learn (Ryan & Deci, 2000). While it is often conceptualized as an individual personality trait or mental state (Loewenstein, 1994), curiosity can also be conceptualized as a social practice. In his book, *The Practice of Theoretical Curiosity* (2012), Mark Zuss asserts that, "curiosity is the spirit of an abiding inquisitiveness realized in distinct social practices" (p. vii).

Curiosity is not simply a generic desire for any knowledge, but rather, it always has a particular object (Inan, 2012; Schmitt & Lahroodi, 2008). For natural scientists, the object of curiosity is natural phenomena. Their main objective is to develop naturalistic explanations for phenomena supported by empirical evidence (Pennock, 2011). The NRC *Framework* asserts that scientific studies

> are driven by curiosity and undertaken with the aim of answering a question about the world or understanding an observed pattern. For science, developing such an explanation constitutes success in and of itself, regardless of whether it has an immediate practical application (2011, pp. 47-48).

Scientists own accounts support this view of science as driven by curiosity about the world. For example, Nobel Prize winning physicist Richard Feynman (1999) describes the "pleasure of finding things out" (p. 12) and says that as scientists, "we're exploring, we're trying to find out as much as we can about the world" (p. 23). Feynman's account of science highlights both a cognitive dimension—finding out—as well as an affective dimension—pleasure—of scientific curiosity.

The cognitive and affective dimensions of curiosity are supported by many other accounts of scientific work (e.g. Sacks, 2002; Shubin, 2009; Watson, 2001). They emphasize that the goal of science is figuring out how the natural world works and reflect the enjoyment inherent in satisfying one's curiosity. In her biography of Barbara McClintock, Evelyn Fox Keller observes that, "Good science cannot proceed without a deep emotional investment on the part of the scientist" (Keller, 2003). This emotional investment is largely driven by curiosity and the gratification that scientists get from the process of satisfying their curiosity. In addition to providing individual motivation for scientific work, curiosity is taken as a shared value among scientists that shapes their practices. Not only is curiosity the driving force behind asking scientific questions, it motivates the other practices that scientists engage in to answer those questions. For example, planning and carrying out investigations, analyzing and interpreting data, developing and using models, and constructing explanations are means to satisfying curiosity about the natural world.

The practices in which scientists engage discipline their curiosity by "coupling it with a method for establishing reliable facts empirically and using them to formulate hypotheses and interpretations" (Ball, 2013, p. 396). Thus, scientific curiosity reflects not only a shared purpose aimed at figuring out how the natural world works, but also an "epistemic value commitment to the authority of empirical evidence" (Pennock, 2011, p. 199). Scientific explanations must be supported by empirical evidence, which reflects scientists' shared conviction that the natural world operates in consistent ways that can be explained through careful observation and experimentation. Scientific models integrate empirical evidence with inferences to represent "current understanding of a system (or parts of a system) under study" (NRC, 2011, p. 57), and are thus an important means of consolidating and communicating the reasoning that supports scientific explanations.

Although scientific studies are often carried out by individuals and small groups, their findings are subject to the scrutiny of the larger community of practice. The knowledge produced by individuals and small groups is subject to peer review and corroboration with other lines of evidence before it is accepted by the field. This holds scientists accountable to shared model-based reasoning and the epistemic commitments of the community of practice in which they participate. Therefore, scientists' curiosity is shaped by their community through a shared purpose of explaining natural phenomena and the shared commitment to the epistemic authority of empirical evidence. However, the "pleasure of finding things out" is personal. In addition, individual scientists exercise personal agency by engaging in scientific practices to contribute knowledge to the field. Thus, I propose three key features of scientific curiosity:

1. **Purpose:** The shared goal of the scientific community is explaining natural phenomena.

2. **Epistemic Authority:** The scientific community demonstrates a shared epistemic commitment to the authority of empirical evidence.
3. **Epistemic Agency:** Individual scientists engage within the larger social structure of science to carry out scientific practices, and are often motivated by a personal desire to satisfy their own curiosity about the natural world.

THEORETICAL FRAMEWORK

The NRC *Framework* is built on the assumptions that science is driven by curiosity about the natural world (p. 47-48) and that children are naturally curious about their world (p.11). *Science for All Americans* linked scientists' curiosity with students' curiosity saying,

> Scientists thrive on curiosity—and so do children. Children enter school alive with questions about everything in sight, and they differ from scientists only in not yet having learned how to go about finding answers and checking to see how good those answers are. Science education that fosters curiosity and teaches children how to channel that curiosity in productive ways serves both students and society well (AAAS, 1989, Ch. 12).

Science for All Americans points out that students require support to refine their natural inquisitiveness into scientific curiosity. Although children are naturally curious about the world, scientific curiosity is disciplined by scientific practices and habits of mind that must be learned. The NRC *Framework* lays out a vision for how engaging students in the science and engineering practices, crosscutting concepts, and disciplinary core ideas to explain phenomena can guide students "toward a more scientifically based and coherent view of the sciences and engineering, as well as the ways in which they are pursued and their results can be used" (2011, p. 11).

Achieving the vision of three-dimensional learning in classrooms is not an easy task. Scientific curiosity shaped by scientific practices and ways of thinking is an important accomplishment that takes years of experience to cultivate. However, the NRC *Framework* and

NGSS make pursuing scientific curiosity a goal for all students, not just those who will go on to scientific careers. These documents point out that current science education in the United States falls short of the vision of three-dimensional learning because instruction "emphasizes discrete facts" and "does not provide students with engaging opportunities to experience how science is actually done" (NRC, 2011, p. 1).

Decades of research in science classrooms has demonstrated that typical instruction promotes *procedural display* rather than developing and using scientific knowledge in authentic ways. Procedural display refers to "getting the lesson done" (Bloome, Puro, & Theodorou, 1989), and is similar to what others have referred to as "doing school" (Ford & Wargo, 2012) or the "classroom game" (Lemke, 1990). The construct of procedural display emphasizes both the teachers' and students' perspective in terms of what is happening in the classroom, and how they cooperate to perform a lesson. Bloome et al. (1989) describe procedural display as, "the interactional strategies cooperatively and concertedly used by the teachers and the students" that serve to get "through the lesson rather than substantive engagement in some academic content" (p. 282).

Thus, procedural display is enacted through *classroom discourse*, which includes the talk, routines, norms of interaction, and activities engaged in by teachers and students. While the term discourse is sometimes used to refer to strictly written or spoken language, I follow Gee in using the term more broadly to refer to "a socially accepted association among ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaningful group" (Gee, 1991). Thus, classroom discourse includes the talk, norms of interaction, and activities and the meanings that these hold for the teachers and students that make up a classroom community. Procedural display is deeply entrenched in classrooms because it helps to maintain order and manage the performance for grade exchange (Doyle, 1983). Typical classroom discourse, which I call *task-driven discourse*, aims at procedural display as students learn about science.

Classroom discourse aimed at procedural display is fundamentally different from three-dimensional learning aimed at figuring out phenomena. Figuring out phenomena requires that questions about the natural world and a shared drive to answer those questions are at the core of classroom discourse. I call this *curiosity-driven discourse* because it is motivated by the desire to explain natural phenomena. Task-driven and curiosity-driven discourse differ in the purposes that are established for learning activities, the sources of authority that are invoked, and in how students are positioned in terms of developing and using knowledge.

Curiosity-driven discourse is focused on figuring out phenomena by engaging in scientific practices and applying disciplinary core ideas and crosscutting concepts. Thus, just as in the work of scientists, empirical evidence and scientific models serve as the authority for knowledge claims in a classroom characterized by curiosity-driven discourse. When students take on the role of figuring out phenomena they are positioned as epistemic agents (Stroupe, 2014) responsible for constructing knowledge. Classrooms engaged in procedural display may engage in many of the same activities, but their purposes for doing so are limited to completing the task at hand, generally with the intention of acquiring some discrete knowledge or skill. In addition, when classrooms are engaged in procedural display, authoritative knowledge from the teacher or curriculum materials tends to serve as the source of authority for knowledge claims. Thus, students are positioned as receivers of authoritative knowledge, rather than as epistemic agents responsible for constructing knowledge.

Whether classroom discourse is curiosity-driven or task-driven largely depends on the purposes that the teacher conveys for activities and the scaffolding they provide learners. Wood, Bruner, and Ross (Wood, Bruner, & Ross, 1976) first used the term scaffolding to describe the supports that an adult supplies to a child to help solve a problem that the child would be unable to solve on their own. The term scaffolding is now used to describe a range of material or social supports used to assist learners (Sawyer, 2014). Vygotsky's (1978) notion of the zone of proximal development (ZPD), the distance between what a novice can do on their own and what they can do with support from others, is central to the concept of scaffolding. While assistance can take many forms, scaffolding must be aligned to a learner's ZPD in order to be effective (Walqui, 2006). Researchers have pointed out that "Scaffolding supports the complex interactions among cognition, motivation, and affect so students become engaged and remain involved in learning for learning's sake" (Turner, Meyer, Cox, Logan, & Thomas, 1998, p. 732). Thus, this study rests on the assumption that scaffolding provides students with both cognitive and affective support for science learning.

Curiosity-driven classroom discourse scaffolds scientific curiosity and fosters three-dimensional learning. Through curiosity-driven discourse students not only construct new knowledge, but also deepen their own curiosity and learn to channel it for intellectual pursuits. Engel asserts that, "talking about what interests or perplexes children gives them a chance to cultivate and expand their curiosity as an intellectual tool" (2011, p. 638). If students are also held accountable to disciplinary norms concerning the use of empirical evidence and scientific models, this type of discourse supports students in three-dimensional learning. Therefore, curiosity-driven classroom discourse scaffolds all three aspects of scientific curiosity:

1. **Purpose:** A shared purpose of figuring out natural phenomena is scaffolded through clearly articulated questions about phenomena that drive classroom activities.
2. **Epistemic Authority:** An epistemic commitment to the authority of empirical evidence is scaffolded by requiring that claims be supported by empirical evidence and clearly connecting scientific models and empirical evidence.
3. **Epistemic Agency:** Students' epistemic agency is fostered as they take on the responsibility of developing and using knowledge to figure out phenomena and their personal curiosity is cultivated.

Purpose. Lemke asserts that "All social cooperation is based on participants sharing a common sense of the structure of the activity: of what's happening, what the options are for what comes next, and who is supposed to do what (Lemke, 2001, p. 19). Students come to classrooms with experiences and conceptions about the purposes for learning activities which influence their participation in classroom discourse. However, teachers can invite students to participate in new purposes by explicitly stating those purposes and supporting students in adopting them. Thus, the teacher's framing of the purpose of activities in an important form of scaffolding in classroom discourse (Ford & Wargo, 2012).

Doyle pointed out that the main activity in classrooms is producing answers to teachers' questions and that, "the answers a teacher accepts and rewards define the real tasks in classrooms" (1983, p. 182). Similarly, Mehan (1978) described how classroom lessons are structured through the initiate-respond-evaluate (I-R-E) discourse pattern in which the teacher poses questions to the students and evaluates their responses. The I-R-E pattern facilitates orderly interaction between the teacher and students and allows the teacher to maintain control of the lesson, but it often reduces the knowledge and skills to be learned into discrete easilyidentifiable pieces such as facts and vocabulary. Thus, the I-R-E pattern tends foster procedural display. However, multiple scholars point out that the I-R-E pattern can also be used to negotiate meaning rather than directly transmitting knowledge from the teacher to the students (Ford & Wargo, 2012; O'Connor & Michaels, 2007). Therefore, the I-R-E pattern could be enacted by teachers in a way that scaffolds students in making sense of phenomena.

Epistemic Authority. In science classrooms students and teachers can appeal to different sources of authority for supporting knowledge claims. Teachers sanction particular sources of epistemic authority through explicit statements, as well as implicitly through their questioning. When a teacher asks predominantly factual questions of students and evaluates the correctness of their answers, it elevates the teacher as the epistemic authority in the classroom. Thus, the I-R-E discourse pattern tends to position the teacher as the epistemic authority in the classroom. However, the I-R-E pattern could be enacted by teachers in a way that emphasizes the role of empirical evidence and scientific models in making sense of phenomena. For example, when teachers ask students to support a claim with observations or data, they implicitly invoke the authority of empirical evidence. In addition, open-ended questioning and talk strategies that encourage students to discuss explanations with their peers can be structured in a way that holds students' ideas accountable to the epistemic authority of empirical evidence.

Epistemic Agency. Curiosity-driven discourse fosters students' epistemic agency by positioning them as questioners, investigators, and creators of knowledge as they explain phenomena. Whenever a student asks a question, shares their own idea, or uses evidence to formulate a claim they are exercising epistemic agency. However, in many classrooms task-driven discourse aimed at procedural display is the norm. In these classrooms, students are offered very little epistemic agency. Instead, their main role is to learn authoritative knowledge and repeat it back to the teacher.

There are many reasons that task-driven discourse aimed at procedural display is so common in classrooms. Researchers have related the underlying causes to teachers' practices related to maintaining order and to students' and teachers' strategies for minimizing ambiguity and risk. This relationship between students' epistemic agency and teachers' practices reflects the idea that "agency refers to acts done intentionally," but also that "people are contributors to, rather than the sole determiners of, what happens to them" (Bandura, 1997, p. 3). Thus, the epistemic agency that students exercise in classrooms is a product of their own free will, but also shaped by teachers' practices that position students in particular ways with respect to developing and using knowledge.

Curiosity-driven and task-driven discourse thus represent two different frames for classroom discourse. Framing includes the signals exhibited in talk and actions that reveal participants' sense of the goals and meanings of the activities in which they are engaging (Tannen, 1993). Multiple scholars have used the term epistemological framing to refer to teachers' and students' framing with respect to knowledge and learning during classroom activities (Hutchison & Hammer, 2010; Russ & Luna, 2013). However, I follow Kitchener (2002) in distinguishing between the theory of knowledge (epistemology) and knowledge itself (the epistemic). Therefore, I use the term epistemic framing, rather than epistemological framing, to indicate that I am not studying teachers' or students' theories of knowledge directly, but rather what their discourse reveals about their epistemic aims.

OVERVIEW OF STUDY

In this study, I analyze videos from five high school classrooms as they enacted an NGSS-aligned curriculum called *Carbon: Transformations in Matter and Energy* (*Carbon TIME*) to describe teachers' and students' epistemic framing in classroom discourse. Because the classrooms were using the same curriculum materials, I could focus my analysis on how *Carbon TIME* activities were framed through classroom talk. Several features of classroom discourse that support three-dimensional learning have been described including: clearly established purposes for talk, accountability to disciplinary norms and to the classroom community, responsiveness to students' ideas, and fostering student agency (Engle & Conant, 2002; Michaels & O'Connor, 2012; Thompson et al., 2016). This study builds on the body of literature about productive classroom talk to describe how it can orient students toward figuring out phenomena and the challenges teachers face in establishing and maintain curiosity-driven discourse. The study was guided by the following research questions that reflect my theoretical framework:

1. How do teachers indicate the purposes for classroom activities and scaffold students in taking up those purposes?
2. What sources of epistemic authority serve to support knowledge claims in classroom discourse?
3. How do students exhibit epistemic agency in classroom discourse and for what purposes?

The *Carbon TIME* project reflects design-based research's "commitment to studying activity in naturalistic settings, with the goal of advancing theory while at the same time directly impacting practice" (Barab, 2014, p. 151). Each of the five classrooms represents a case study. A *Carbon TIME* researcher, or "coach" worked closely with each case study teacher to support them in implementing the curriculum and to collect data about the implementation. In addition to the classroom videos analyzed in this study, the *Carbon TIME* project collected field notes from the case study coaches, videos of selected focus students as they engaged in *Carbon TIME* activities, teacher and student surveys, interviews with the teacher and focus students, and student assessment data. This study reports on an analysis of videos collected as the classrooms enacted first unit of the *Carbon TIME* curriculum, but other data sources and my participation in the larger project have undoubtedly influenced my conclusions.

The *Carbon TIME* curriculum is designed to support three-dimensional learning (disciplinary core ideas, science and engineering practices, and crosscutting concepts) about carbon-transforming processes—combustion, digestion, biosynthesis, photosynthesis, and cellular respiration—at organismal, ecosystem, and global scales. Thus, *Carbon TIME* units focus on phenomena that are caused by carbon-transforming processes, such as plant and animal growth and movement, decay, and combustion. The idea that figuring out phenomena fosters three-dimensional learning is supported by many lines of evidence cited in the NRC *Framework* (2011), but I do not directly test the relationship between classroom discourse and student learning outcomes in this study. Instead, my goal is to understand how the differing epistemic frames of learning about science and figuring out phenomena are established and maintained through classroom discourse.

Two features of the *Carbon TIME* curriculum are especially relevant to this study because of their influence on classroom discourse: the Three Questions and the Process Tools. The Three Questions serve as the criteria for a complete scientific explanation of a carbon-transforming process and include: (1) the Matter Movement Question (Where are molecules moving?), (2) The Matter Change Question (How are atoms being rearranged into different molecules?) and (3) the Energy Change Question (What is happening to energy?). The Process

Tools scaffold student thinking and writing around the Three Questions at four key stages of the unit: (1) Expressing Ideas: articulating initial ideas and questions about phenomena at the beginning of a unit, (2) Predictions: articulating reasoning about what students expect to happen before an investigation, (3) Evidence-Based Arguments: linking claims with evidence after an investigation, and (4) Explanations: constructing explanations at the end of a unit. Thus, the Three Questions and how participants engage with the Process Tools are important aspects of the epistemic framing in classroom discourse.

The videos analyzed in this study were recorded at the beginning of the 2015 – 2016 school year during the months of September and October as teachers implemented the first unit of the *Carbon TIME* curriculum, *Systems & Scale*. In this unit students investigate and explain the phenomenon of ethanol burning through a series of five lessons that spans two to three weeks of class time. The Process Tools throughout the unit include the driving question "What happens when ethanol burns?" and scaffold students toward a complete explanation that addresses each of the Three Questions. The *Systems & Scale* unit also includes an investigation of soda water fizzing to introduce students to the method of tracing matter by measuring the mass of materials and the use of bromothymol blue (BTB) to test for the presence of CO_2. For a more complete description of the lessons in the *Systems & Scale* Unit, see the materials online at http://carbontime.bscs.org

METHODS

I analyzed three videos from each of the five classrooms designated by the pseudonyms for each case study teacher: Ms. Callahan, Mr. Harris, Ms. Nolan, Mr. Ross, and Ms. Wei. See Appendix for additional information about the video data from each classroom. Prior to the 2015 – 2016 school year, Ms. Nolan, Mr. Ross, and Ms. Wei had some experience implementing selected activities from the *Carbon TIME* curriculum, while Ms. Callahan and Mr. Harris did not. The five case study classrooms were from five different public high schools in Michigan and Washington state (Table 2.1). The choice of case study classrooms was purposeful in that we wanted to study implementation in classrooms that represented a range of teaching practices and different types of learners. However, the sampling was not random—the teachers volunteered to participate in the *Carbon TIME* project and later agreed to take on the additional role of a case study classroom.

Table 2.1. Descriptions of the case study classrooms.

Teacher	**Grade level of majority of students**	**School context**	**Approximate school enrollment in 2015-16**
Ms. Callahan	9	Regional math and science center drawing students from high schools in urban/suburban Michigan	300
Mr. Harris	9	Public high school in suburban/rural Michigan	1500
Ms. Nolan	10	Public high school in urban Washington	1100
Mr. Ross	9	Public high school in suburban Michigan	1600
Ms. Wei	9/10	Public high school in urban Washington	1600

The classroom videos were analyzed using Studiocode software. In a previous study (Sutdy One of this dissertation), I used grounded theory methods (Birks & Mills, 2011) to develop an analytical framework for analyzing epistemic framing in classroom discourse. My coding framework included three categories of codes that were further refined in this study:

1. ***Teacher's Purposes*****:** The ways that teachers frame and scaffold activities.
2. ***Epistemic Authority*****:** The sources of authority to which participants appeal when making knowledge claims.
3. ***Students' Epistemic Agenc*****y:** The purposes for activities that students' questions convey and the epistemic roles that they take on in the classroom community.

The codes for these categories were further refined through constant comparative analysis of the videos from the five high school classrooms included in this study. Thus, the current study included advanced coding that was aimed at theoretical integration (Birks & Mills, 2011) to better explain how classroom communities establish and maintain curiosity-driven or task-driven discourse.

My coding framework is summarized in Table 2.2. The three categories reflect my theoretical framework for curiosity-driven classroom discourse, while the indicators and codes reflect my analysis of the data. Thus, the coding framework represents both a theoretical construct as well as an empirical result of this study.

Table 2.2. Summary of the video coding scheme. The codes in green represent curiosity-driven framing, the codes in red represent task-driven framing and the codes in yellow are task-driven or curiosity-driven depending on the context.

Category	Description	Indicators	Codes
Teacher's Purposes	How the teacher frames the purpose of the activity and scaffolds students toward those learning goals	Introduction to activities	Question about phenomena
			Task-driven
		Questioning purposes	Scaffolding sensemaking
			Sharing ideas
			Reviewing or evaluating
		Metacommentary about purposes broader than the current activity	Conceptual
			Procedural
			Epistemic
Epistemic Authority	What serves as the source of authority for knowledge claims in classroom discourse	Explicit or implicit appeals to authority	Scientific models
			Empirical evidence
			Book or curriculum
			Teacher as authority
Students' Epistemic Agency	How students are positioned in the classroom in terms of constructing and using knowledge	Students' questions	Conceptual
			Procedural
		Teachers' response to students' questions	Scaffolding sensemaking
			Conceptual
			Procedural
		Teachers' responses to students' difficulties	Scaffolding sensemaking
			Scaffolding answers or procedures

My coding framework mirrors my theoretical framework to conceptualize the *Teacher's Purposes* as an important form of scaffolding in classroom discourse. I identified three ways that teachers convey to students their purposes for activities: (1) how they introduce activities, (2) the types of questions that they ask, and (3) the metacommentary that they provide about purposes that are broader than the activity at hand. I was only able to identify instances where the teacher invoked a source of *Epistemic Authority*. I did not identify any instances where students invoked an epistemic authority, although this could be related to the fact that the student talk that I analyzed was from whole-class discussions and interactions primarily with their teacher (rather than small group work where students interact primarily with their peers).

Students' Epistemic Agency is an emergent property that is influenced by how teachers position students through the *Teacher's Purposes* and appeals to *Epistemic Authority* as well students' own actions. Students generally do not explicitly state their own purposes for activities. Therefore, I inferred students' purposes in classroom discourse through the questions that they asked during lessons. I coded *student questions* as either *conceptual* or *procedural*. Conceptual questions indicate that students are trying to make sense of scientific concepts (figuring out phenomena frame), while procedural questions indicate that students are focused on gathering discrete information such as correct vocabulary or procedures to follow (learning about science frame). For more a more detailed explanation of the coding framework see Appendix.

RESULTS

My coding and analysis revealed that while each of the five teachers maintained well-managed classrooms and faithfully enacted *Carbon TIME* activities, curiosity-driven discourse aimed at figuring out phenomena was consistently evident only in Ms. Nolan's classroom. Task-driven discourse predominated in the other four classrooms. The discourse in each classroom is summarized in Table 2.3.

My analysis demonstrated that *Teacher's Purposes* had the most substantial impact on classroom discourse. In all five classrooms, the purposes that the teacher established through their *introduction to activities*, *questioning*, and *metacommentary* provided the foundation for the taken-as-shared frame and led to either curiosity-driven or task-driven discourse. The *Epistemic Authority* to which teachers appealed served to reinforce the *Teacher's Purposes* and sanctioned particular types of *Student Epistemic Agency* in their classrooms. Though in Ms. Wei's classroom *students' questions* sometimes challenged the purposes and roles prescribed by

Teacher's Purposes and the *Epistemic Authority* to which she appealed, generally students adopted their teacher's epistemic framing. Thus, in Ms. Nolan's classroom, curiosity-driven discourse aimed at figuring out what happens when ethanol burns predominated during the *Systems & Scale* Unit, while in the other four classrooms task-driven discourse aimed at learning about science prevailed.

Table 2.3. Summary of discourse in the five case study classrooms.

Teacher	Teacher's Purposes	Epistemic Authority	Students' Epistemic Agency
Ms. Nolan	**Figuring out phenomena.** The teacher stated a driving question about the phenomenon and repeated it multiple times each lesson. Procedural instructions focused on reasoning. Majority of teacher's questioning instances scaffolded sensemaking about the phenomenon. Conceptual, procedural and epistemic metacommentary tended to co-occur as the teacher made connections and situated activities in a larger context.	Empirical evidence and scientific models were authority for knowledge claims. Facts and rules about atoms were the authority for building molecular models.	Students asked 33 conceptual questions to which the teacher responded with conceptual answers or scaffolded sensemaking. Students responsible for using evidence and scientific models to explain phenomena.
Ms. Callahan	**Rigorous conceptual understanding.** The teacher did not state a driving question about a phenomenon. Activities were framed in a task-driven way. Majority of teacher's questioning instances focused on reviewing information or evaluating students' knowledge. Teacher's metacommentary focused on learning from mistakes and procedural issues.	Teacher's focus on rigor and assessment positioned her as the authority. Teacher emphasized empirical evidence when discussing the investigation and facts and rules about atoms when building models.	Students asked 16 conceptual questions (15 were in one class period and mostly during a small-group modeling activity) to which the teacher responded with conceptual answers or scaffolded sensemaking. Students responsible for learning rigorous content knowledge.
Ms. Wei	**Learning about science.** The teacher framed activities in a task-driven way. She stated a driving question about a phenomenon one time during the unit when she read it from a *Carbon TIME* PowerPoint slide. Questioning scaffolded sensemaking in about a third of instances, while the rest focused on reviewing information, evaluating students' knowledge, or sharing ideas. Teacher's metacommentary focused on procedural aspects of activities and how she was evaluating their work.	Teacher's classroom management clearly established her as the authority responsible for evaluating students' knowledge. Her fact-based responses to students' questions also reinforced her authority. She emphasized the role of empirical evidence as the source of authority for claims during discussions of the results of investigations.	Students asked 21 conceptual questions, many of which occurred within a few clusters of intense questioning by multiple students. The teacher responded with a mix of procedural, conceptual, and fact-based answers, but rarely scaffolded sensemaking. Students responsible for following directions and learning information.

Table 2.3 (cont'd)

Teacher	Teacher's Purposes	Epistemic Authority	Students' Epistemic Agency
Mr. Ross	**Learning about science.** The teacher stated a driving question about a phenomenon once in the middle of a modeling activity. Activities were framed in a task-driven way. Less than half of teacher's questioning instances facilitated sensemaking, with the remainder focused on sharing ideas or reviewing information. Teacher's metacommentary focused on the process of learning and being OK to make mistakes.	Teacher emphasized the role of empirical evidence in science and "thinking like scientists" in multiple lessons. Teacher's classroom management strategies that tightly controlled who talked and when established him as the authority.	Students asked three conceptual questions. Teacher responded to two with conceptual answers and one with a fact-based answer. Students responsible for following directions and learning information.
Mr. Harris	**Learning about science.** The teacher never stated a driving question about a phenomenon and there was very little attention to conceptual transitions among the many different activities that occurred within each class period. Activities were framed in a task-driven way. Episodes of questioning were very brief and accounted for less than 10% of class time, although half of questioning instances focused on sensemaking. Teacher's metacommentary focused on it being OK to make mistakes and purpose of sharing ideas. He also talked about the role of questions and evidence in science.	Teacher's classroom management that focused on staying organized and quickly moving between activities established him as the authority in the classroom. The teacher talked about the importance of evidence in science multiple times, but in a very generalized way.	Students asked one conceptual question to which the teacher responded by scaffolding sensemaking. Students responsible for following directions and learning information.

Ms. Nolan established a curiosity-driven frame by explicitly stating the driving question, "What happens to ethanol when it burns?" multiple times during each videotaped class period. Similarly, her questioning focused on scaffolding students' sensemaking about the phenomenon. In addition, Ms. Nolan frequently emphasized the epistemic authority of empirical evidence and scientific models for answering the driving question. Thus, the *Teacher's Purposes* and *Epistemic Authority* in Ms. Nolan's classroom fostered *Students' Epistemic Agency* by positioning them as responsible for using empirical evidence and scientific models to figure out phenomena. *Students' questions* focused on making sense of the phenomenon and occurred frequently throughout the unit, indicating that they adopted the curiosity-driven purpose established by their teacher.

In the other four classrooms, task-driven discourse aimed at learning about science was more evident. Ms. Callahan, Ms. Wei, Mr. Ross, and Mr. Harris framed activities in a way that emphasized completing tasks, confirming authoritative knowledge, and following procedures. In addition, their patterns of questioning tended to emphasize reviewing information and evaluating students' knowledge. Despite these similarities in the teachers' framing, there were several differences among the classrooms. Ms. Callahan and Ms. Wei were more skillful in eliciting and responding to students' ideas than Mr. Ross and Mr. Harris, and their students asked a substantial number of conceptual questions. Mr. Ross and Mr. Harris lacked strategies for eliciting and building upon students' ideas, and their students asked very few conceptual questions. In addition, the discourse in Ms. Callahan's was more rigorous than the other three classrooms characterized by task-driven discourse. Although my coding framework does not completely account for these differences, a better description of Ms. Callahan's classroom might be *rigor-driven discourse*, which recognizes that fact that it was not completely task-driven in that the teacher attended to important conceptual connections. Although discourse in Ms. Callahan's classroom fell short of positioning students as epistemic agents responsible for figuring out phenomena, rigor-driven discourse seems more aligned to the vision of three-dimensional learning than task-driven discourse alone.

Below I illustrate how I applied my coding framework to analyze discourse using examples from Ms. Nolan's, Ms. Wei's, and Ms. Callahan's classrooms. I describe each classroom separately to highlight how *Teacher's Purposes*, *Epistemic Authority*, and *Students' Epistemic Agency* interacted to produce a taken-as-shared frame for discourse in each classroom. While each of the teachers ran a successful classroom in terms of maintaining order and engaging students in the *Carbon TIME* activities, they differed in the purposes that they established for those activities. In addition, the epistemic authority to which the teachers appealed reinforced their purposes and sanctioned particular roles for students in the classroom.

Ms. Nolan's Classroom: Curiosity-Driven Discourse

Introduction to Activities. Ms. Nolan began each class period by going over the agenda and goals for the day using a PowerPoint slide that she had prepared. Her introduction included emphasizing the driving question about the phenomenon and explaining how the activities for that day related to each other conceptually. For example, at the beginning of the unit Ms. Nolan began class saying,

> Today you will be explaining what you think happens when something burns and then begin to become comfortable with looking at things at different scales. I know neither of these things feels especially like biology, the study of life, but we need to have very solid background skills in understanding what's going on when something is burning. You are going to find out why this applies to life very soon, and you've got to become really comfortable zooming in on things and then looking at the big picture back and forth in order to be successful for the next several units in here.

Thus, Ms. Nolan began the *Systems & Scale Unit* by indicating that students would be learning about the phenomenon of burning and situating the unit within the larger goals for the entire course. During the lesson she clearly established the driving question for the unit, “What happens to ethanol when it burns?” In addition to beginning each class period with an agenda and goals for the day, Ms. Nolan clearly marked the beginning of each activity by explicitly stating the purpose of the activity, and explaining how the activity would help students answer the driving question for the unit.

For example, as Ms. Nolan transitioned from the discussion in which students expressed their initial ideas and questions about ethanol burning, into activities focused on developing foundational knowledge about levels of scale, she indicated the connection between these activities in multiple ways. She summarized the key ideas and questions that students had shared about ethanol burning and pointed out that, “It looks like you want to zoom in on that ethanol and get a better understanding of what is inside that ethanol.” She told students that throughout the unit, “We are going to work together on this to come up with our answer to this question—What happens when ethanol burns?” Ms. Nolan then transitioned to the activities focused on different levels of scale saying, “We are going to get some background information that you need in order to have a deeper understanding of what’s happening when ethanol burns. The information we need is understanding scale.” Each of the three videos from Ms. Nolan’s class included multiple *Carbon TIME* activities. In each lesson, she introduced the goals of the activities at the beginning of the period and then explicitly marked the transition between activities. Every time Ms. Nolan transitioned from one *Carbon TIME* activity to the next, she explained the conceptual connections between the activities and emphasized how they would help students figure out what happens when ethanol burns.

Questioning Purposes. The majority of Ms. Nolan's questioning scaffolded students' sensemaking about phenomena. For example, after students had individually worked on the Evidence Based Arguments Tool for ethanol burning, they went over it as a class. During this discussion, Ms. Nolan asked a series of questions and used students' responses to model on the board how to complete the Explanation Tool. The following instance of questioning scaffolded students' reasoning about what happened to carbon atoms when ethanol burned:

> **Ms. Nolan:** What evidence do we have about carbon, Julie?
> **Julie:** Ethanol lost mass by one gram and the BTB turned green.
> **Ms. Nolan:** For the carbon question we are just going to go with the BTB one. [*she had just explained this distinction in a previous exchange*]. What color was it when it started?
> **Students:** Blue
> **Ms. Nolan:** Yeah, BTB was blue and turned?
> **Students:** Green
> **Ms. Nolan:** Alright, so this tells us a bit about the carbon atoms…. So the evidence was that the BTB changed, and Sarah, what conclusion can we draw from that?
> **Sarah:** Carbon moved from ethanol into the air and then into the BTB.
> **Ms. Nolan:** And what molecule was the carbon a part of before and after? [*3 second wait time*] What is your guess, what molecule had the carbon to begin with do you think? [*4 second wait time*] Where do you think the carbon started?
> **Sarah:** Not sure
> **Ms. Nolan:** Ok, how about this, where did the carbon end up?
> **Sarah:** As CO_2.
> **Ms. Nolan:** As CO_2. OK, let's put that then…. [*reading the words as she writes on them on the board*] the carbon ended up as a part of CO_2. I like that Sarah was like, "I'm not really sure where it started, maybe it was already in the air." So that would be an unanswered question. [*As she writes it on the board*] Where did the carbon start?

In this series of questions Ms. Nolan asks students to provide evidence as well as reasoning about the meaning of the evidence. Sarah couldn't answer Ms. Nolan's question about where the carbon atoms started, so the teacher invited her to make a guess (likely because Sarah had originally said that carbon moved from ethanol into the air). When Sarah indicated that she was not sure where the carbon started, Ms. Nolan used her uncertainty to scaffold an unanswered question. Thus, Ms. Nolan's questioning positioned her students as epistemic agents responsible for using evidence, giving reasoning, and identifying unanswered questions. While she occasionally asked questions to review information, the majority of Ms. Nolan's questioning scaffolded students' sensemaking about phenomena.

Metacommentary. Ms. Nolan's metacommentary further emphasized the purpose of figuring out phenomena. She provided more metacommenary than any of the other teachers and emphasized a mix of conceptual, procedural and epistemic issues. Ms. Nolan often wove metacommentary into her transitions between activities. For example, after reviewing the class data for the ethanol investigation Ms. Nolan said,

> Your class average [for the change in mass of ethanol] is negative 0.51 grams. You guys are saying that on average Ms. Nolan's classes lost 0.51 grams. So, here is where we are going today. We just went through the class data, we are going to analyze it a bit more now and come up with conclusions about what this data is telling us. We are going look at these to say what does this data tell us about the Three Questions… If you have forgotten what those Three Questions are, they are on a poster in the back. Then when we are done figuring out what we know at the macroscopic scale, we are going to look at the microscopic scale and model what happened in this lab. On Friday you did some observations, we burned the ethanol and took measurements. Today we are going to write our evidence based arguments, so what does this data show us, and then we are going to model what happened at the atomic molecular scale. By the end of class today you are going to start to have an idea of what happens when ethanol burns, [and] by the end of the day tomorrow you should know. You should feel confident at the macroscopic and atomic molecular level what happens when ethanol burns. If you don't by the end of the day tomorrow, you should come in and see me for help because we have a test on Friday. So, we just looked at our data and did our cleaning, so I am going to hand out to you now the Evidence Based Arguments Tool. You have done this before for the soda water lab, so you might want to use that one as a model. You are going to look at that data and determine what conclusions can we draw at the macroscopic scale. What can we say about atoms, what can we saw about carbon atoms, and what can we say about energy [*passing out the handout*]?

The example of Ms. Nolan's metacommentary above includes conceptual, procedural, and epistemic elements. She explained why they calculated a class average for the change in mass of ethanol, how they would use the data from the investigation to make claims about events at the macroscopic scale, as well as how the modeling activity would help them explain what is happening at the atomic molecular scale (*epistemic metacommentary*). She also reminded students of the *Carbon TIME* Three Questions and their role in explaining phenomena (*conceptual metacommentary*). In addition, Ms. Nolan gave information about the upcoming test and when students should be ready to completely explain the phenomena (*procedural metacommentary*). Ms. Nolan's sophisticated metacommentary throughout the *Systems & Scale Unit* continually reinforced the purpose of figuring out phenomena and wove many disparate tasks including learning activities, assessments, and key *Carbon TIME* scaffolds such as the Three Questions, together within this larger goal.

Teacher's Purposes. As the examples above illustrate, Ms. Nolan introduced activities as way to figure out phenomena and emphasized the conceptual connections between activities. In addition, her questioning focused on scaffolding students' sensemaking about the phenomenon, and her frequent and sophisticated metacommentary emphasized the conceptual and epistemic aspects of the activities while providing important procedural information as well. Thus, the codes for Ms. Nolan's *introduction to activities*, *questioning purposes*, and *metacommentary* all support the conclusion that the *Teacher's Purpose* for classroom activities was figuring out phenomena.

Epistemic Authority. Ms. Nolan often invoked a source of authority outside of herself as the teacher or the curriculum materials when making knowledge claims. While all the teachers emphasized the role of empirical evidence in making scientific claims at some point during the unit, Ms. Nolan was the only teacher that explicitly invoked scientific models as a source of authority. Ms. Nolan compared the roles of empirical evidence and scientific models while going over the agenda at the beginning of the class period which included the molecular modeling activity for soda water fizzing. She said,

> So, last time we talked about the macroscopic scale things we observed. We observed that the mass [of the soda water] changed and that the BTB changed colors. Today we are going to zoom in and see what's happening at the atomic molecular scale, something we can't even use the microscope for, so we are going to use molecular model kits for that.

Thus, Ms. Nolan made it clear that students had collected empirical evidence at the macroscopic scale about soda water fizzing through their investigation, but that they could also use molecular models to figure out what was happening at a scale too small to be seen.

In addition to Ms. Nolan's frequent references to the role of empirical evidence and scientific models, the clear purpose of figuring out "what happens when ethanol burns" that she established, also served to elevate evidence and models as the source of authority for claims. By framing activities as a way to figure out phenomena by using empirical evidence and scientific models, Ms. Nolan's authority as the teacher was clearly distinguished from the sources of epistemic authority that validate knowledge claims in science. Although she was clearly an authority figure in that she was responsible for managing the learning environment, in Ms. Nolan's classroom her authority as the teacher was separate from the epistemic authority that validates knowledge claims. Thus, Ms. Nolan's appeals to empirical evidence and models aligned with the *Teacher's Purpose* of figuring out phenomena, while also situating students as epistemic agents.

Students' Questions. Students in Ms. Nolan's class asked a greater number of conceptual questions than students in any other classroom. In addition, the students asked conceptual questions during both whole-class discussions and during individual and small-group work across all three lessons that I analyzed. Ms. Nolan often responded by providing the specific information requested by the student, but she regularly also responded with questions to scaffold their thinking. For example, as students worked in groups on the Explanation Tool for the soda water investigation, Ms. Nolan circulated and checked in with each group. After reading one student's work the following exchange occurred:

> **Ms. Nolan:** This is not a complete explanation because you are not answering… what molecules were the carbon atoms in before and what molecules were they in after.
> **Student:** Oh, OK, I get it. So I am supposed to be explaining on a molecular level?
> **Ms. Nolan:** Yeah, Exactly.
> **Student:** Got it… I have a question though. Is all of the soda water made up of H_2CO_3?
> **Ms. Nolan:** No, that is just one of the molecules that is in the water.
> **Student:** OK. When it fizzes is that when it changes?
> **Ms. Nolan:** Yes. You got it! And those bubbles, what do you think is in those bubbles?
> **Student:** CO_2
> **Ms. Nolan:** Yes. You've got it!

In this exchange, the student responded to Ms. Nolan's statement about the weakness of his explanation by asking a series of conceptual questions to better understand the phenomenon of soda water fizzing and what scale his explanation should address. Ms. Nolan answered his questions, but then also directed a question back at him that returned to her assertion that a complete explanation must account for the carbon atoms at both the beginning and the end of the reaction. In this way, Ms. Nolan scaffolded the student's reasoning about the connection between the CO_2 released and the bubbles in the soda water, rather than providing it for him. This exchange illustrates how Ms. Nolan typically responded to students' questions, both during individual and small group work time as well as during whole-class discussions.

Teacher's Response to Students' Questions and Difficulties. Just as she responded to the students' questions in the example above both by providing information and scaffolding sensemaking, Ms. Nolan's response when individuals or small groups seemed to be struggling with an activity included both providing key information and scaffolding sensemaking. Ms. Nolan was particularly adept at visiting every group of students and quickly assessing their understanding during small group activities. She often had a specific targeted question that she asked each group which helped her to quickly assess their understanding and address key conceptual issues. Her responses to students fostered students' epistemic agency by supporting them in figuring out phenomena.

Students' Epistemic Agency. Students' epistemic agency is an emergent property of both the codes in this category of my coding framework which focus on *students' questions* and how the teacher responded to their questions and difficulties, as well as how the *Teacher's Purposes* and *Epistemic Authority* positioned the students in the classroom. This reflects the notion that students' epistemic agency is both a product of their own actions as well as the context (especially their teacher's practices) within which they act. In Ms. Nolan's classroom, the *Teacher's Purposes* emphasized figuring out phenomena and her appeals to empirical evidence and scientific models as the *Epistemic Authority* for answering questions about phenomena, positioned the students as epistemic agents. The large number of conceptual questions that her students asked demonstrated that they accepted the purpose of figuring out phenomena and took on the role of figuring out phenomena. Ms. Nolan's response to students' questions and difficulties provided further positive feedback that reinforced students' epistemic agency. Thus, in Ms. Nolan's classroom, a taken-as-shared frame emerged through the actions of both the teacher and the students that resulted in curiosity-driven discourse aimed at the purpose of figuring out phenomena.

Ms. Wei's Classroom: Task-driven Discourse

Introduction to Activities. Like Ms. Nolan, Ms. Wei put a written agenda up on the screen and went over it with her students during every class period. However, Ms. Wei's discussion of the agenda focused exclusively on the tasks students would do rather than the purposes for the activities. For example, one class period began with students working on the Explanation Tool for the soda water investigation. Ten minutes into the class period Ms. Wei put the agenda on the board and said,

> Here is our agenda for today. I have some announcements for you and then we are going to do a quick summary of the lab from two days ago so that we can recall what it was that we were looking at the in lab. And then we are going to do a group explanation for what exactly happened in that soda fizz lab. [*Gives announcements about opportunities to get extra science help and how to make up the lab if they were absent*]. Now, let's talk about the lab.

Thus, the agenda Ms. Wei shared with her students was solely procedural in that it told students what they were going to do, but did not mention how the activities were connected to each other or to the phenomenon they were trying to figure out. Although she referenced the soda water investigation and said they were going to review what happened, Ms. Wei did not state a driving question about the phenomenon or explain how the day's activities would build conceptually on the investigation they had done previously.

All three videos from Ms. Wei's classroom began with students working on a warm-up activity while she did administrative tasks such as checking previous assignments for completion. While the warm-up was conceptually related to the activities planned for that class period, the connections were not made explicit to students. For example, the warm-up for the class period that included expressing ideas about ethanol burning asked students to discuss with their table groups the similarities and differences that they observed between two vials filled with clear liquids. Ms. Wei then asked students to share what they noticed about the liquids. Students suggested that the liquids smelled differently and may weigh different amounts or have different boiling points. Ms. Wei validated students' ideas and added, "Another property of matter is its flammability…. one thing that could tell us whether or not these things are different is whether or not they are flammable."

Ms. Wei then poured the contents of one vial into a five-gallon plastic bottle and demonstrated what happened when she lit a match and added it to the bottle. This popular chemistry demonstration of the combustion of ethanol is known as the "Whoosh Bottle," but it is not included in the *Carbon TIME* materials. Students were very excited to see the flame shoot out of the bottle. However, when Ms. Wei poured the contents of the second vial into the bottle and tossed in a burning match, a similar, but smaller, flame shot out. Ms. Wei explained that the liquid that caused the larger flame was ethanol and the other liquid was water, and that there must have been some residual ethanol in the bottle that made the water ignite. Ms. Wei then decided to do the demonstration as written in the *Carbon TIME* teacher's guide using Petri dishes filled with water and ethanol to demonstrate that ethanol burns while water does not.

Ms. Wei's decision to deviate from the *Carbon TIME* Teachers' Guide by starting the Expressing Ideas activity with students comparing two vials of unknown liquids and to use the Whoosh Bottle demonstration indicate that student engagement was a high priority for her. Unfortunately, these additions distracted students from the key question about what happens when ethanol burns. Ms. Wei invited students to share their ideas about why ethanol burns but water does not, and then assigned the Expressing Ideas Tool as homework. The only purpose she ascribed to the Expressing Ideas Tool as she introduced it was that students should "Fill this out and be ready to share your ideas on Monday." This pattern of adding engagement strategies into the *Carbon TIME* activities was common in Ms. Wei's classroom. In addition, the other videotaped lessons were similar to the one described here in that she framed activities in a task-driven way that never referenced a driving question about a phenomenon. In fact, the only time the question “What happens when ethanol burns?” was ever stated in the videos that I analyzed was when she read it from one of the *Carbon TIME* PowerPoint slides during a modeling activity.

Questioning Purposes. While Ms. Wei’s questioning sometimes scaffolded students’ sensemaking, it was more often aimed at reviewing information and evaluating students’ knowledge. For example, after students modeled the dissociation of carbonic acid into carbon dioxide and water, the teacher asked a series of questions to review the activity:

> **Ms. Wei:** We first built this molecule over here [*pointing to the diagram of a carbonic acid molecule on the screen*] which was what? Everybody say it.
> **Multiple students**: Carbonic acid
> **Ms. Wei:** Thank you, carbonic acid. When I pop open that can of soda, then that carbonic acid undergoes a chemical change. You guys should have, with your molecule models, done what to that carbonic acid?
> **Male Student:** Ripped it apart into H_2O and CO_2.
> **Ms. Wei:** Yes, you should have ripped it apart and created with those same atoms carbon dioxide and water. So this sort of answers our Movement Question, right? What about our Carbon Question, what happens to the carbon atoms? What is the molecule that carbon starts out in?
> **Male Student:** Carbonic acid.
> **Ms. Wei:** Carbonic acid. And what is the molecule that carbon dioxide ends up in?
> **Male Student:** CO_2
> **Ms. Wei:** Carbon dioxide, exactly. CO_2.

Ms. Wei went on to explain that individual carbon atoms were not released during the reaction, but rather carbon dioxide molecules were produced, and that it was the CO_2 molecules that had caused the BTB to change color during the investigation. Although this discussion likely helped students to solidify their understanding of the chemical reaction, Ms. Wei’s questions required students only to provide the names of molecules. This illustrates a common pattern in Ms. Wei’s questioning that positioned students as responsible for filling in the blanks with factual information they head learned. Ms. Wei's questioning rarely positioned students as the ones making sense of phenomena. Instead, students were responsible for learning correct answers.

Metacommentary. Ms. Wei's metacommentary focused on procedural issues and was often related to assessment and grading. For example, on one day's agenda she reminded students about upcoming assignments and quizzes and explained,

> I am doing this because I want you to have a couple of opportunities to explain your understanding. The more information I get from you about what you understand, the more accurate your grade will be on that learning target. What I am looking at when I am grading you is your overall picture… like when you take the quiz and do the explanation, overall does it look like you understand atoms and molecules based on your answers there. The more information that you give me, the better, like the higher your grade, generally speaking, will go.

The above example from Ms. Wei's classroom illustrates a broader pattern of emphasizing grades and accountability which often sidelined the goal of conceptual understanding. Similarly, Ms. Wei employed several strategies for holding students accountable for participating in activities by assigning points for their participation. In addition, Ms. Wei emphasized particular talk moves in which she wanted students to engage, and had a checklist for them to use to document their use of the talk moves during small group work. While grading and accountability are important issues in classrooms, Ms. Wei's emphasis on how she was assigning points fostered task-based framing rather than curiosity-driven framing of activities.

Epistemic Authority. Ms. Wei emphasized the authority of empirical evidence for making claims when students discussed the results of investigations. She also invoked the authority of empirical evidence at other times in lessons. For example, when a student suggested that ethanol and water might differ in their boiling and freezing point, Ms. Wei replied, "How would we be able to test that for these two liquids?" Her question signaled that students would need to collect physical data in order to validate the claim, thus invoking empirical evidence as the source of authority. However, because Ms. Wei did not frame the purpose of activities in terms of figuring out phenomena or state a driving question for the unit, her appeals to the authority of empirical evidence did not seem as salient as it was in Ms. Nolan's classroom. In addition, Ms. Wei's classroom management strategies, emphasis on grading and accountability, and patterns of questioning, all served to establish her as the main epistemic authority in the classroom. Students challenged her epistemic authority on several occasions, especially through their questioning.

Students' Questions. Students' questions in Ms. Wei's classroom often occurred in clusters as multiple students pressed her about the same topic. For example, as Ms. Wei presented information on chemical bonds before a modeling activity, three students asked a series of four questions about bond energy. The students' questions reflected their frustration with the vague definition of high energy bonds that she asked them to copy into their notes. The students pressed her to compare high energy and low energy bonds and to explain why the *Carbon TIME* materials labeled certain bonds as high energy. Ms. Wei acknowledged that, "That is a complicated question," but still attempted to answer them with simple facts and definitions. One student in particular was very unsatisfied by her responses. As the class moved on to work on the modeling activity in groups he approached the teacher to ask, "Why would we need to label these bonds if all of them have energy in them?" Ms. Wei responded by reiterating that, "We want to distinguish between high energy bonds and low energy bonds, so we are only labeling the high energy bonds."

In another instance in this same period of Ms. Wei's class, a similar situation occurred in which multiple students asked a number of questions that seemed to be a response to their dissatisfaction with her definitions of chemical versus physical change:

Ms. Wei: When you guys get to chemistry you are going to find out that there are some chemical reactions that can reverse each other.
Student 1: Like what?
Ms. Wei: I am not going to say it right now. In this particular case [*pointing to picture of a rotting apple on the screen*] one thing that tells us that this is a chemical change is that this isn't reversible. You can't un-decompose an apple.
Student 2: So, you are saying that a chemical change is something that cannot be reversed?
Ms. Wei: For the purposes of our class, at this moment in time, we are going to say that the chemical changes that we have seen so far cannot be reversed. However, we are going to learn later on that there are some chemical changes that can be reversed. But like this example right here [*pointing to picture of the rotting apple*] can't be reversed. You still look confused [*to student 2].*
Student 2: It is still an apple. And you are saying that for it to be a chemical change it has to be something else.
Ms. Wei: Good point. It is still an apple, so in order to understand that this is a chemical change, can we stay on the macroscopic scale?
Student 3: But there are decomposers
Ms. Wei: And the decomposers are at the microscopic scale right?
Student 3: Yes, so there is something else involved which is separating the nutrients.
Ms. Wei: Right, and the decomposer is actually separating those nutrients on an atomic molecular scale. On the macroscopic scale we still consider it an apple, but on the atomic molecular scale those molecules are in fact different from each other on the two halves of the apple.
Student 4: What is the apple reacting with?
Student 5: [its reacting to] Age.
Ms. Wei: Can it react to time?
Student 6: Yeah.
Ms. Wei: Time doesn't have any substance to it. It doesn't have any matter. It has to be reacting with some kind of matter. The sugar molecules within the apple are reacting with some other substance to form a new set of molecules.
Student 4: What is the other substance?
Ms. Wei: I think you are right that air is involved.
Student 7: Does that mean that if an apple was in space that it wouldn't decompose?

For another minute and a half the class continued to discuss the role of air and oxygen in decomposition. The tone of the conversation seemed to change at this point to genuine interest rather than challenging Ms. Wei's definitions. Ms. Wei then told the class about an article that she read about a scientist who studied landfills and found hot dogs and newspapers from the 1960s that were not decomposing because there was no oxygen present. Ms. Wei then said, "I got distracted you guys," and returned to the slides with the information she was presenting. The above series of student questions indicated that students in Ms. Wei's class were engaged and trying to make sense of concepts. However, the students' tone at the beginning of this exchange, as well as in the previous example of students' questions about bond energies, also indicated that they were frustrated with the facts and definitions that Ms. Wei presented.

Teacher's Response to Students' Questions and Difficulties. Ms. Wei typically responded to students' questions by providing factual information. However, students often seem dissatisfied with the information she supplied, and in the two cases described above they asked additional questions that seemed to challenge her authoritative knowledge. These clusters of questions in Ms. Wei's class might have been a bid by students to have their ideas acknowledged as well as a way to challenge the notion of the teacher as the epistemic authority. When Ms. Wei interacted with individuals and small groups that seemed to be struggling with a task, in about half instances she provided information, while in the other half she attempted to scaffold their sensemaking. This may indicate that Ms. Wei was more comfortable scaffolding sensemaking with small groups than she was in a whole-class discussion. Teachers may be more likely to take on the challenge of scaffolding students' thinking when interacting with individuals or small groups than they are in whole-class discussions, if they are concerned with maintaining order and making sure that students get the correct answer.

Students' Epistemic Agency. Ms. Wei's practices indicated that she valued conceptual understanding and student engagement. The warm-up activity that asked students to compare vials of ethanol and water and the Whoosh Bottle demonstration are examples of activities that she added to *Carbon TIME* lessons to make them more engaging for her students. She may have also believed that adding topics such as chemical versus physical change increased the rigor of the *Carbon TIME* materials. In addition, Ms. Wei often scaffolded students' sensemaking in small groups, and employed a number of strategies for encouraging students to participate during small group and whole-class discussions. However, the activities and strategies that Ms. Wei added often detracted from the phenomenon and driving questions of the *Carbon TIME* unit. In addition, she introduced activities and questioned students in task-driven ways, and employed a number of practices that served to situate her as the epistemic authority in the classroom. While the students at times challenged Ms. Wei's task-driven purposes and her epistemic authority, for the most part they adopted the purposes and roles that her framing prescribed for them. Thus, Ms. Wei's students' attempts to establish different purposes and roles was not frequent or robust enough to counter her framing. Instead, a taken-as-shared frame emerged that resulted in predominantly task-driven discourse aimed at the purpose of learning about science topics.

Ms. Callahan's Classroom: Rigor-Driven Discourse

Introduction to Activities. Like Ms. Wei, Ms. Callahan began each class period with a more procedural introduction. While she often began class by reviewing previous activities, she did not make the conceptual connections between prior activities and what they would be doing that day explicit, and a driving question about a phenomenon was never stated. For example, Ms. Callahan began the class period that included the Evidence-Based Argument Tool for the ethanol burning investigation with announcements and reminders about upcoming tests and assignments. Six minutes into the period Mr. Callahan shifted to the content of the lesson saying,

> Last Friday we burned ethanol, but before we burned ethanol we watched this video. We are going to watch the end of the video. For those of you who weren't here on Friday, this will give you an idea of what we did. It's really important that you pay attention to it.

After saying this, Ms. Callahan also indicated that watching the video would help students who had performed the investigation remember what they had done. After the video she asked a series of questions to review what students had observed in the investigation and gave them time to answer the questions on the investigation handout. Next, she passed out the Evidence Based Arguments Tool and said,

> What I really want to get at is an idea of what your concepts are of what's happening when ethanol burns. Please put everything away. This is not a quiz, but this gives me insight into what you understand about ethanol burning. So if there are any areas that we need to work on, we can certainly clarify before your post-test on Thursday.

Thus, Ms. Callahan framed the Evidence Based Arguments Tool as a way to assess students' understanding, rather than as a way to continue to construct knowledge as a class about what happens when ethanol burns. While the *Carbon TIME* Teacher's Guide suggests giving students an opportunity to discuss their work on the Evidence Based Arguments Tool in both small groups and as a whole class, Ms. Callahan decided to make it an individual assignment to be used for assessment purposes. The other videos from Ms. Callahan's class demonstrate a similar pattern of emphasizing assessing students' knowledge rather than constructing knowledge as a group. While she indicated that she wanted to assess what students knew about ethanol burning, she never stated an explicit driving question in the three class periods that I analyzed.

Questioning Purposes. Ms. Callahan engaged in questioning to scaffold students' sensemaking about phenomena much less frequently than Ms. Nolan did. Instead, like Ms. Wei, her questioning tended to focus on reviewing information and assessing students' knowledge. For example, in Ms. Callahan's class after students had completed the soda water modeling activity they discussed the overall reaction for the dissociation of carbonic acid into carbon dioxide and water:

> **Ms. Callahan:** [*Indicating the overall reaction written on the board*] This has to be balanced and we know that atoms last forever. The number of atoms in the reactants should equal the number of reactants [sic] in our products. Did that happen on your worksheet?
> **Multiple students:** Yeah
> **Ms. Callahan:** We had three oxygen atoms [*pointing to formula for carbonic acid*], did we have three over here [*pointing to products*]? [*waits 4 seconds with no response*] We had two [*pointing to* CO_2] and then [*pointing to* H_2O]?
> **Multiple students:** one
> **Ms. Callahan:** Yeah… so we have three. And we have two hydrogens over here [*pointing to reactants*] do we have two hydrogens on this side [*pointing to products*]? [waits *5 seconds with no response*] Yeah. Excellent. And we have one carbon [*pointing to carbonic acid*] and one carbon [*pointing to products*]. It's balanced. This is a very nice equation, it balances quite easily.

Although this discussion was aimed at helping students to develop conceptual understanding of what it means for a reaction to be balanced, Ms. Callahan did the sensemaking for the students. Instead of asking questions that scaffolded their sensemaking, she asked a series of questions that only required students to state the number of each type of atom. She began by telling them that the reaction had to be balanced because atoms last forever, then asked a series of questions about the number of atoms on each side. Many of her questions went unanswered by the students, and Ms. Callahan answered them herself. After comparing the number of atoms on each side of the equation, Ms. Callahan summarized, "It's balanced. This is a very nice equation, it balances quite easily."

The example of questioning from Ms. Callahan's classroom above illustrates a common pattern in her classroom. Like in Ms. Wei's classroom, Ms. Callahan's questioning tended to position the students as responsible for stating correct answers, but not for making connections or constructing knowledge for themselves. In addition, since Ms. Callahan and Ms. Wei did not state a driving question about a phenomenon, their questions often seemed more decontextualized and more like playing a "classroom game," versus the questioning in Ms. Nolan's classroom that was directly linked to the phenomenon they were trying to figure out.

Metacommentary, Epistemic Authority, and Teacher's Purposes. Ms. Callahan's metacommentary was very similar to Ms. Wei's in that in generally focused on procedural issues including grading and assessment. Ms. Callahan's metacommentary also focused on the process of learning itself. She frequently reminded students that it was OK to make mistakes and that learning from mistakes is important. Ms. Callahan's appeals to *Epistemic Authority* were also very similar to Ms. Wei's in that she emphasized the role of empirical evidence when discussing investigations, but her classroom management strategies and her fact-based questioning positioned herself as the epistemic authority in the classroom. Thus, like Ms. Wei the *Teacher's Purposes* in Ms. Callahan's classroom were primarily aimed at learning about science topics rather than figuring out phenomena.

Although my coding of the *Teacher's Purposes* depicted a similar pattern in Ms. Callahan's and Ms. Wei's classrooms, I noticed an interesting difference in the rigor of the discourse between the two classrooms. While Ms. Callahan's and Ms. Wei's questioning usually did not require students to engage in sensemaking, Ms. Callahan's questions were more rigorous overall. In addition, while Ms. Callahan's questioning was generally fact-based, she often supplied conceptual reasoning to students, while Ms. Wei generally did not. Ms. Callahan's questions tended to be more focused on the key ideas developed in the *Carbon TIME* activities, while Ms. Wei's questions were less targeted and often included topics outside of the scope of the *Carbon TIME* materials. Finally, Ms. Callahan more rigorously attended to two *NGSS* crosscutting concepts in classroom discourse: (1) Energy and Matter: Flows, Cycles, and Conservation and (2) Scale, Proportion, and Quantity. These crosscutting concepts are a key focus of *Carbon TIME* materials, but when Ms. Wei referenced them she tended to state them as facts, while Ms. Callahan tended to explain how the crosscutting concepts were being applied.

Students' Questions and Teacher's Responses. I identified 16 conceptual questions in Ms. Callahan's class. However, all of them except one occurred within one class period, with the majority of those questions occurring as students worked in groups on an activity to model the dissociation of carbonic acid as soda water fizzes. While Ms. Callahan tended to respond to students' questions as they worked on the modeling activity by scaffolding their sensemaking, in the few instances that students asked a conceptual question during a whole class discussion, Ms. Callahan provided conceptual answers without scaffolding students' sensemaking. For example, as Ms. Callahan presented information on the number of bonds that each type of atom can make, a student asked her to clarify the difference between "forming bonds versus having bonds" (Ms. Callahan had been using the language of "forming bonds" and "having bonds" interchangeably). Ms. Callahan responded with a detailed conceptual response to the students' question.

Ms. Callahan's rigorous response to the student's question focused on valence electrons and the stability of atoms. She explained that, "carbon atoms have four unpaired electrons in its outer orbital which means it needs to form four bonds to become stable." She then explained the number of unpaired electrons that oxygen and hydrogen atoms have and how that relates to the number of bonds these atoms can form. Finally, Ms. Callahan said, "that was a great question" and added, "Carbon is going to be sort of the core [of a lot of molecules] because so many things can form around it. You are going to see that today, and it is going to be pretty exciting." Ms. Callahan's response to the student's question indicates the priority she placed on rigorous conceptual understanding. She decided to provide information beyond the scope of the *Carbon TIME* curriculum about unpaired electrons and the stability of atoms in order to answer the student's question in a conceptually rigorous way.

Response to Students' Difficulties. When Ms. Callahan responded to students' difficulties during small group work she almost always attempted to scaffold students' sensemaking. For example, when she responded to one group's incorrect model of a carbonic acid molecule she said, "That's interesting. I am not saying it's wrong or it's right. But if you remember, does oxygen like to pair with oxygen or no?" This response demonstrates a pattern indicating that Ms. Callahan clearly valued students' figuring things out for themselves. However, she generally only scaffolded sensemaking during small group work. This was similar to the pattern in Ms. Wei's classroom, and may indicate that teachers have a more difficult time scaffolding sensemaking in whole-class discussions than in small group work.

Students' Epistemic Agency. Ms. Callahan's practices that I coded in the *Teacher's Purposes* and *Epistemic Authority* categories established task-driven purposes for activities, but also supported disciplinary rigor. Ms. Callahan's classroom was situated within a science and math magnet school that students voluntary elected to attend, which likely influenced her desire to promote rigor and undoubtedly influenced her students' responses to classroom activities. Her students did not ask many conceptual questions during whole class discussions, but seemed content with her rigorous conceptual explanations. When students asked questions during the modeling activity, Ms. Callahan responded by scaffolding their sensemaking. This difference in how Ms. Callahan responded to students' questions during small-group and whole-class discussions may indicate that she framed the purposes of whole class discussions differently than she framed small group work. The priority that Ms. Callahan placed on rigor seems to have influenced how she answered students' questions during whole-class discussions, as well as her decision to use the Evidence Based Argument Tool as an assessment rather than a means for collective sensemaking. Thus, in Ms. Callahan's classroom a taken-as-shared frame emerged that resulted in predominantly rigor-driven discourse aimed at conceptual understanding of key scientific ideas.

DISCUSSION

Ms. Nolan's classroom was the only one of the five that I analyzed that consistently exhibited curiosity-driven discourse which established a taken-as-shared frame for activities as figuring out phenomena. This frame was established through the teacher's frequent explicit attention to the driving question—What happens when ethanol burns?—which positioned students as epistemic agents responsible for figuring out phenomena. Ms. Nolan's use of questioning to scaffold students' sensemaking, as well as her emphasis on the authority of empirical evidence and scientific models for answering scientific questions, supported students in figuring out phenomena. Students' own questions indicate that they adopted the role of figuring out phenomena in Ms. Nolan's classroom.

Thus, Ms. Nolan led her students in establishing a classroom learning community that shared key features of curiosity-driven discourse with scientific communities. The features of curiosity-driven classroom discourse exhibited in Ms. Nolan's classroom and their significance for student learning are summarized in Table 2.4.

Table 2.4. Summary of curiosity-driven discourse in Ms. Nolan's classroom.

Aspect of epistemic framing	**How it supported curiosity-driven classroom discourse**	**Significance for student learning**
Purpose	Ms. Nolan led a classroom discourse community with the shared purpose of developing a scientific answer to the driving question "What happens to ethanol when it burns?" She introduced a specific phenomenon (ethanol burning) and gave students the opportunity to observe and discuss it. The teacher guided the discussion to develop the driving question and repeated it multiple times, explaining how each activity would help students figure out some aspect of what happens when ethanol burns. Ms. Nolan's reinforced the purpose of figuring out phenomena through carefully sequenced questions that scaffolded students' reasoning.	Clearly establishing figuring out phenomena as the purpose for classroom activities engaged students' curiosity and gave the activities context and relevance. "Anchoring the development of general science ideas in investigations of phenomena helps students build more usable and generative knowledge" (p. 3).
Epistemic Authority	Ms. Nolan scaffolded students in collecting and analyzing evidence and using scientific models to answer the driving question about the phenomenon. She clearly articulated how empirical evidence and scientific models support scientific claims. She pressed students to support claims with evidence and helped them to relate scientific models to observations of phenomena.	Clearly establishing empirical evidence and scientific models as the epistemic authority for claims helps students develop an appreciation for how scientific knowledge is developed and used. "The goal of building knowledge in science is to develop general ideas, based on evidence, that can explain and predict phenomena" (p. 1).
Students' Epistemic Agency	Students engaged as epistemic agents responsible for developing and using knowledge to explain phenomena. They discussed their ideas in small and large group discussions. Students asked many conceptual questions indicating that they accepted the role of figuring out phenomena. Ms. Nolan responded to students' questions and difficulties by providing key information and asking carefully sequenced questions to scaffold their sensemaking.	Students engaged in scientific practices to develop and use knowledge in authentic ways. They were positioned as epistemic agents and their ideas and questions were honored and used in classroom discourse.

Ms. Callahan's, Ms. Wei's, Mr. Ross', and Mr. Harris' classrooms all exhibited more task-driven discourse that established a taken-as-shared frame for activities as learning about science. The teachers established this frame by introducing activities in a procedural way that did not link them to a driving question about phenomena. In addition, the teachers' questioning practices and instructional decisions tended to position themselves or the curriculum materials as the epistemic authority in the classroom and positioned the students in a more passive role responsible for learning authoritative knowledge. While these teachers attempted to implement the *Carbon TIME* curriculum with fidelity and their students were highly engaged, the classrooms were unable to shift the taken-as-shared frame from the more traditional stance of learning about science to the framing of figuring out phenomena.

Understanding Task-driven Discourse

My analysis suggest that task-driven discourse was the norm in most classrooms not because the teachers or students were deficient in some way, but because establishing and maintaining curiosity-driven discourse is different and challenging. The teachers were all knowledgeable, experienced, and dedicated professionals. They voluntarily participated in the *Carbon TIME* project because they believed that the curriculum could enhance their practice and help them support students in three-dimensional learning. Their students were attentive and hardworking, and they did everything their teachers asked of them. However, even with NGSS-aligned curriculum materials, classrooms struggled to shift the frame for discourse from the more traditional frame of learning about science to the frame of figuring out phenomena.

Curiosity-driven discourse requires that a particular phenomenon is clearly established as an object of collective curiosity and that scientific questions about it are clearly articulated. This study highlights the important role that teachers play in this process. Although the activities in the *Carbon TIME Systems and Scale* Unit were explicitly designed to scaffold students in figuring out what happens when ethanol burns, in most classrooms the driving question was rarely or never explicitly stated. For example, the question “What happens when ethanol burns?” was written at the top of each of the *Carbon TIME* Process Tools that students used throughout the *Systems & Scale* Unit. However, as teachers introduced the Process Tools they tended to focus on procedural aspects of completing them, rather than on their role in helping students to figure out the phenomenon. Ms. Nolan’s frequent reference to the driving question and her metacommentary that explicitly connected each activity to that question, seem to be key reasons that curiosity-driven discourse was established in her classroom.

While the science education research community has recognized the importance of centering instruction on explaining natural phenomena, teachers have often not experienced this type of learning in their own educational backgrounds. In addition, many science teachers have little experience engaging in authentic scientific research. Yet, studies have found that teachers’ experiences doing science significantly influence how they teach science (Stroupe, 2017; Varelas, House, & Wenzel, 2005). Without engaging in authentic scientific inquiry themselves, teachers’ understanding of what constitutes an observable phenomenon, how to formulate scientific questions about it, and how these can drive instruction are quite limited. In our work with teachers through *Carbon TIME* professional development activities, we have found that teachers often struggle to identify the phenomenon that a unit is designed to explain and to recognize how each activity connects to that overall purpose. In particular, teachers have difficulty differentiating between processes such as combustion, photosynthesis, and cellular respiration, and the phenomena that these processes help to explain.

My analysis also revealed that teachers’ practices often shifted attention away from the purpose of figuring out phenomena toward other goals. While these practices undermined curiosity-driven discourse, they were aimed at other valuable purposes including student engagement, rigor, and assessment. However, not only did these practices detract from the purpose of figuring out phenomena, they diminished students' epistemic agency and situated the teacher as the epistemic authority in the classroom. Thus, it is important to understand how teachers' practices can undermine curiosity-driven discourse and how Ms. Nolan's classroom was able to align these priorities to achieve it.

Prioritizing Engagement. When teachers deviated from the *Carbon TIME* lesson plans their reasons for doing so often seemed to be an attempt to engage their students. For example, Ms. Wei and Mr. Ross both decided to use the Whoosh Bottle demonstration, likely because they believed that the large flame would be more interesting for students than burning ethanol in a small Petri dish as proposed by the *Carbon TIME* materials. However, in both cases the Whoosh Bottle demonstration served to distract from the phenomenon that the unit was designed to address and may help explain why the driving question, "What happens to ethanol when it burns?" was never clearly established in their classrooms.

In addition, both Ms. Wei and Mr. Ross frequently used strategies for calling on students randomly during lessons to keep them engaged. However, by tightly controlling when students talked and what they shared, these strategies inhibited students from sharing ideas freely and encouraged procedural display rather than sensemaking. Ms. Wei also incorporated several strategies aimed at supporting students in using particular talk moves during their small group work. While supporting productive talk is certainly important, talking seemed to become a purpose in and of itself in Mr. Ross' and Ms. Wei's classroom, rather than serving to scaffold students' sensemaking about phenomena. These examples illustrate how even "best practices" for fostering student engagement can undermine the purpose of figuring out phenomena.

It is important to note that it was not the engagement strategies themselves, but rather how they were employed that undermined curiosity-driven discourse in Mr. Ross and Ms. Wei's classrooms. For example, Ms. Nolan also occasionally called on students randomly, but she did so during brainstorming sessions when the goal was to get as many ideas on the table as possible. She explained to students that she would randomly draw names to add their ideas to the list, and that afterward students could volunteer to add any ideas that were not captured. In addition, Ms. Nolan always clearly linked the purpose of classroom discussions to the phenomena that students were trying to explain. Thus, in Ms. Nolan's classroom strategies to encourage participation did not undermine the purpose of figuring out phenomena.

Prioritizing Rigor. Disciplinary rigor also seemed to be a competing priority that undermined the purpose of figuring out phenomena. For example, while the discourse in Ms. Callahan's classroom attended rigorously to disciplinary core ideas and crosscutting concepts, the teacher often did the sensemaking for students. Conversations shared by her case study coach indicate that Ms. Callahan valued disciplinary rigor, especially given her context at a science and math magnet school. In addition, these conversations indicated that she believed her students were capable of sensemaking, even though she often unintentionally provided information that circumvented it. For example, while the students waited for the results of the burning ethanol investigation, Ms. Callahan showed a video that explained why a candle loses mass when it burns and why the chemical reaction releases water and carbon dioxide. Her decision to show the video, while likely intended to promote conceptual understanding and help students see the similarities between burning ethanol and burning a candle, presented all the "answers" that the investigation was designed to help students figure out. Similarly, Ms.

Callahan's fact-based questioning and her detailed conceptual answers to students' questions, elevated disciplinary rigor above sensemaking.

While disciplinary rigor is a worthy goal, prioritizing it above figuring out phenomena diminishes students' epistemic agency. Instead of using evidence and models to explain phenomena, students are presented with authoritative knowledge that explains phenomena. Even when a teacher hopes to engage students in sensemaking, they may inadvertently circumvent it by presenting the "correct" answer too early or by providing the reasoning that links evidence to scientific explanations rather than asking students to articulate the reasoning. Teachers often perceive tension between discourse that is responsive to students' ideas and rigorous disciplinary work that prioritizes correct answers. In order for curiosity-driven discourse to occur, teachers must become comfortable letting students share incorrect ideas and partial explanations, and develop strategies for scaffolding students' sensemaking rather than providing the reasoning for them.

Ms. Nolan was able to simultaneously foster disciplinary rigor and students' epistemic agency by focusing on supporting students' sensemaking. While the discourse in her classroom attended rigorously to key disciplinary ideas and crosscutting concepts, this was accomplished by asking strategic questions and being responsive to students' ideas, rather than by presenting authoritative knowledge. For example, when students asked conceptual questions, Ms. Nolan most often responded by providing key information and posing a question back to the students. Rather than proving the complete answer, she supplied or reminded them of key information, but left it up to the students to make important connections. This fostered students' epistemic agency by signaling that the teacher believed students were capable of the intellectual work and leaving the students with the feeling that they had solved the problem on their own.

Assessment Practices. My analysis suggests that teachers' assessment practices may have been especially difficult for them to reconcile with the seemingly contradictory goal of scaffolding students in figuring out phenomena. Many of the teachers substituted accountability or evaluation for sensemaking as they enacted *Carbon TIME* activities. For example, most of the teachers used questioning during whole-class discussions primarily to review and evaluate students' knowledge. Even fairly early on in the unit, the teachers asked close-ended questions and responded primarily with indications of how correct students' answers were. This emphasis on rehearsing correct answers limited students' epistemic agency to engage in sensemaking and positioned the teacher as the epistemic authority.

In addition, teachers often chose to use the *Carbon TIME* Process Tools primarily to collect assessment data, rather than to guide small-group and whole-class sensemaking discussions. The *Carbon TIME* Teachers' Guide describes a process of giving students time to work on the Process Tool individually, share in small groups, and finally discuss as a whole class. This is particularly important for the Evidence Based Arguments Tool which helps students connect data from an investigation to claims and to formulate unanswered questions about the phenomena that will be addressed in future activities. However, many teachers shortened or eliminated these discussions and instead used the Evidence Based Argument Tool to collect individual assessment data. There are many practical reasons a teacher might substitute assessment for sensemaking including: time constraints and the pressure to move on to the next lesson, a need to provide grades to students and parents, and a preference for collecting formative assessment data in the form of individual written responses. In addition, our work with teachers has demonstrated that they often underestimate how much time and support students need in reasoning about phenomena. Thus, teachers may have believed that the data collected in the investigation was self-evident and that students did not need support in formulating claims or unanswered questions.

While most of the teachers focused on the role of assessment in providing them with information to evaluate students' knowledge, Ms. Nolan emphasized the importance of students understanding their own ideas and recognizing how their ideas changed over time. She did this by frequently returning to the initial ideas and questions that students raised about the phenomenon, as well as by referring students back to their previous Process Tools as they moved through the unit. In addition, while many of the other teachers emphasized how they were assigning points during class activities, talk about grading was virtually absent in Ms. Nolan's classroom. Ms. Nolan emphasized what expected students to learn, rather than how she would grade them. For example, when discussing an upcoming test, Ms. Nolan said, "You should feel confident at the macroscopic and atomic molecular level what happens when ethanol burns. If you don't by the end of the day tomorrow, you should come in and see me for help because we have a test on Friday." In this way, Ms. Nolan integrated the purpose of figuring out phenomena with assessment rather than treating them separately.

Implications for Future Research

The results of this study lead to a very important question: Why was Ms. Nolan's classroom able to establish curiosity-driven discourse using the *Carbon TIME* curriculum while the other classrooms were not? Other data collected through the *Carbon TIME* project may be able to help address this question in future studies. The interviews with teachers have suggested that they differed significantly in their understanding of the vision of three-dimensional science learning and in their priorities and skills for guiding classroom discourse. For example, the interviews indicate that Ms. Nolan had a strong grasp of the goal of three-dimensional learning before implementing the *Carbon TIME* curriculum. She recognized the importance of building on students' initial ideas questions about phenomena, and had many strategies for engaging students in rigorous and responsive classroom discourse. Thus, Ms. Nolan's teaching practice was already "preadapted" to the *Carbon TIME* curriculum, which allowed her to focus on scaffolding students in figuring out phenomena through classroom discourse. Interviews with the other teachers indicated that they had varying levels of understanding of the goals of three-dimensional learning. Future studies may begin to help us understand how to better design professional learning experiences to support teachers in making the changes necessary to shift the frame for classroom discourse from learning about science to figuring out phenomena.

This study also raises important questions about how students experience the discourse in their classrooms and how it influences their engagement, learning, and attitudes toward science. Other data collected through the *Carbon TIME* project may help to begin to address these questions. For example, videos of focus students as they participated in small group work can help us to better understand how individual students understood the purposes of activities and the epistemic agency they exercised while interacting with their peers. Assessment data and student surveys were also administered that can help us begin to understand how classroom discourse influences student outcomes. Future research that clearly links classroom discourse with student outcomes is vital for understanding the mechanisms that support three-dimensional learning in classrooms.

Limitations

The findings of this study represent the discourse in five high school classrooms based on three class periods that were videotaped during the first unit of the *Carbon TIME* curriculum. Because the camera and microphone were centered on the teachers, I have more evidence about how they framed and scaffolded classroom activities than I do from the students. In addition, although all five classrooms were enacting the *Carbon TIME* curriculum, there are many other features of these classrooms and their school and community contexts that likely differed. While the findings here do not represent the discourse in every high school classroom, they offer important contributions for understanding how curiosity-driven discourse supports students in adopting the role of figuring out phenomena and highlight how common teaching practices may divert students away from this goal.

Contributions of the Study

The practices of scientists are driven by curiosity about natural phenomena and a commitment to the epistemic authority of empirical evidence. Thus, the NRC *Framework* and *NGSS* emphasize the importance of instruction that engages students in figuring out phenomena to help students understand how scientific knowledge is developed and used. This study shows how it is possible to establish and sustain curiosity-driven classroom discourse that supports students in figuring out phenomena. At the same time, it helps explain why task-driven discourse is common in most science classrooms and the challenges for teachers and students in shifting the frame from learning about science to figuring out phenomena.

The findings in this study reiterate the importance of establishing driving questions about phenomena and supporting students' epistemic agency to address those questions. Thus, my analysis echoes many lines of research about productive discourse in science classrooms (e.g. Engle, 2011; Ford & Wargo, 2012; O'Connor & Michaels, 2007; Thompson et al., 2016). This study also contributes rich descriptions of how classroom activities are framed in ways that are more and less productive. Perhaps most importantly, my theoretical framework points to curiosity about phenomena as the driver of productive discourse in science classrooms. While other studies have identified similar features of productive discourse, they have not articulated the role of curiosity about natural phenomena in driving productive framing or examined how activities can be framed in a way that engages students' curiosity and scaffolds them in figuring out phenomena to satisfy that curiosity.

In this light, the curiosity-driven discourse in Ms. Nolan's classroom is understood to be a significant accomplishment. Thus, the descriptions of the discourse in her classroom add to our understanding of both theory and practice around three-dimensional learning. In particular, this study describes specific strategies that position students as epistemic agents in figuring out phenomena (summarized in Table 2.4). Analysis of the discourse in the other classrooms is also important because it suggests key challenges that classrooms face in establishing and maintaining curiosity-driven discourse. Positioning students as epistemic agents responsible for figuring out phenomena is a new paradigm for classroom learning. Every time a teacher fails to connect an activity with a driving question or a student recites a fact without understanding it, the quality of classroom discourse is degraded with respect to scientific curiosity about phenomena and students' view of their own agency in developing and using scientific knowledge.

Thus, curiosity-driven discourse is fragile and requires teachers to align their practices to a new goal—supporting students in figuring out phenomena. A wealth of literature exists that speaks to the challenges that teachers face in managing competing goals for lessons and why procedural display is so common in schools (e.g. Bloome et al., 1989; Kennedy, 2005; Lemke, 1990). This study adds to that literature by highlighting three challenges that teachers face in establishing and maintaining curiosity-driven discourse: (1) lack of experience in using questions about phenomena to drive instruction (2) prioritizing other goals such as engagement or rigor, and (3) assessment practices that elevate correct answers over sensemaking and situate the teacher or curriculum materials as the epistemic authority.

Shifting classroom discourse from learning about science toward figuring out phenomena is no easy task. This study suggests that almost any instructional practice could potentially get in the way of curiosity-driven discourse if the classroom community does not adopt a view of learning which recognizes it as a "combination of both knowledge and practice" (p. 254) and which honors students' role in constructing knowledge through their own experiences. Therefore, fostering three-dimensional learning requires not only carefully crafted curriculum materials, but also a teacher who is skillful in engaging and scaffolding students' curiosity about natural phenomena, as well as students who are ready to take on the intellectual challenge of satisfying their curiosity.

APPENDIX

Video Data

I analyzed three videos of each classroom recorded by the case study coach over a period of 2 – 3 weeks as they engaged in the *Systems & Scale Unit*. *Carbon TIME* lessons are segmented into activities that require 20 – 50 minutes of class time. Table 2.5 shows the activities that were recorded in each classroom and the total time of the three videotaped lessons. While not all the same activities were recorded in every classroom, a range of types of lessons were captured which allows me to compare how teachers and students framed the purposes of activities throughout the unit.

Table 2.5. Summary of video data from each case study classroom.

	Ms. Callahan	**Mr. Harris**	**Ms. Nolan**	**Mr. Ross**	**Ms. Wei**
Total video time (min)	140	206	224	176	206
Activity 1.2 Expressing ideas about ethanol burning		X	X	X	X
Lesson 2 Scale		X	X		
Activity 3.3 Soda water fizzing evidence-based arguments	X			X	
Activity 3.4 Modeling soda water fizzing	X		X	X	
Activity 3.5 Explaining soda water fizzing			X		X
Activity 4.1 Predictions about ethanol investigation	X	X			
Activity 4.2 Investigating ethanol burning	X	X		discussion of results	
Activity 4.3 Ethanol burning evidence-based arguments	X	X	X	given as homework	X
Activity 4.4 Modeling ethanol burning		X	X	X	X

Coding

My coding framework attends to the three features of curiosity-driven discourse that mirror scientific curiosity: (1) the purpose of figuring out phenomena, (2) epistemic authority of empirical evidence and scientific models, and (3) students' epistemic agency. At the same time, I also wanted to be able to describe different purposes, sources of epistemic authority, and roles for students across classrooms. Thus, I developed codes in each category that capture the range of curiosity-driven and task-driven discourse that I observed in the videos. Below I describe in more detail how I identified instances in the videos and classified them with codes.

Teachers' Purposes. The codes in the *Teacher's Purposes* category describe the teacher's epistemic framing of activities and how they scaffold students in adopting the purposes that they promoted. I identified three main ways that teachers indicate their purposes and scaffold students in taking them up during lessons: *introduction to activities*, *questioning purposes,* and *metacommentary* about broader purposes. I found that when teachers introduced activities they either indicated that the purpose was to help answer a question about a phenomenon or they introduced the activity in a task-driven way. Task-driven introductions could include conceptual or procedural rationales for the activity, but did not directly reference a question about the phenomenon that the *Carbon TIME* activity was designed to address. Sometimes the teacher did not provide any rationale for the activity other than "this is what we are going to do next," which I also coded as a task-driven introduction.

One of the most prominent discourse structures across all lessons was teacher questioning in which the teacher asked a question directed at the whole class and students either called out answers, raised their hand to answer, or the teacher used some method of randomly calling on students. Teacher questioning also occurred when teachers worked with small groups of students who were engaged in a task. Each instance of questioning was marked in Studiocode and assigned one of three codes: *scaffolding sensemaking*, *sharing ideas*, or *reviewing or evaluating*.

1. I coded an instance of teacher questioning as *facilitating sensemaking* if the questions focused on making meaning from empirical evidence or scientific models or on making conceptual connections between ideas. These instances generally included a series of questions that the teacher used to scaffold students' thinking about a key concept and sometimes included asking students to explain their reasoning.
2. *Sharing ideas* questioning episodes were marked by the teacher asking students to share what they thought about a phenomenon or what they observed in an investigation, but did not press students to explain their reasoning or try to develop a class consensus about the ideas. The sharing ideas instances of questioning occurred most often in conjunction with the Expressing Ideas activity and Process Tool, but also occurred at other points of the unit.
3. *Reviewing or evaluating* questioning episodes followed an I-R-E pattern in which the teacher asked a question, one or more students responded with an answer, and the teacher indicated whether their answer was correct or not. These instances often focused on reviewing information from previous activities.

Teachers also occasionally explicitly indicated purposes that were beyond the immediate activity at hand. I marked these instances as teacher *metacommentary* and coded them as *conceptual*, *procedural*, or *epistemic*. *Conceptual metacommentary* focused on making conceptual connections among activities. For example, when Ms. Nolan introduced the *Carbon TIME* Three Questions she said, "You are going to want to get really used to these questions… These are really important in all of our labs that we do this semester." *Procedural* *metacommentary* focused on establishing classroom norms for activities such as class warm-ups or whole-class discussions. *Epistemic metacommentary* focused on the nature of science or issues related to knowledge and learning more generally. For example, Mr. Harris talked about the role of questions in science. He used statements such as "questions lead us" to explain that scientific investigations are guided by questions. Mr. Ross used *epistemic metacommenatry* to focus on the process of learning. Statements such as "we learn by making mistakes" and "learning is connecting ideas together" attended to the nature of learning and served to establish purposes related to developing skills as learners.

Epistemic Authority. I marked each time I noticed an implicit or explicit reference to a source of authority that supported a knowledge claim in classroom discourse. I was only able to identify instances where the teacher invoked a source of epistemic authority. I did not identify any instances where students invoked an epistemic authority, although this could be related to the fact that the student talk that I analyzed was from whole-class discussions and interactions primarily with their teacher (rather than small group work where students interact primarily with their peers).

I marked utterances that explicitly or implicitly appealed to a source of authority to validate knowledge claims and then categorized the sources of authority that were invoked. I identified instances in which teachers appealed to the authority of the textbook or curriculum, their own authority as the teacher, and to the authority of empirical evidence and scientific models. When teachers emphasized the role of empirical evidence or scientific models it served to support curiosity-driven discourse aimed at figuring out phenomena. However, when teachers emphasized the authority of the textbook or curriculum or their own authoritative knowledge, it supported task-base discourse oriented discourse aimed toward learning about science.

Teachers' appeals to sources of authority also promoted particular roles for students in the classroom. When teachers appealed to empirical evidence and scientific models, it helped to position students as epistemic agents responsible for using evidence and models to construct knowledge. However, when teachers appealed to the textbook, curriculum, or their own authority, it positioned students as passive receivers of knowledge. Thus, the epistemic authority that was established in classroom discourse appears to be an important link between teachers' epistemic framing and the epistemic agency that they offer to students.

Students' Epistemic Agency. The *student epistemic agency* codes attend to the roles that students assume in relation to developing and using knowledge in classroom discourse. Students' epistemic agency is an emergent property that is influenced by how teachers position students through the *Teacher's Purposes* and appeals to *Epistemic Authority* as well students' own actions. This reflects the idea that "agency refers to acts done intentionally," but also that "people are contributors to, rather than the sole determiners of, what happens to them" (Bandura, 1997, p. 3). Thus, although the *Teacher's Purposes* and *Epistemic Authority* categories focused on teachers' actions, they also speak to students' epistemic agency more broadly in that the actions by teachers suggest particular roles for students to take on in the classroom. Therefore, in some ways the distinction between students' and teachers' actions is somewhat arbitrary, but for analytical reasons it is much clearer to code student actions and teacher actions separately in the videos.

It is also important to note that my data includes more evidence of the teachers' talk and actions than of the students' talk and actions because the teachers wore the microphone. While the teachers' microphones recorded student talk that occurred during whole class discussions, I was not able to analyze all of the student talk that occurred when students worked in pairs or small groups. When the teacher moved near a small group or interacted with them, the microphone recorded their conversations, and thus this talk is included this in my analysis. I used the combination of teacher and student talk that was included on the videos to characterize students' purposes for activities. However, my conclusions about students' epistemic agency in classroom discourse are informed by all three coding categories.

Students generally do not explicitly state their own purposes for activities. Therefore, I inferred students' purposes in classroom discourse through the questions that they asked during lessons. I coded *student questions* as either *conceptual* or *procedural*. Conceptual questions indicate that students are trying to make sense of scientific concepts, while procedural questions indicate that students are focused on gathering discrete information such as correct vocabulary or procedures to follow. To distinguish conceptual questions from procedural ones I used the context in which the question was asked, the words the student used, and the teacher's response to understand the meaning that the question conveyed within the classroom community. I also coded teachers' responses to students' difficulties. This code was used when teachers interacted with small groups of students that seemed to be experiencing difficulty with the task. In these instances, the teachers responded with some type of verbal scaffolding. I distinguished between scaffolding that focused on *sensemaking*, which was accomplished by asking students a series of questions to aid them in making an important conceptual connection, versus scaffolding *answers or procedures*, which focused on helping students by providing them factual information or procedural guidance.

REFERENCES

REFERENCES

American Association for the Advancement of Science, A. (1989). *Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology*. Retrieved from Washington, D.C.: http://www.project2061.org/publications/sfaa/online/sfaatoc.htm

Ball, P. (2013). *Curiosity: How Science Became Interested in Everything*. Chicago: University of Chicago Press.

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York: W.H. Freeman and Company.

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 151-170). Cambridge: Cambridge University Press.

Birks, M., & Mills, J. (2011). *Grounded Theory: A Practical Guide*. Thousand Oaks, California: Sage Publications.

Bloome, D., Puro, P., & Theodorou, E. (1989). Procedural display and classroom lessons. *Curriculum Inquiry, 19*(3), 265-291.

Doyle, W. (1983). Academic Work. *Review of Educational Research, 53*(2), 159-199.

Engel, S. (2011). Children's need to know: Curiosity in Schools. *Harvard Educational Review, 81*(4), 625-645.

Engle, R. A. (2011). The Productive Disciplinary Engagement Framework: Origins, Key Concepts, and Developments. In D. Y. Dai (Ed.), *Design Research on Learning and Thinking in Educational Settings: Enhancing Intellectual Growth and Functioning*. New York: Routledge.

Engle, R. A., & Conant, F. R. (2002). Guiding Principles for Fostering Productive Disciplinary Engagement: Explaining an Emergent Argument in a Community of Learners Classroom. *Cognition and Instruction, 20*(4), 399-483.

Feynman, R. P. (1999). *The Pleasure of Finding Things Out* (J. Robbins Ed.). Cambridge, MA: Helix Books.

Ford, M. J., & Wargo, B. M. (2012). Dialogic framing of scientific content for conceptual and epistemic understanding. *Science Education, 96*(3), 369-391.

Gee, J. P. (1991). *Rewriting LIteracy: Culture and the Discourse of the Other*. London: Bergin & Garvey.

Hutchison, P., & Hammer, D. (2010). Attending to student epistemological framing in a science classroom. *Science Education, 94*, 506-524.

Inan, I. (2012). *The Philosophy of Curiosity*. New York: Routledge.

Keller, E. F. (2003). *A feeling for the organism: The life and work of Barbara McClintock*. New York, NY: Holt.

Kennedy, M. M. (2005). *Inside Teaching: How Classroom Life Undermines Reform*. Cambridge: Harvard University Press.

Kitchener, R. F. (2002). Folk epistemology: An introduction. *New Ideas in Psychology, 20*(2-3), 89-105.

Lemke, J. L. (1990). *Taking Science: Language, Learning, and Values*. Norwood, NJ: Ablex Publishing.

Lemke, J. L. (2001). Articulating Communities: Sociocultural Perspectives on Science Education. *Journal of Research in Science Teaching, 38*(3), 296-316.

Loewenstein, G. (1994). The Psychology of Curiosity: A Review and Reinterpretation. *Psychological Bulletin, 116*(1), 75-98.

Mehan, H. (1978). Structuring school structure. *Harvard Educational Review, 48*(1), 32-64.

Michaels, S., & O'Connor, C. (2012). *Talk Science Primer*. Retrieved from Cambridge, MA: http://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

National Research Council (NRC). (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Retrieved from https://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Retrieved from https://www.nextgenscience.org

O'Connor, C., & Michaels, S. (2007). When Is Dialogue 'Dialogic'? *Human Development, 50*(5), 275-285.

Pennock, R. T. (2011). Can't Philosophers Tell the Difference Between Science and Religion?: Demarcation Revisited. *Synthese, 178*, 177-206.

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching, 50*(3), 284-314.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68-78.

Sacks, O. (2002). *Uncle tungsten: Memories of a chemical boyhood*. New York: Vintage.

Sawyer, R. K. (2014). The New Science of Learning. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 1-18). Cambridge: Cambridge University Press.

Schmitt, F. F., & Lahroodi, R. (2008). The Epistemic Value of Curiosity. *Educational Theory, 58*(2), 125-148.

Shubin, N. (2009). *Your inner fish: A journey into the 3.5-billion-year history of the human body*. New York: Vintage.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education, 98*(3), 487-516.

Stroupe, D. (2017). Ambitious teachers' design and use of classrooms as a place of science. *Science Education, 101*(3), 458-485.

Tannen, D. (1993). What's in a frame? Surface evidence for underlying expectations. In D. Tannen (Ed.), *Framing in Discourse*. New York: Oxford University Press.

Thompson, J., Hagenah, S., Kang, H., Stroupe, D., Windschitl, M., & Colley, C. (2016). Rigor and responsiveness in classroom activity. *Teachers College Record, 118*(5), 1-58.

Turner, J. C., Meyer, D. K., Cox, K. E., Logan, C., & Thomas, C. T. (1998). Creating contexts for involvement in mathematics. *Journal of Educational Psychology, 90*(4), 730-745.

Varelas, M., House, R., & Wenzel, S. (2005). Beginning teachers immersed into science; Scientist and science teacher identities. *Science Education, 89*(3), 492-516.

Vygotsky, L. (1978). Interaction between learning and development *Mind and Society* (pp. 79-91). Cambridge, MA: Harvard University Press.

Walqui, A. (2006). Scaffolding instruction for English language learners: A conceptual Framework. *The International Journal of Bilingual Education and Bilingualism, 9*(2), 159-180.

Watson, J. D. (2001). *The double helix: A personal account of the discovery of the structure of DNA*. New York, NY: Touchstone.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*, 89-100.

Zuss, M. (2012). *The Practice of Theoretical Curiosity* (Vol. 20). New York: Springer.

STUDY THREE

Students' Perceptions of Classroom Discourse

INTRODUCTION

The discourse in most high school science classrooms traditionally has focused on *learning about* science topics. However, the vision for three-dimensional learning put forth in the National Research Council's (NRC) *Framework for K-12 Science Education (NRC, 2011)* contends that more productive science learning is aimed at *figuring out* phenomena. Three-dimensional learning requires experiences that engage students in developing and using all three dimensions of science—practices, crosscutting concepts, and disciplinary core ideas—to explain observable natural phenomena. The *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) integrates the three dimensions into performance expectations and asserts that, "learning to explain phenomena and solve problems is the central reason students engage in the three dimensions" (NGSS Website, 2016). Therefore, the *NGSS* represent not just a new way to package content and process goals for science education, but a new paradigm for science learning that positions students as epistemic agents who engage in science practices, apply crosscutting concepts, and develop and use disciplinary core ideas to explain phenomena in science classrooms.

Science instruction aimed at figuring out phenomena requires that questions about the natural world and a shared drive to answer those questions are at the core of classroom discourse. I call this *curiosity-driven discourse* because it is motivated by the desire to explain natural phenomena. Curiosity-driven discourse fosters three-dimensional learning because it engages students in science practices to construct knowledge and emphasizes the transfer of knowledge and skills to new situations. In contrast, more traditional classroom discourse, which I call *task-*

driven discourse, is aimed at learning about science topics. Task-driven discourse tends to foster procedural display (Bloome, Puro, & Theodorou, 1989) because it emphasizes acquiring discrete facts and skills. Therefore, curiosity-driven and task-driven discourse differ primarily in the purposes that are established for learning activities: curiosity-driven discourse aims at figuring out phenomena, while task-driven discourse aims at learning about science. The purposes established in classroom discourse are important because they not only determine the goals for students learning, but they influence students' engagement and motivation to achieve those goals.

In my analysis (Study Two of this dissertation) of five high school classrooms implementing the *NGSS*-aligned *Carbon TIME* curriculum, I found that only one achieved curiosity-driven discourse. This conclusion was based on the talk and actions of the teachers and students captured in the videotaped lessons that I analyzed. While students' actions in the videos revealed particular purposes for activities and roles that they took on, the videos do did not reveal what students actually thought or felt about classroom discourse. This raises questions such as: What did students perceive their teacher's goals to be? Did students feel like their ideas were valued in their classroom? Did classroom discourse nurture students' own curiosity about the world? Students' perceptions of these aspects of classroom discourse are important because they influence students' emotional responses to activities, affect their motivation to Given the importance of students' perceptions, I developed a student survey to address the research question: How do students perceive the discourse in their science classrooms? Answering this question is relevant not only for comparing students' perceptions to my own assessment from the video analysis, but also for determining whether a student survey could potentially identify the degree of curiosity-driven discourse in the absence of more time-intensive classroom observations.

The survey measured multiple affective constructs related to the key features of curiosity-driven discourse. It was administered to the students in each of the five case study classrooms when they had finished implementing the *Carbon TIME* curriculum. I had two main goals in developing, administering, and analyzing the survey: (1) compare students' perceptions of classroom discourse across the case study classrooms to my findings from the video analysis, and (2) determine whether the results from the student survey could stand in for more intensive analyses of classroom discourse.

Curiosity-Driven Discourse and Theories of Motivation

While the *NGSS* describe cognitive performances to be accomplished by individuals, the three-dimensional learning experiences required to achieve the performance expectations include social and affective components that engage students' collective curiosity and motivate them to explain natural phenomena. Achieving the performance expectations requires socializing students into communities of practice motivated by curiosity about the natural world. Therefore, curiosity plays an important role in motivating productive science learning. Susan Engel has extensively studied the role of curiosity in elementary classrooms and calls curiosity "the mechanism that underlies the best learning" (Engel, 2011, p. 626).

Curiosity has both cognitive and affective dimensions that influence learning. It is not simply a generic desire for any knowledge, but curiosity always has a particular object of focus (Inan, 2012; Schmitt & Lahroodi, 2008). Thus, curiosity focuses the learner on developing particular types of knowledge. In addition, curiosity is associated with enjoyment and learning for its own sake (Ryan & Deci, 2000). Enjoyment derived from particular learning activities has been shown to increase motivation and improve learning (Shumow & Schmidt, 2014). In addition, to its cognitive and affective dimensions, curiosity has a social dimension. Engel points out that, “children’s curiosity unfolds within a social context… their curiosity is influenced by those around them” (2011, p. 629).

The notion that curiosity-driven discourse supports productive learning is supported by key psychological theories of motivation including achievement goal theory (Senko, Hulleman, & Harackiewicz, 2011) and self-determination theory (Ryan & Deci, 2000). These theories highlight how individuals’ goals, perceived autonomy, and social relationships influence their motivation and achievement. The key aspects of motivation highlighted by these theories directly relate to my conceptualization of curiosity-driven discourse and its role in fostering productive learning. Curiosity-driven classroom discourse positions students as epistemic agents responsible for using empirical evidence and scientific models to answer questions about natural phenomena. The role of the teacher in curiosity-driven discourse is to orient students toward productive questions about phenomena and to scaffold their sensemaking. Thus, curiosity-driven discourse is aimed at a particular epistemic goal—figuring out phenomena, it fosters students’ autonomy by positioning them as epistemic agents, and it involves social relationships that support their sensemaking including scaffolding from the teacher and discourse with peers.

Achievement goal theory explains student motivation in terms of the students’ reasons for engaging and persisting in classroom activities (Meece, Anderman, & Anderman, 2006). Many scholars have described two main types of achievement goals, which are often summarized as “mastery” and “performance” orientations (Shumow & Schmidt, 2014). The mastery approach is characterized by a desire to understand and develop competence in a particular area, while the performance approach is characterized by a desire to outperform other students. The performance orientation can also manifest as performance avoidance in which students avoid tasks if they believe they will fail. Many lines of research have demonstrated that the mastery orientation fosters greater persistence and deeper learning than the performance orientation (Meece et al., 2006). While students who have strong performance goals may do well in school, if they do not also hold mastery goals, then they often avoid challenging tasks or courses and are less intrinsically motivated to deeply engage with the material.

It is important to note that mastery and performance goals are not mutually exclusive. In addition, research has found that student goal structures differ in different situations and are influenced by their educational contexts and teachers' practices. However, because curiosity-driven classroom discourse promotes learning for its own sake, I expect students in these classrooms to adopt more mastery-oriented goal structures. On the other hand, I would expect classrooms that engage in task-driven discourse to support more performance-oriented goal structures.

A mastery orientation has shown to be positively related to academic self-efficacy (Meece et al., 2006). Perceived self-efficacy refers to a person's belief in their "capability to organize and execute the courses of action required to produce given attainments" (Bandura, 1997, p. 3). A student's level of self-efficacy affects their motivation, effort, and persistence in science classrooms. Shumow and Schmidt (2012) found that students' self-efficacy in their science classes varies throughout the school year and tends to be related to teachers' practices. Their study showed that students' self-efficacy tended to increase in classrooms in which teachers used more questioning and emphasized critical thinking over recall of facts. Thus, I expect classrooms that adopt curiosity-driven discourse to foster increased academic efficacy versus classrooms that emphasize recall of facts. However, multiple surveys throughout the school year would be necessary to measure the degree to which the classroom discourse actually affects students' ability beliefs over time.

Research shows that students are intrinsically motivated to engage in appropriately challenging activities (Shumow & Schmidt, 2014). Many lines of research on classroom discourse also support the notion that academically productive talk that fosters conceptual reasoning and presses students to explain their ideas is critical for science learning (Michaels & O'Connor, 2012). Curiosity-driven classroom discourse challenges students by positioning them as epistemic agents capable of developing and answering scientific questions about phenomena. The teacher scaffolds students to meet this challenge by pressing them to analyze evidence and explain their reasoning. The degree to which teachers foster rigorous thinking and encourage learning beyond procedural display is referred to as academic press (Murphy, Weil, Hallinger, & Mitman, 1982). Academic press implies that students are challenged, but it also fosters self-efficacy because, "When a teacher challenges his or her students, students receive an implicit positive message about their abilities and the teacher's confidence in them" (Shumow & Schmidt, 2014).

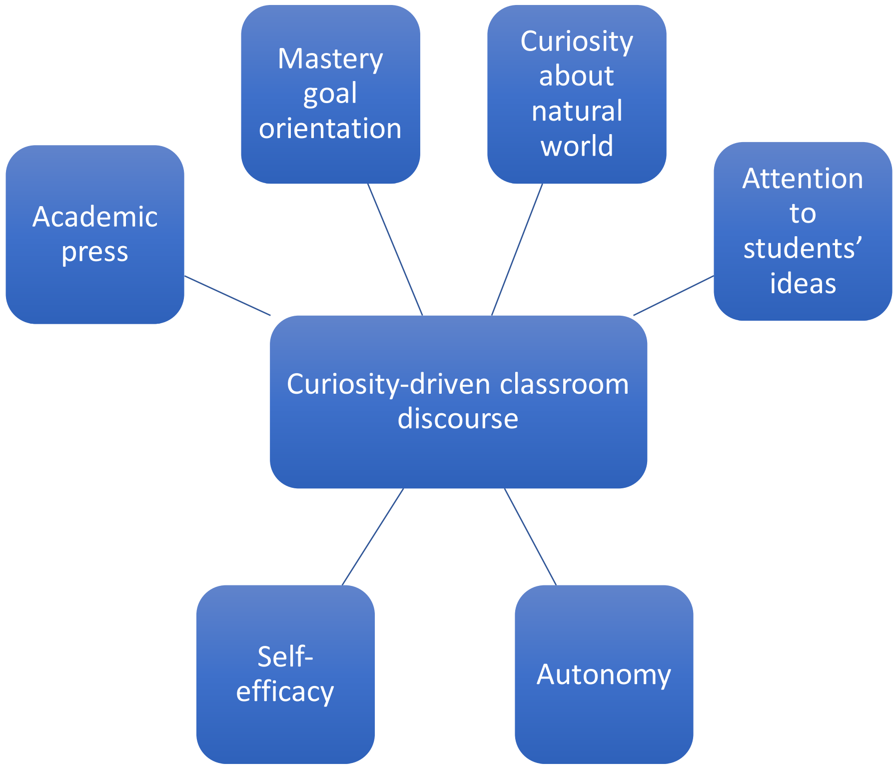
Self-determination theory (SDT) explains motivation in terms of three psychological needs: competence, relatedness, and autonomy (Ryan & Deci, 2000). Competence is another word for self-efficacy as described above. Relatedness refers to a person's perception of their social relationships, with higher relatedness connected to increased intrinsic motivation. In the classroom, these relationships include both a student's relationships with peers as well as with their teacher. Autonomy refers to a person's sense of independence or freedom within a particular context. Students' sense of autonomy in the classroom is especially influenced by their teacher's practices. Research has shown that teaching practices that support students' perceived autonomy promote intrinsic motivation (Ryan & Deci, 2000).

Curiosity-driven classroom discourse supports the three aspects of intrinsic motivation emphasized by self-determination theory. It promotes a feeling of competence by positioning students as epistemic agents responsible for explaining phenomena and supporting them in achieving that goal through intentional scaffolding. It supports relatedness through dialogic discourse that encourages students to share their ideas and reasoning and through working together toward a common goal of explaining phenomena. Finally, curiosity-driven discourse supports students' sense of autonomy by engaging their own curiosity and supporting them in developing questions and using empirical evidence and scientific models to answer those questions.

Measuring Students' Perceptions of Curiosity-Driven Discourse

Figure 3.1 depicts the constructs considered in this study which were measured by the survey. At the center of the image is curiosity-driven classroom discourse, surrounded by the key features. Academic press, mastery goal orientation, self-efficacy, and autonomy were constructs identified in the psychology literature that positively influence students' motivation to learn and are directly related to my conceptualization of curiosity-driven discourse. Although not previously described in the literature on motivation, curiosity about the natural world and attention to students' ideas are also important components of my conceptualization of curiosity-driven classroom discourse because they position students as epistemic agents responsible for figuring out phenomena. Thus, I developed a student survey that included a scale for each of these six constructs.

Figure 3.1. Key components of curiosity-driven discourse measured by the student survey.



The survey items ask students to indicate their degree of agreement to statements about their teacher's or classroom's goals and purposes for activities. Thus, the survey measures students' perceptions of classroom discourse, rather than their individual degree of any of these constructs. In the video analysis of the case study classrooms (study 2 of this dissertation), I described my coding scheme for analyzing classroom discourse. The constructs included in the survey directly relate to these key features of classroom discourse. The *Teacher's Purposes* identified in the video analysis are measured by the constructs of academic press, mastery goal orientation, curiosity about the natural world, and attention to students' ideas. These constructs relate to the purposes that teachers establish for activities, whether teachers press students toward conceptual understanding, and the role of curiosity about phenomena and students' own ideas in classroom discourse. In the video analysis, *Students' Epistemic Agency* was conceptualized as the actions that students take to indicate their framing of the purposes of lessons as well as how they are positioned in relation to developing and using knowledge. The constructs of self-efficacy and autonomy on the survey are closely aligned to these aspects of *Students' Epistemic Agency* because they measure students' perceptions of their competence for achieving the goals in their classroom and the degree to which their teacher positions them as epistemic agents.

In the video analysis (study 2 of this dissertation), I compared the discourse in five high school classrooms implementing the *Carbon TIME* curriculum (see Table 2.1 for an overview of the five classrooms). I found that only Ms. Nolan's classroom achieved curiosity-driven discourse, while the other four exhibited more task-driven discourse. The survey described in this study was designed to compare students' perceptions of the discourse in these classrooms to my own analysis. Additionally, agreement between my analysis of classroom discourse and students' responses on the survey would suggest that the survey might be used as a less time-intensive method of measuring the degree of curiosity-driven discourse in science classrooms.

SURVEY INSTRUMENT

The survey included six scales that each measure a specific aspect of curiosity-driven classroom discourse. The constructs measured are depicted in Figure 3.1 and the survey scales that measure them are described in Table 3.1. In the literature on achievement goal theory and self-determination theory, I identified four published scales that measure constructs that are central to my conceptualization of curiosity-driven discourse (the scales marked PALS and SDT in Table 3.1). Because I could not locate published scales to measure students' perception of the role of curiosity about the natural world or whether their ideas were encouraged and valued in classroom discourse, I developed scales to measure these aspects of curiosity-driven discourse.

I conducted a pilot study in the fall of 2015 in which I administered the survey to a group of students that was not participating in the *Carbon TIME* project. The pilot survey included additional scales that were removed from the final survey because they were determined to be redundant or unnecessary for measuring the degree of curiosity-driven discourse. The pilot study demonstrated that both the published scales and the ones that I developed for measuring the role of curiosity and students' ideas in classroom discourse all had acceptable reliability using the standard measure of Cronbach's $\alpha > 0.7$.

The final survey measuring curiosity-driven discourse consisted of 35 items that asked students to indicate their degree of agreement on a 5-point Likert scale (See Appendix for the list of items). The survey was administered to 315 students across the five *Carbon TIME* high school case study classrooms during the 2015 – 2016 school year. The reliability of each of the scales ranged from $\alpha = 0.781$ to $\alpha = 0.925$ (Table 3.1). The reliability scores of $\alpha > 0.7$ indicate acceptable reliability for each scale included on the survey.

Table 3.1. Scales measuring key aspects of curiosity-driven discourse included in the survey.

Survey Scale	**Measures the students' perception of…**	**Reliability of the scale in this study (Cronbach's α)**
PALS Classroom Mastery Goal Structure	The purpose for classroom activities is developing competence and conceptual understanding	0.895
PALS Academic Efficacy	Students' perception of their competence for classroom activities (self-efficacy)	0.921
PALS Academic Press	The teacher challenges students and presses for understanding	0.912
SDT Learning Climate Questionnaire (Autonomy Support)	The student feels understood and supported by the teacher (autonomy)	0.925
Curiosity about the natural world in classroom discourse	Classroom discourse encourages appreciation of nature or curiosity about the world	0.781
Role of students' ideas in the classroom	Students have opportunities to share their ideas in the classroom and feel that their ideas are valued	0.779

The Patterns of Adaptive Learning Scales (PALS) were developed to measure students' perceptions of the learning environment in their classroom (Midgley et al., 2000). The PALS included in this survey measure students' perceptions of (1) classroom mastery goal orientation (2) self-efficacy and (3) the degree of academic press that they felt from their teacher. I also included the PALS Classroom Performance-Approach Goal Structure scale to test whether classrooms differed in their emphasis on performance goals such as getting correct answers and scoring high on tests. I found no statistical difference ($p = 0.264$) across the five classrooms in students' responses on the PALS Classroom Performance-Approach. The performance approach scale was the only scale included that was not hypothesized to correlate with curiosity-driven discourse, and thus it was removed from the survey total score. Thus, the total survey score is a measure of students' perception of the overall degree of curiosity-driven discourse in a classroom.

The Learning Climate Questionnaire (Deci & Ryan, undated) was developed by SDT researchers to measure the degree to which students feel that their teacher supports their autonomy in the classroom. Thus, it was included to measure students' epistemic agency in the classroom. The two scales that I developed for the role of curiosity about the natural world and students' own ideas in classroom discourse measure constructs that were not previously identified in the motivation literature. However, these constructs are essential components of the NRC *Framework's* vision of three-dimensional learning that emphasizes the importance of students' sensemaking about phenomena. These scales were tested in the pilot study, and the reliability in this study of $\alpha = 0.781$ for the Curiosity scale and $\alpha = 0.7779$ for the Ideas scale (Table 3.1) further confirms that the scales I developed are reliably measuring a single construct.

The Curiosity scale is made up of six items that focus on whether the class has increased students' curiosity about the natural world or their appreciation of nature, whether the class is boring or fun, and whether the topics in the class relate to their life outside of school. These items are meant to measure students' perceptions of the classroom discourse rather than students' own inherent curiosity about science. However, responses are likely influenced by students' personal interest in science. I also developed four items measuring students' perceptions of the role of their own ideas in classroom discourse. While the PALS Academic Press scale measures the degree to which teachers press students to explain their answers, and the SDT Learning Climate Questionnaire measures the degree to which a student feels understood and supported by their teacher, neither scale specifically asked about whether students feel that they can share their ideas in class and that their ideas are valued. For example, it is possible that academic press and autonomy support could occur through written feedback and a teacher's interactions with individuals. However, I am also interested in whether students feel that sharing their ideas with their peers is encouraged in the classroom. Thus, the Curiosity and Ideas scales that I developed capture important aspects of curiosity-driven discourse that have not been studied through student surveys previously.

RESULTS

The survey was administered to 315 students across the five case study classrooms. Most students took the survey online in the spring of 2016 in conjunction with their completion of *Carbon TIME* post-tests at the conclusion of the units. Mr. Harris' students took a paper version of the survey, while the students in the other four classrooms completed on online version of the survey. Analysis of the mean scores in each classroom revealed the same pattern across all six scales: the mean for Ms. Callahan's classroom was highest, followed by Mr. Harris', Ms. Wei's, and Ms. Nolan's, with the lowest scores on each scale in Mr. Ross' classroom (See Appendix for the results of each scale). Thus, the mean scores on the individual scales are highly correlated to each other in all five classrooms. This suggests that students' perceptions of these features of curiosity-driven classroom discourse are not discrete variables.

The survey total score represents students' perceptions of the degree to which their classroom engaged in curiosity-driven discourse. Some students did not complete all parts of the online survey which resulted in missing data for certain scales. Because sum scores could not be computed for these students, the final sample size for the total survey score was 271 students. Ms. Callahan asked her students to complete the survey outside of class time which resulted in few students participating. The sample size for each classroom and the mean sum score for the survey are reported in Table 3.2.

Table 3.2. Results of the student survey in the case study classrooms.

Teacher	Sample Size	Mean Total	Standard Deviation	Median Total	Skewness	Adjusted Significance (differs from the following other classrooms)
Callahan	12	153.92	10.09	154.00	-0.826	Ross (p < 0.001) Wei (p = 0.008) Nolan (p = 0.008)
Harris	42	139.86	19.31	142.00	-0.839	Ross (p < 0.001)
Wei	54	131.57	20.29	131.00	-0.037	Callahan (p = 0.008)
Nolan	85	129.13	27.56	137.00	-1.201	Callahan (p = 0.008)
Ross	78	118.86	30.30	115.50	-0.375	Callahan (p < 0.001) Harris (p < 0.001)

The total survey scores in each classroom were not normally distributed and classrooms had different numbers of respondents. Therefore, the nonparametric Kruskal-Wallis H test was used to compare the medians across the classrooms instead of a one-way ANOVA (Lomax & L., 2012; Midgley et al., 2000). Distributions of the total survey scores were similar for all groups as assessed by visual inspection of the boxplots. The Kruskal-Wallis H test demonstrated that there were significant differences in the total survey scores among the classrooms, $\chi^2(4) = 31.608$, $p < 0.001$. Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons (Lomax & Hahs-Vaughn, 2012). Adjusted *p*-values are presented in Table 3.2. This post hoc analysis revealed statistically significant differences in median total survey scores between Ms. Callahan's students and Mr. Ross' ($p < 0.001$), Ms. Wei's students ($p = 0.008$), and Ms. Nolan's students ($p = 0.008$) as well as between Mr. Harris' and Mr. Ross' students ($p < 0.001$), but not between any other classroom combinations.

DISCUSSION

My previous analysis of classroom discourse (study 2 of this dissertation) revealed that only Ms. Nolan's classroom engaged in curiosity-driven discourse that positioned students as epistemic agents responsible for figuring out phenomena. The other four classrooms were characterized by more task-driven discourse that positioned students as learning authoritative science knowledge. Ms. Nolan established a driving question about a phenomenon that she linked to each activity, she supported students' epistemic agency by scaffolding them in figuring out phenomena and pressing them to explain their answers. Ms. Nolan's students demonstrated their scientific curiosity by asking a large number of conceptual questions throughout the unit that I analyzed. Their questions and other participation also suggested that they felt comfortable sharing their ideas in the classroom. Thus, my findings from the video analysis lead to the prediction that Ms. Nolan's students would have the highest average total survey scores.

Although my previous analysis found that the other four classrooms engaged in more task-driven discourse, I also noticed that the discourse in Ms. Callahan's classroom was more rigorous than the discourse in Ms. Wei's, Mr. Ross', and Mr. Harris' classroom. Due to the emphasis on conceptual understanding in Ms. Callahan's classroom, I would expect her students to rate the discourse in their classroom higher on this survey than the students in Ms. Wei's, Mr. Ross' and Mr. Harris' classrooms. Although the discourse in Ms. Callahan's classroom fell short of positioning students as epistemic agents responsible for figuring out phenomena, there was a strong emphasis on conceptual understanding that I would expect to positively impact students' perceptions of classroom goals related to mastery, academic press, and self-efficacy. Both Mr. Harris and Mr. Ross struggled to illicit students' ideas and to respond to students' ideas in class discussions. In addition, they rarely pressed students to explain their answers and did little to foster students' epistemic agency. Therefore, my findings from the video analysis lead to the prediction that Mr. Ross' and Mr. Harris' students would have the lowest average total survey scores.

My predictions about students' responses across the classrooms were not supported by the survey data. The most surprising results were from Ms. Nolan's classroom, in which the students tended to rate the degree-of curiosity driven discourse lower than I expected, and Mr. Harris' classroom, in which the students tended to rate the degree of curiosity-driven discourse higher than I expected. The total survey scores in Ms. Nolan's classroom had a high degree of variability and were negatively skewed (Table 3.2), indicating that the results in her classroom were influenced by a number of outliers who rated the discourse much lower than the rest of the students. This group of students may not have taken the survey seriously, or they may have disliked the teacher or the class and responded negatively to all of the questions. The outliers may partially explain the lower than expected results in Ms. Nolan's classroom.

Mr. Harris' students rated the degree of curiosity-driven discourse much higher than expected. Although outside the scope of this study, preliminary analysis of other data sources collected through the larger *Carbon TIME* project suggests some reasons why this may have occurred. I served as the case study coach in Mr. Harris' classroom, and my interviews with the focus students indicated they felt his classroom was much more engaging than most of the other classes at their school. They reported more opportunities to share their ideas, increased hands-on activities, and a higher degree of curiosity about the natural world than they experienced in other science classes. Thus, Mr. Harris' higher-than-expected survey scores are likely attributable to the fact that students' perception of classroom discourse is a function of their experiences in other classrooms. Therefore, although as a researcher comparing discourse across the five classrooms I perceived the degree of curiosity-driven classroom discourse to be very low in Mr. Harris' classroom, when his students compared the classroom discourse to their experiences in even more task-driven classrooms at their school, it actually seemed more curiosity-driven.

The fact that students' perceptions of the discourse in a particular classroom is a function of their experiences in other classrooms may also explain why Ms. Nolan's survey scores were lower than expected. If students at her school experienced other classes that were even more curiosity-driven than hers, it would have caused them to rate her classroom somewhat lower in comparison. Ms. Nolan has shared with *Carbon TIME* staff that most of her students had a teacher the previous year that was particularly skilled at orchestrating classroom discourse. This supports the conclusion that her students may have rated the discourse in her classroom somewhat lower simply because it seemed more normal to them rather than out of the ordinary.

If students' perception of classroom discourse is a function of their experiences in other classrooms, a different research design would be necessary to compare the survey responses across the case study classrooms. One option would be to ask the students to complete the survey about all of their classes, and then use the results from other classes to statistically control for their responses about their science class. Another option would be to give the survey multiple times across the year to look at how students' responses change over time. However, even with the limitations of the design of this study, future analysis of other data collected through the *Carbon TIME* project may shed light on why the students responded the way that they did. For example, other research groups within the *Carbon TIME* project are currently analyzing work samples, interviews, and video recordings of students' small group work for a selected group of focus students from these case study classrooms. Analysis of these student-facing data sources, in conjunction with the information gleaned from interviews with the teachers, may help explain the results presented here.

CONCLUSION

The survey instrument I developed for this study reflects the theoretical framework that guided my analysis of classroom videos in study 2 of this dissertation. Thus, I expected that classrooms exhibiting a higher degree of curiosity-driven classroom discourse would score higher on the survey than classrooms that exhibited more task-driven discourse. However, the results of the survey did not support this hypothesis. While Mr. Harris' classroom exhibited very task-driven discourse in the video analysis, his students rated each of the components of curiosity-driven discourse included on the six scales of this survey quite high. In contrast, although Ms. Nolan's classroom exhibited the highest degree of curiosity-driven discourse in the video analysis, her students did not rate the degree of curiosity-driven discourse very high on the survey. These findings indicate that students' perceptions of classroom discourse do not match my own.

Of course, there are many possible reasons that students' perception of classroom discourse do not match my perception. A likely reason is that students' responses to the survey items were heavily influenced by their experiences in other classrooms. Other data collected from the *Carbon TIME* case study classrooms suggests that students' views of the discourse in their science classroom is shaped by their experiences other classrooms and what they have come to expect as normal. If this is true, then the study design of administering a single student survey is not sufficient to draw conclusions about the degree of curiosity-driven discourse in a particular classroom.

Whatever the reason for the mismatch between students' perceptions of classroom discourse and the results of my video analysis, the survey results call into question any research design that infers the quality of classroom discourse from student surveys alone. Researchers and evaluators often use student surveys in study designs that do not include classroom observations. However, the results of this study raise serious concerns about the legitimacy of the claims that they make. If students perceive classroom discourse differently from researchers and evaluators, it would be a mistake to draw conclusions about the quality of classroom discourse from student surveys in the absence of classroom observations.

While the results of this study did not match my predictions based on my video analysis of classroom discourse, students' responses suggest that engagement and motivation were fairly high in all of the *Carbon TIME* classrooms. The average score in each classroom for each survey item was greater than three, which corresponded to "somewhat true" on the Likert scale. Students' tendency to rate the items related to curiosity-driven discourse as "somewhat true" or "very true" in their classrooms indicates that overall they perceived classroom discourse positively. Thus, it may be that the *Carbon TIME* curriculum itself had a positive influence on classroom discourse. More research is needed to understand the effects of particular features of classroom discourse on students' perceptions of classroom discourse in *Carbon TIME* classrooms.

APPENDIX

The survey items below were randomly organized on the final instrument (not grouped by scale). Students were given the following directions for completing the survey:

Directions:
Carbon TIME researchers are interested in understanding students' perceptions of their current science class. Your answers are completely confidential and will not impact your grade in any way. Your teacher will not see your individual answers, but only a summary of the class totals for each question.

Please circle the number that represents your agreement or disagreement with the statements.

- Circle only one number for each question. The more you agree with the statement, the higher the number you should choose.
- Answer these questions specifically for your current science class (the one in which you participated in *Carbon TIME* activities).

Rating scale

1	2	3	4	5
Not at all true		Somewhat true		Very true

Survey Scales:

PALS Classroom Mastery Goal Structure
In our class, trying hard is very important.
In our class, how much you improve is really important.
In our class, really understanding the material is the main goal.
In our class, it's important to understand the work, not just memorize.
In our class, learning new ideas and concepts is very important.
In our class, it's OK to make mistakes as long as you are learning.

PALS Academic Efficacy
I'm certain I can master the skills taught in class this year.
I'm certain I can figure out how to do the most difficult class work.
I can do almost all the work in class if I don't give up.
Even if the work is hard, I can learn it.
I can do even the hardest work in this class if I try.

PALS Academic Press
When I've figured out how to do a problem, my teacher gives me more challenging problems to think about.
My teacher presses me to do thoughtful work.
My teacher asks me to explain how I get my answers.

When I’m working on something, my teacher tells me to keep thinking until I really understand.
My teacher doesn’t let me do just easy work, but makes me think.
My teacher makes sure that the work I do really makes me think.
My teacher accepts nothing less than my full effort.

SDT Learning Climate Questionnaire (autonomy support)
I feel that my teacher provides me choices and options.
I feel understood by my teacher.
My teacher has confidence in my ability to do well in the course.
My teacher encourages me to ask questions.
My teacher listens to how I would like to do things.
My teacher tries to understand how I see things before suggesting a new way to do things.

Curiosity about the natural world in classroom discourse
What we learn in this class is connected to the real world or my everyday life.
The topics in this class do not relate to my life outside of school. (reverse coded)
This class makes learning science fun.
I am usually bored in this class. (reverse coded)
This class has made me more curious about the world.
This class has increased my appreciation of nature.

Role of students’ ideas in the classroom
I feel like my ideas are valued in this classroom.
I have opportunities to share my ideas in this class.
I feel comfortable sharing my ideas in a whole class discussion in this class.
I’d rather not tell anyone when I don’t understand something in this class. (Reverse coded)
My teacher tries to help students figure things out on their own rather than telling them answers.

Table 3.3 Student Survey Results on Each Scale by Classroom.

Teacher NREL ID			PALS Classroom Mastery	PALS Academic Efficacy	PALS Academic Press	SDT Learning Climate (Autonomy)
Ross	N	Valid	84	84	82	82
		Missing	1	1	3	3
	Mean		21.2262	16.9524	23.7927	20.7805
	Median		22.0000	18.0000	23.0000	20.5000
	Std. Deviation		5.79853	5.79968	6.89200	6.50550
	Variance		33.623	33.636	47.500	42.322
Wei	N	Valid	61	63	61	59
		Missing	4	2	4	6
	Mean		23.1148	19.8413	25.7869	22.8475
	Median		23.0000	20.0000	26.0000	23.0000
	Std. Deviation		4.37835	4.10824	5.74490	4.97169
	Variance		19.170	16.878	33.004	24.718
Nolan	N	Valid	88	94	90	90
		Missing	6	0	4	4
	Mean		22.3409	19.1915	25.8444	22.5444
	Median		24.0000	20.0000	27.0000	24.0000
	Std. Deviation		5.67488	4.91274	6.41612	5.93061
	Variance		32.204	24.135	41.167	35.172
Callahan	N	Valid	16	17	13	13
		Missing	1	0	4	4
	Mean		26.9375	21.2353	31.3846	26.1538
	Median		27.5000	22.0000	31.0000	26.0000
	Std. Deviation		2.86284	4.11597	2.46774	2.30384
	Variance		8.196	16.941	6.090	5.308
Harris	N	Valid	50	54	50	52
		Missing	4	0	4	2
	Mean		25.4000	20.0556	28.4400	24.4423
	Median		26.0000	21.0000	29.5000	26.0000
	Std. Deviation		3.33809	3.74879	4.43161	4.09884
	Variance		11.143	14.053	19.639	16.801

Table 3.3 (cont'd)

Teacher NREL ID			Curiosity in Classroom Discourse	Role of Students' Ideas in Classroom Discourse
Ross	N	Valid	83	83
		Missing	2	2
	Mean		18.3735	16.7229
	Median		18.0000	17.0000
	Std. Deviation		5.62597	4.40430
	Variance		31.651	19.398
Wei	N	Valid	61	60
		Missing	4	5
	Mean		20.1967	18.9667
	Median		20.0000	19.0000
	Std. Deviation		4.51966	3.27790
	Variance		20.427	10.745
Nolan	N	Valid	90	90
		Missing	4	4
	Mean		20.1000	19.1111
	Median		21.0000	20.0000
	Std. Deviation		4.86688	4.19857
	Variance		23.687	17.628
Callahan	N	Valid	16	12
		Missing	1	5
	Mean		24.2500	22.2500
	Median		24.5000	22.0000
	Std. Deviation		3.64234	1.71226
	Variance		13.267	2.932
Harris	N	Valid	52	52
		Missing	2	2
	Mean		21.3269	19.6154
	Median		22.0000	20.0000
	Std. Deviation		4.35089	3.59277
	Variance		18.930	12.908

Figure 3.2. Student Perceptions of Mastery Goal Structure.

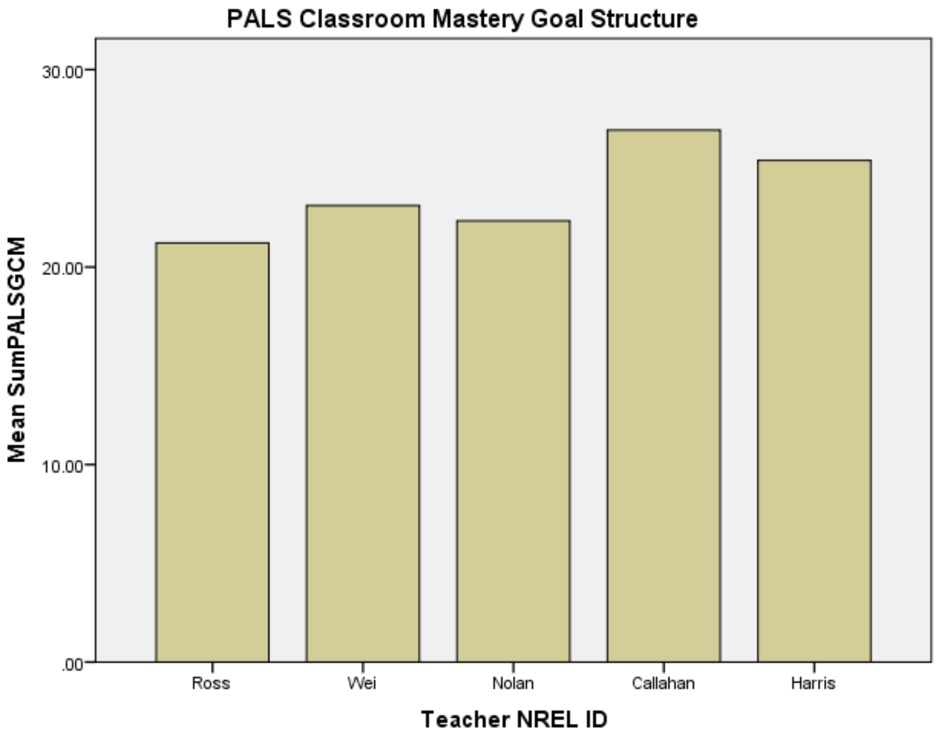


Figure 3.3. Student Perceptions of Academic Efficacy.

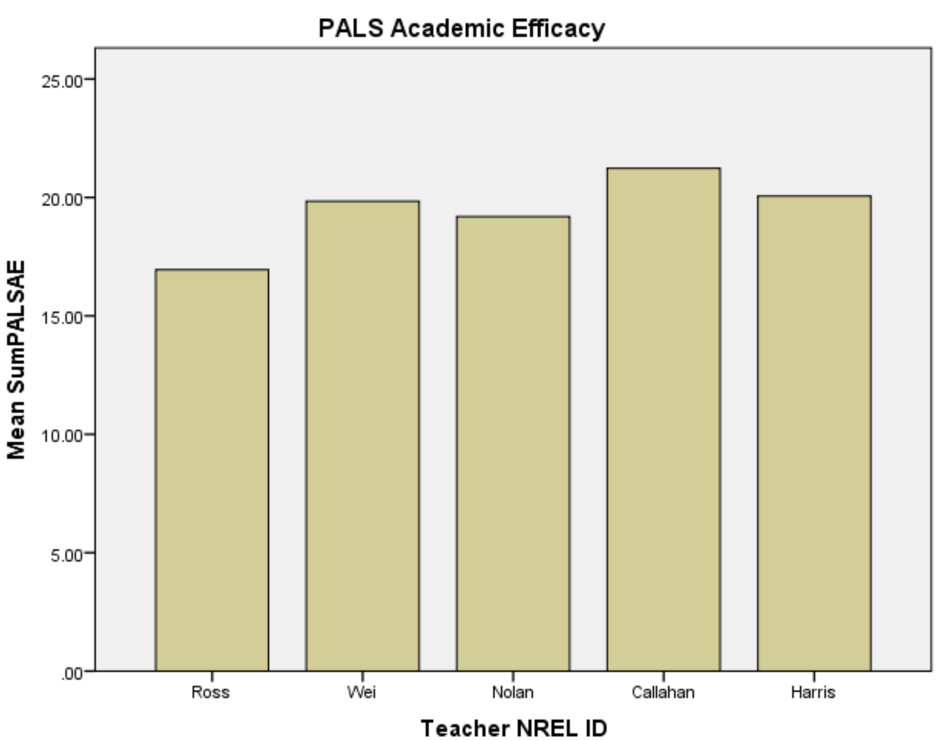


Figure 3.4. Student Perceptions of Academic Press.

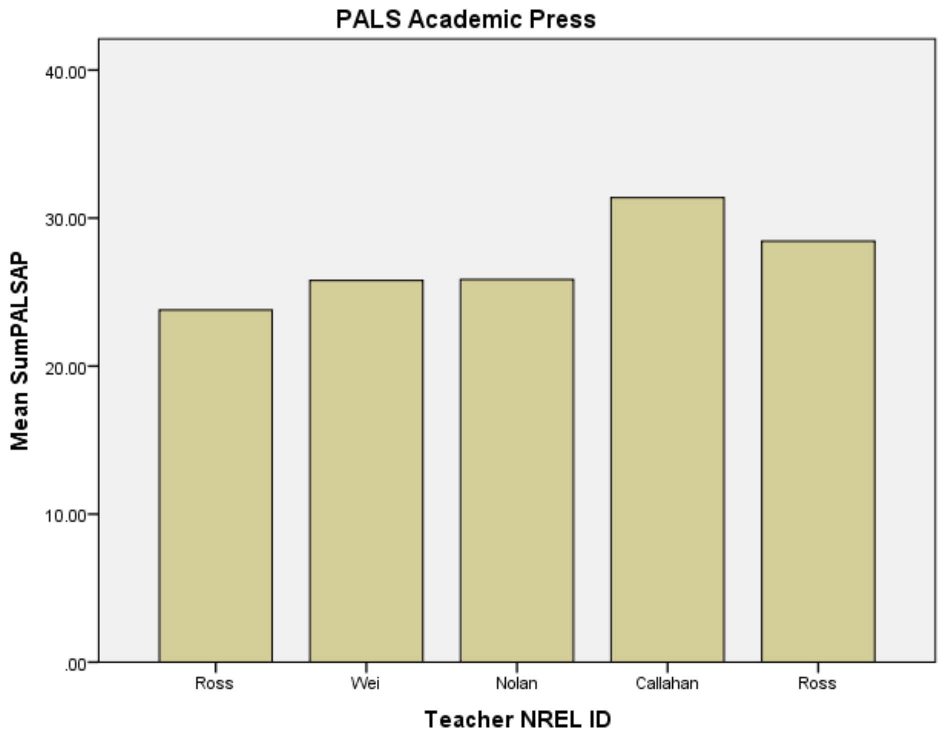


Figure 3.5. Student Perceptions of Autonomy.

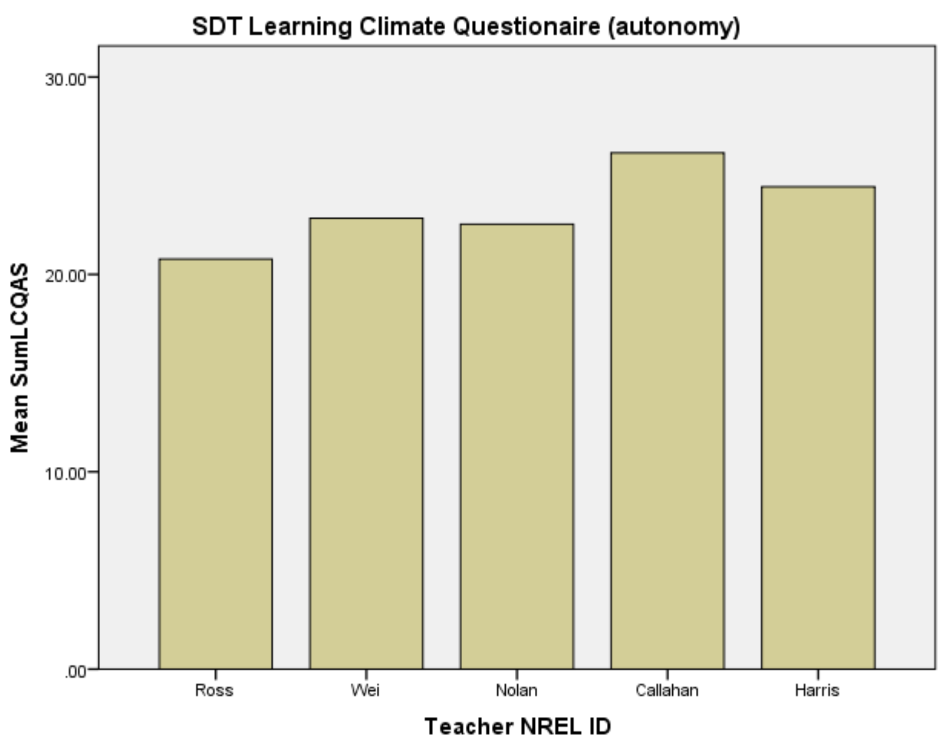


Figure 3.6. Student Perceptions of Curiosity in Classroom Discourse.

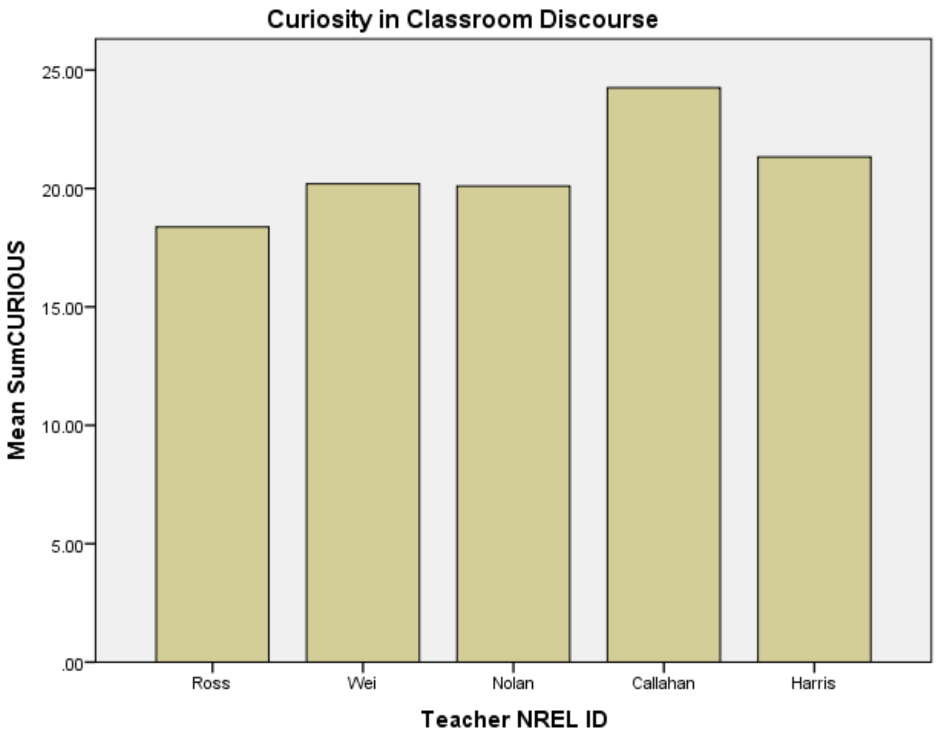
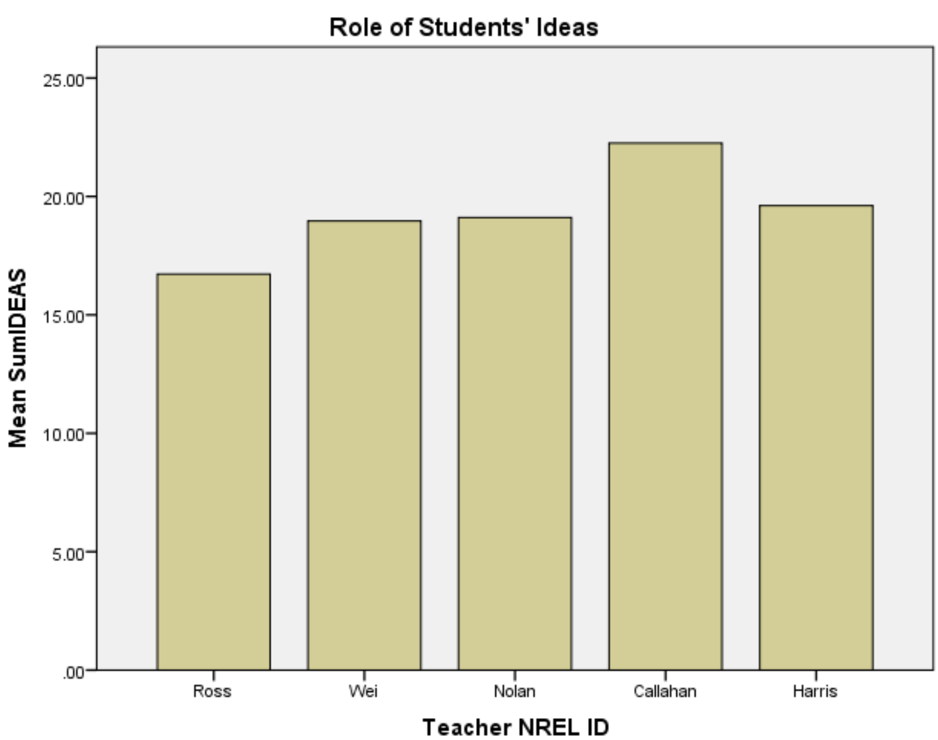


Figure 3.7. Student Perceptions of the Role of Their Ideas in Classroom Discourse.



REFERENCES

REFERENCES

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York: W.H. Freeman and Company.

Bloome, D., Puro, P., & Theodorou, E. (1989). Procedural display and classroom lessons. *Curriculum Inquiry, 19*(3), 265-291.

Engel, S. (2011). Children's need to know: Curiosity in Schools. *Harvard Educational Review, 81*(4), 625-645.

Inan, I. (2012). *The Philosophy of Curiosity*. New York: Routledge.

Lomax, R. G., & L., H.-V. D. (2012). *An Introduction to Statistical Concepts* (3rd ed.). New York: Routledge.

Meece, J. L., Anderman, E. M., & Anderman, L. H. (2006). Classroom goal structure, student motivation, and academic achievement. *Annual Review of Psychology, 57*, 487-503.

Michaels, S., & O'Connor, C. (2012). *Talk Science Primer*. Retrieved from Cambridge, MA: http://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

Midgley, C., Maehr, M. L., Hruda, L. Z., Anderman, E., Anderman, L., Freeman, K. E., . . . Urdan, T. (2000). *Manual for the Patterns of Adaptive Learning Scales*. The University of Michigan. Retrieved from http://www.umich.edu/~pals/manuals.html

Murphy, J. F., Weil, M., Hallinger, P., & Mitman, A. (1982). Academic press: Translating high expectations into school policies and classroom practices. *Educational Leadership, 40*(3), 22-26.

National Research Council (NRC). (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Retrieved from https://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Retrieved from https://www.nextgenscience.org

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68-78.

Schmidt, J. A., & Shumow, L. (2012). Change in self-efficacy in high school science classrooms. In S. Brittner (Ed.), *Psychology of self-efficacy*. Hauppauge, N.Y.: Nova Publishers.

Schmitt, F. F., & Lahroodi, R. (2008). The Epistemic Value of Curiosity. *Educational Theory, 58*(2), 125-148.

Senko, C., Hulleman, C. S., & Harackiewicz, J. M. (2011). Achievement goal theory at the crossroads: Old controversies, current challenges, and new directions. *Educational Psychologist, 46*(1), 26-47.

Shumow, L., & Schmidt, J. A. (2014). *Enhancing Adolescents' Motivation for Science: Research-Based Strategies for Teaching Male and Female Students*. Thousand Oaks, CA: Corwin Press.