

Paper 5: *Carbon TIME* Teacher Orientations and Contexts: Making Connections to Classroom Discourse and Student Learning

Christie Morrison Thomas¹, Beth A. Covitt², James Brian Hancock II³, Qinyun Lin⁴,
Stefanie Marshall⁵, & Charles W. Anderson¹

¹ Michigan State University (morris73@msu.edu), ²University of Montana, ³Alma College,

⁴University of Chicago, ⁵University of Minnesota, Twin Cities

Subject/Problem

As expressed in the introduction to this Paper Set, we're trying to understand how large-scale reforms affect teachers and students in individual classrooms. To this end, Paper 5 analyzes teacher interviews from the same five teachers whose classroom discourse we explored in Paper 4 (Covitt, Morrison Thomas, Lin, de los Santos & Anderson, 2020).

As presented in Paper 4 (Covitt et al., 2020), some *Carbon TIME* classrooms are succeeding in “1D doing school,” while others are able to go beyond “1D doing school” and are – in addition – engaging in rigorous and responsive instruction in which teachers are assessing and scaffolding students’ three-dimensional performances so that students experience productive disciplinary engagement.

We know that *Carbon TIME* teachers make a difference. Paper 3 (Lin, Frank, Anderson, Draney, Bathia, & Thomas, 2020) highlighted that teachers are the most important factor in explaining variance in *Carbon TIME* student learning gains – even more than students’ own prior knowledge (pretest scores) or school factors including percent free and reduced lunch (FRL) and percent marginalized students of color. Paper 4 (Covitt et al., 2020) provided evidence that teachers are doing different things in different classrooms; classroom discourse differs across classrooms and impacts student learning. We are interested in understanding not only *why* this is the case, but also how these observed differences in classroom discourse make sense given the classroom and organizational resources teachers perceive to be available.

In previous papers, we described classroom and organizational resources that appear to be affecting teachers’ classroom decisions and enactments (Anderson, de los Santos, Bodbyl Roels, Covitt, Edwards, Hancock, Lin, Morrison Thomas, Penuel & Welch, 2018). Building on this work, we consider resources at two levels. At the classroom level, we are paying attention to the teachers’ professional identities and orientations, as well as their practical knowledge and skills for using *Carbon TIME* in their classrooms. At the organizational level, we are focusing on qualities of teachers’ professional communities (including norms and obligations) and teachers’ perceptions of available material, human, and social resources. We expand on this list in the theoretical framework that follows.

Theoretical Framework

Our theoretical framework includes five attributes that we hypothesize affect teachers’ enactment of *Carbon TIME* in their classrooms and, consequently, their students’ learning gains as measured by *Carbon TIME* assessments. These attributes are organized at two levels. *Classroom-level resources* include teachers’ practical knowledge of what and how to teach *Carbon TIME*; teachers’ beliefs about students’ motivation toward mastery; and teachers’ stories

of themselves and their growth as educators. *Organizational-level resources* include obligations and norms of teachers' school professional communities and the material, human, and social resources of the teachers' departments, schools, and districts.

Classroom Resources

Classroom-level resources include the teachers themselves and the orientations, skills, and knowledge they possess, as well as their perceptions of the resources their students bring with them. We consider their practical knowledge (the understanding they develop from experiences in their classrooms), their orientation toward three-dimensional learning goals and their perceptions of their students' motivation toward these goals (which we've called "motivation toward mastery"), as well as their professional identities. Professional identity includes their story, as teachers describe "who I am" and "how I work" to us, the interviewers (Sfard & Prusak, 2005), as well as their orientation toward professional growth.

Practical Knowledge. Van Driel, Beijaard & Verloop (2001) describe teachers' practical knowledge as their "knowledge and beliefs about their own teaching practice, [which] is mainly the result of their teaching experience" (p. 138). In our interviews, we noticed examples of the experience-based understanding teachers are developing, since teachers' practical knowledge is one variable that affects teachers' classroom discourse.

From our project's perspective, the practical knowledge requisite for using *Carbon TIME* to scaffold and assess three-dimensional learning in rigorous and responsive ways involves teachers being able to elicit and use students' ideas and questions to move the class from the initial phenomenon to its model-based explanation. It involves being able to use *Carbon TIME* tools to scaffold productive disciplinary engagement (Engle & Conant, 2002), equitable development of students' science identities (Carlone, Haun-Frank & Webb, 2011), and curiosity-driven discourse (Johnson, 2017). It also includes supporting students in assessing and revising their engagement as questioners, investigators, and explainers. All the while, teachers must also tend to the management of classroom pragmatics – organizing and supporting groupwork, providing investigation materials, etc. – in ways that support equitable sense-making.

Motivation toward mastery. Teachers' practical knowledge includes their knowledge and beliefs, and teachers' beliefs may be particularly important because they can act as a filter through which new information is understood (van Driel et al., 2001). A key belief that we have focused on is their approach to what students find (our could find) motivating. We think of this as a tension that teachers perceive between maintaining students' motivation and interest and supporting students in mastering challenging learning goals.

Specifically, *Carbon TIME*'s learning goal is for students to engage in three-dimensional performances, such as constructing an explanation for how a novel animal uses food to move and grow. Some teachers describe mastery as a meaningful outcome for students: Accomplishing complex, three-dimensional performances is worthwhile and motivating. Other teachers describe students' motivation as being in opposition to mastery: Students are motivated by interesting and varied classroom science experiences, while mastering complex learning goals is not motivating. These different orientations are also encapsulated in Hess & Azuma's (1991) comparison of "Quick and Snappy" versus "Sticky-Probing" teachers, which was referenced in the Introduction to this Paper Set.

In this paper we investigate ways that teachers' orientations toward motivation and mastery affect how teachers make decisions about and make sense of classroom experiences, as well as how teachers frame classroom work and discourse. By framing, we mean the way the teacher's talk and actions establish particular priorities and goals for classroom work (Johnson,

2017; Tannen, 1993). This is relevant in relationship to *Carbon TIME* because such framing can guide students' engagement and act as scaffolding, therefore playing an important role in classroom discourse and related student performances (Johnson, 2017; Russ, Lee & Sherin, 2012).

Teacher's story. Another important set of beliefs that teachers (and others) hold are mindsets, or beliefs about human attributes including abilities and intelligences (Dweck, 2008). The term "growth mindset" represents an orientation toward intelligence and abilities as qualities that are not fixed, but instead changeable and improvable "through hard work, good strategies, and good mentoring" (Dweck, 2008, p. 10). Researchers are just beginning to apply these ideas specifically to educators, through constructs such as a "teacher mindset" – beliefs about the nature of one's teaching ability and its capacity to improve through experience and learning (Gero, 2013).

Variations of this orientation come across in the stories that teachers share during their interviews, while they discuss themselves as teachers and professionals. These stories are shared as teachers represent themselves – their professional identities – to us as interviewers (Sfard & Prusak, 2005), as well as in their descriptions of their own professional practice. Many teachers describe changes in their science teaching practice over time that represent movement toward supporting students in three-dimensional engagement with phenomena.

Professional Communities & Organizational Resources

Through our "three legs of the stool" approach – described in the Introduction to this Paper Set – teachers engaged in the *Carbon TIME* professional development course of study with others in the same *Carbon TIME* network. These networks were developed through research-practice partnerships between the *Carbon TIME* project and a particular local education association (LEA). One LEA was a large urban school district, while others included smaller school districts, a network of rural schools connected to a scientific research field station, and a statewide teachers' union. This network design was intentional, aiming to provide teachers with colleagues alongside whom they could learn and change.

Though we know these networks were valuable to individual teachers, and the research-practice partnerships they provided are a critical part of our DBIR approach (Anderson et al., 2018), we also recognize that teachers spend far more time in their local professional communities than in their *Carbon TIME* ones. These local settings – teachers' science departments, schools, and districts – are ones in which teachers need to make sense of and enact students' three-dimensional engagement around natural phenomena (de los Santos, 2017), and studies suggest that teachers' perception of incoherence among reform-oriented professional development and their local contexts can limit their shifts in practice (Allen & Penuel, 2015). Teachers' professional communities – as referenced in their interviews – primarily include the school- and district-based groups of peers and administrators with whom teachers interact. Often these communities include teachers' grade-level and/or course-level teams, science departments, and similar collegial groups.

Obligations and norms. We anticipate that the obligations and norms of teachers' local professional communities will shape teachers' perceptions of accountability, as well as their sense of support and/or conflict for teaching *Carbon TIME*. Teachers' obligations tend to be categorized broadly into components including teaching curriculum, engaging students, managing students, providing and interpreting assessments, and communicating with stakeholders (Danielson, 2014; Jackson, 1990; Kennedy, 2016). We additionally delineate these obligations as formal requirements or expectations to which teachers feel accountable: state

science standards, state and district teacher evaluation systems, common district or course assessments, and other areas of focus for the district or school, such as an International Baccalaureate® program. We interpret the less formal expectations as the norms of the teachers' communities of practice, including "normal" or expected ways of teaching, collaborating, and making decisions. These norms are quite relevant, as interactions with colleagues may exert normative pressure that impacts teacher's classroom instruction (Allen & Penuel, 2015).

Organizational resources. Classroom communities engaged in three-dimensional learning require material, human, and social resources (Gamoran, Anderson, Quiroz, Secada, Williams & Ashmann, 2003; Spillane, Diamond, Walker, Halverson, & Jita, 2001). Together, these organizational resources are consequential. Our own quantitative data – shared in Paper 3 – indicate that *Carbon TIME* classrooms in higher poverty schools (as measured by percent of free and reduced lunch (FRL)) tend to have lower learning gains. Previous studies show that this measure (% FRL) can serve as a proxy for organizational resources, including students' access to experienced teachers (Darling-Hammond, 2004) as well as the overall quality of conditions in which teachers work (Johnson, Kraft & Papay, 2012).

In science classrooms using *Carbon TIME* and other three-dimensional student engagement, *material resources* include laboratory space for investigations, equipment such as grow lights and digital scales, consumable materials such as seeds and mealworms, technology for online simulations and assessments, other curricular resources such as textbooks, as well as the money and time available to support teachers in professional learning experiences. (We note that other professional development endeavors may coordinate with or compete against *Carbon TIME* goals.)

Human resources refer to the "individual knowledge, skills, and expertise" of people (Spillane et al., 2001, p. 920) in our *Carbon TIME* teachers' professional communities. We extend this to include colleagues' and administrators' expectations of, visions for, or dispositions to teaching and learning.

Social resources broadly encompass relationships among individuals as well as larger organizational cultures (Cohen, Raudenbush & Ball, 2003) including specific affective aspects such as trust, openness, and collegiality (Johnson et al., 2012). We recognize that the material, human, and social resources available to our network teachers differ, and hypothesize that this influences their classroom enactment and students' success.

Research Questions

Together, these constructs are ones we hypothesize impact teachers' enactment of *Carbon TIME* in their classrooms (described in Paper 4, Covitt et al., 2020) and, consequently, their students' learning gains (described in Paper 3, Lin et al., 2020). We have investigated these ideas through the following three research questions:

1. How do teachers describe their classroom resources, including their understanding of their classroom work; their orientations and those of their students, and their professional identities?
2. How do teachers describe their professional communities, including the local school community's obligations, norms, and the material, human, and social resources?
3. How do teachers' descriptions of their classroom resources and professional communities relate to observed classroom discourse and student learning outcomes?

Methods

Case Study Teacher Selection

Our *Carbon TIME* project worked with seventeen Case Study Teachers, each of whom participated in one or more years of data collection including multiple classroom observations, student work samples, post-observation conversations, and recorded interviews. For Paper 4 (Covitt et al., 2020) and this Paper 5, we selected (Maxwell, 2013) five of these for cross-research-team analyses. All five of these teachers are White with ten or more years of teaching experience. As shown in Table 1, these Case Study Teachers' classrooms exhibited a range in observed student learning gains. Other criteria for selecting these five Case Study Teachers were their initial diverse patterns of classroom discourse (Covitt, Morrison Thomas, Bodbyl, Lin, Hancock, Kohn, de los Santos & Anderson, 2018) and differences in each school's percent of students with free and reduced lunch (FRL), which provided us with an expectation for differences across organizational obligations, norms, and resources (Anderson et al., 2018; Spillane et al., 2001).

The teacher comparisons presented in Table 1 supported a division of the five Case Study Teachers into higher and lower learning gains groups – the higher learning gains group includes Ms. Callahan, Ms. Eaton and Mr. Gilbert and the lower learning gains group includes Mr. Harris and Ms. Barton. Again, these divisions are reaffirmed in our newest value-added models, as shared in Paper 3 (Lin et al., 2020).

Teacher & School Year (alphabetical by pseudonym)	Learning Gains: Teacher Comparisons*	Grade Level	School % FRL	Initial patterns of classroom discourse and engagement**
Barton (15-16)	27/27	MS	23%	Ss responses are elicited; T & Ss develop a collection of ideas w/out consensus
Callahan (16-17)	7/78	HS	1%	Ss' ideas & reasoning are elicited; T makes 3D sense, Ss learn about 3D science
Eaton (16-17)	8/78	MS	13%	Intellectually responsive to Ss' ideas & reasoning; T & Ss make 3D sense together
Gilbert (16-17)	10/78	HS	56%	Ss' ideas & reasoning are elicited; T tells & Ss learn about science facts
Harris (15-16)	24/27	HS	15%	(not included in initial discourse review)
*Teacher comparisons (using raw student learning gains) are out of 27 teachers in 2015-16 and out of 78 teachers in 2016-17.				
**(Covitt et al., 2018)				

Data Collection

Paper 5 relies primarily on Network Teacher Interviews conducted in the spring and summer of 2018, reaching 68 of 131 currently involved *Carbon TIME* teachers. These teachers were either finishing their first or second year of network participation or were completing a third (post-network) year of *Carbon TIME* data collection. The majority of these teachers are in schools and districts in three states (Colorado, Michigan, and Washington), though teachers in one online network are located across the country. However, for Ms. Barton and Mr. Harris, this paper shares analyses of their final post-Case Study Teacher interview (collected in the school

year after their Case Study Teacher participation). Since they were not participating in post-network data collection in the spring of 2018, they did not participate in Network Teacher Interviews.

Network teachers were initially notified that interview opportunities would be available during the face-to-face *Carbon TIME* professional development workshops in early 2018. Later, teachers received email invitations to participate from their *Carbon TIME* Network Leader. Finally, interviewers contacted interested teachers to establish connection times. Interviews were voluntary and a small gift card was provided to compensate teachers for their time.

Interviews lasted approximately 30 minutes and were conducted and recorded via a virtual meeting platform. The interview questions (Appendix A) asked each teacher about his/her vision for science teaching and learning, *Carbon TIME*'s role in meeting that vision, the teacher's perception of his/her students' interactions with *Carbon TIME*, and how the teacher perceives *Carbon TIME* fitting (or not fitting) into various aspects of the local context. The semi-structured protocol (Bartlett & Vavrus, 2017) included suggested probes for each question, affording consistency across the otherwise flexible interview conversations. Interviews were conducted by seven *Carbon TIME* project staff, with project meetings providing opportunities to discuss interview experiences and clarify the interview protocol.

Data Analysis

Carbon TIME Network Teacher Interviews were uploaded to a web-based platform for qualitative data analysis. Interviews were chunked into episodes and coded using a coding framework (Appendix B) developed from prior research (Anderson et al., 2018) and our theoretical framework. Codes were evaluated (Appendix C) based on the strength or intensity of the attribute, as well as its alignment with *Carbon TIME* goals for students' three-dimensional engagement around natural phenomena. We used a multiplicative approach, similar to that used in psychology's expectancy-value theory (Eccles, Adler, Futterman, Goff, Kaczala, Meece, & Midgley, 1983). This means that placing the teacher's statement on the lower end of the continuum reflects that either there was a low strength/intensity or a lack of alignment with *Carbon TIME* goals for the particular attribute, while a response placed at the high end of the continuum reflects both reasonably high strength or intensity of the response as well as reasonably high alignment with *Carbon TIME* goals.

Finally, the five focus teachers were sequentially organized (ranked) along a spectrum for each of our coding attributes. This organization was initially made by comparing the ratio of low-to-high evaluations for each episode coded with a particular attribute. The visual representation of this organization is shown in Figure 1 and is described holistically throughout the Findings section. Overall, we think of this spectrum as lower-to-higher support for students' three-dimensional engagement (as shown in the arrow along the top of Figure 1).

← lower support for students' 3D engagement		→ higher support for students' 3D engagement		
Motivation toward Mastery				
Barton	Harris	Gilbert	Eaton	Callahan
Practical Knowledge				
Barton	Harris	Eaton	Callahan	Gilbert
Teacher's Story				
Barton	Harris	Gilbert	Eaton	Callahan
Obligations & Norms				
Harris	Barton	Callahan	Gilbert	Eaton
Organizational Resources				
Harris	Barton	Eaton	Callahan	Gilbert
lower learning gains classrooms		higher learning gains classrooms		

Figure 1: Comparing teachers across five coding variables

Findings

The following findings are presented as descriptions of the professional identities, classroom resources, and organizational resources for each of our five Case Study Teachers, starting with our most successful classroom (Ms. Callahan's) – as measured by student learning gains – and proceeding in order to our least successful classroom (Ms. Barton's). In this way, we address research questions 1 and 2 in a holistic, narrative fashion.

1: *How do teachers describe their classroom resources, including their understanding of their classroom work; their orientations and those of their students, and their professional identities?*, and

2: *How do teachers describe their professional communities, including the local school community's obligations, norms, and the material, human, and social resources?*

Though part of our work is normative – we're making comparisons between classroom teacher's descriptions and *Carbon TIME*'s three-dimensional goals – we also want to recognize that all of these teachers are making reasonable choices within their context and constraints. Even our teachers in low learning gains classrooms share beliefs and practices that we interpret as sincere attempts to do their work with limited resources.

MS. CALLAHAN coaches conventionally correct, three-dimensional performances while encouraging her students' personal interest and collective sense-making.

As described in Paper 4 (Covitt et al., 2020), Ms. Callahan's High School Biology classroom uses *Carbon TIME* materials in ways that fully support students' three-dimensional engagement with natural phenomena. Ms. Callahan regularly and continuously scaffolds and assesses students' three-dimensional engagement, including their construction of model-based explanations, in ways that support many of her students in achieving Level 4 mastery (as demonstrated in Paper 3, Lin et al., 2020).

Ms. Callahan clearly describes her development and growth as a teacher as one in which her professional changes align with using *Carbon TIME* to support students' three-dimensional engagement around natural phenomena. Ms. Callahan, for example, shared her perspective that she's, "getting better at being less of a sage, and more of a listener ... and hopefully I'll continue

to grow with that in all my years of teaching.” Ms. Callahan further reveals, “I taught biology for a long time ... and I really thought I was doing things right. I know I had ... fantastic notes. ... students were ... doing fantastic on tests ... going to really prestigious schools ... Good things were happening, but along the way what I realized was that the students weren’t making it theirs.” Ms. Callahan now has a focus on *figuring out* natural phenomena such as “how things grow” that she says has “happen[ed] through *Carbon TIME* [and] is something that I didn’t teach before.” She continues, “I always taught units on photosynthesis and respiration, but never really put it at much past ‘then let’s understand electron transport chain’” so “getting them thinking about the fact that this living world is made up of matter and energy transformations ... is something I never consciously thought about doing” before *Carbon TIME*.

Ms. Callahan describes her vision for her science classroom as having students “exploring, understanding, and really questioning this world around them.” She indicates, “I’ve always been fascinated myself by ... how does that happen? Is this magical? ... understanding ... science ... is so valuable to me and I want to be able to share ... that with my students and ... help them develop their own curiosity.” Ms. Callahan’s classroom discourse aligns with this vision: Ms. Callahan consistently acknowledges and elevates her students’ questions and ideas while also supporting them in developing more sophisticated understanding and mastery of three-dimensional performances.

Ms. Callahan’s interview responses show a consistent orientation toward mastery: She is personally motivated to deeply understand science phenomena, she believes her students can be similarly motivated – even when progress toward mastery is effortful – and she describes changes in her teaching practice that suggest she continues to strive toward improvement. Throughout this, Ms. Callahan sees *Carbon TIME* as an important resource, one that “certainly allows the students the chance to explore pretty authentically, to develop their own explanations, to dive into the material and really find the answers to questions that they care about, and I think that that’s really important.”

Ms. Callahan’s classroom resources. Ms. Callahan’s vision for her science classroom is supported by her belief that her students are themselves motivated toward three-dimensional engagement with natural phenomena and related mastery. She describes how “the investment/engagement that the students have [is] pretty authentic, and I really enjoy seeing it happen.” She provides examples of this authenticity: “It’s [the students] saying, ‘I want to see what happened to my radish this morning because I care about it’” and the students are “asking, ‘Why is the root coming? Why is the radish here? Why are my leaves not as big as Johnny’s?’” In these quotes, we see how Ms. Callahan describes aspects of students’ three-dimensional performances – for example, their engagement in roles as authentic questioners, investigators, and (eventually) explainers. She is unique among our focus teachers in how she describes this multi-dimensional and role-oriented mastery. We should also note that Ms. Callahan’s classroom is unique in regard to the resources that students bring with them into their Biology course: Ms. Callahan’s students have the highest pretest scores and are attending a public magnet school focused on science and math.

While Ms. Callahan certainly leverages her students’ personal curiosity, she also believes her students value their individual and collective efforts toward mastery. For example, she discusses how her students assess their progress and re-writing efforts on *Carbon TIME* Explanations Tool, which has a graphic organizer on the front and a space for writing a model-based explanation on the back. She notes that the repeated practice is “so healthy for [students], it’s so good for them, and they know, too ... so they see the reward in it.” Ms. Callahan

simultaneously recognizes the challenge for students in working toward mastery: “I do think it gets a little tiresome after a while because it is a lot of writing. It’s a lot of their work, they have to put the energy in and sometimes that’s hard to find in a 14-year-old brain.” Humorously, she describes her students working on multiple Explanations Tools, “especially ... the *Plants* unit, [students] have an Explanations Tool ... for photosynthesis, an Explanations Tool for cellular respiration, and one for biosynthesis, so they just know the back of that page they have to write paragraphs explaining these processes, and the looks that they give me [laughter]; it’s kind of sweet torture.” In these examples, we see Ms. Callahan discussing her support for students who are working toward mastery, even when that work is “hard,” and we see her and her students’ commitment to conventionally correct writing performances, something *Carbon TIME* adds as an indicator of successful classroom discourse.

Ms. Callahan’s descriptions of using *Carbon TIME* align with project goals for assessing and scaffolding students’ three-dimensional performances; in other words, she is developing practical knowledge that supports *Carbon TIME* performance goals. On the one hand, much of Ms. Callahan’s interview discussions center around students’ ideas and questions – aspects of classroom science engagement supported in the reform literature. For example, Ms. Callahan says, “I really want [students] to be asking the questions. I really want to have discussions that are based on their needs.” And, her comments suggest that her classroom actualizes her goals, as when she shares that – during the *Plants* unit – students “come into my room for about six weeks straight checking on their radishes.” Then the students ask questions that extend their thinking and learning, including, “Where does bark come from on a tree?” and, says Ms. Callahan, “we can follow those paths” so that “each class is able to have that authentic discussion.”

In this way, Ms. Callahan’s elicitation of students’ ideas and questions (assessment) is used to drive classroom discourse and unit progress (scaffolding). Ms. Callahan describes each class as “a really dependent community of learners, and so *Carbon TIME* just really helps to create that climate” as “we have a lot of dialogue and data analysis together.” In her classroom video, we see Ms. Callahan and her students working to these ends – connecting their talk and writing in mutually supportive ways. We hear students sharing their ideas with each other and we also hear them asking each other clarifying questions, making suggestions, or pointing out ways in which one student’s response may be inaccurate or incomplete.

On the other hand, we also hear Ms. Callahan describe her active role in assessing and scaffolding individual student assignments, coaching her students toward conventionally correct performances: “I look at their Explanations Tools with a pretty critical eye because [I’m] giving them feedback in how to improve.” Here, we understand that Ms. Callahan’s feedback scaffolds individual students as they develop their explanation-writing practice. We also recognize that looking at student writing with “a pretty critical eye” is time-consuming, showing Ms. Callahan’s commitment and capacity to support her students in this three-dimensional performance.

Ms. Callahan’s professional community and organizational resources. Ms. Callahan describes approval and support from her school and district professional communities for using *Carbon TIME*, largely through perceived alignment among *Carbon TIME* goals and local norms and obligations. For example, Ms. Callahan describes how “[a district administrator] wants to look at how can biology tie more directly into chemistry, and into physics, and how can chemistry tie more into biology and physics, because he wants [to] find a better way of transitioning students between ideas and courses and not isolating ourselves, because science is no longer really in just one field? And so ... this *Carbon TIME* stuff is really fantastic for him

because it's about themes and ideas and big processes." Here, we see that Ms. Callahan – and her administrator – view *Carbon TIME* as a tool for meeting other science-related district goals.

Additionally, local norms for teacher autonomy around curricula-selection support her use of *Carbon TIME*. Ms. Callahan describes how she (and other science teachers in her building) have “total autonomy over our courses and what we teach and when we teach it ... we have the autonomy to be able to just do what we think is best for the students.” Further, Ms. Callahan describes a lack of formal obligations, due in part to being “the only biology teacher, so I don't have to worry as much about having standardized testing and overlapping, [or finding] common ground” with another colleague.

Though it's clear that these qualities of Ms. Callahan's professional communities do not provide barriers toward her using *Carbon TIME*, we also see that they do not provide avenues for connecting her professional community with her classroom community – they do not “cross the classroom door.” Specifically – and interestingly – there is another, experienced *Carbon TIME* network teacher in Ms. Callahan's building. This teacher is a unique human resource in the sense that she has specific skills and capacities around *Carbon TIME*; she teaches some *Carbon TIME* units in the AP Environmental Science class and has been involved with *Carbon TIME* for at least a decade. As Ms. Callahan describes, “she's so familiar with the first three units because she taught them for so long, she's one of the pilot teachers with the program ... my first year I asked her if she could help me make BTB ... it's a really functional [relationship] and ... [I] know where to find her” if help is needed.

But Ms. Callahan also expresses how this teacher “doesn't really care what I do in my [class]room.” Though Ms. Callahan acknowledges that the other teacher “gives me total control over what's happening” so “I rule the ninth graders, and she rules with the [AP students],” she also indicates that she would enjoy talking more with this colleague about students' sense-making and “initial explanations.” She notes that she and her colleague “don't get into the nitty gritty of the units *per se*, what's working and not working, or talking about ... changes.” Ms. Callahan misses the “reflection piece and [the] collaboration” from her participation in the *Carbon TIME* network and says, “I would like to have [that].”

Again, Ms. Callahan's descriptions highlight valuable human resources (her district administrator and her *Carbon TIME* network teacher colleague) that are sources of support and expertise. Additionally, her conversation suggests affective ties (social resources) such as cohesiveness and trust. And the norms and obligations of Ms. Callahan's professional community align with her using *Carbon TIME*. Though all of this provides an environment of passive support for Ms. Callahan – one without obstacles – Ms. Callahan wants a professional community that connects to her classroom community, providing opportunities to “talk about my teaching” and opportunities to “take the time to reflect, ‘How [did] I really [do]? ... How does that really help my students?’”

MS. EATON scaffolds her students' three-dimensional performances in ways that support them in writing conventionally correct explanations.

As outlined in Paper 4 (Covitt et al., 2020), Ms. Eaton's middle school science classroom uses *Carbon TIME* materials in highly scaffolded ways that support her students' three-dimensional engagement with natural phenomena. As seventh graders, her students have less classroom science experience than many of our other case study classrooms and – as shown in Paper 3 (Lin et al., 2020) – lower initial pretest scores. However, with Ms. Eaton's significant

efforts to guide her students toward conventionally correct writing work, her students emerge with some of the highest learning gains in any *Carbon TIME* classroom.

Like Ms. Callahan, Ms. Eaton describes her own professional growth as an educator in ways that align with using *Carbon TIME* to support students' three-dimensional engagement with natural phenomena. One component of this is her own recognition for how the units are a "completely different way of looking at the human body system and ... plants." Ms. Eaton notices how her classes "used to talked about, you know, food goes in. You get energy. ... it was all about the physical process," while *Carbon TIME* is "definitely more ... chemistry-based than it is physiology-based." This difference, evident in *Carbon TIME*'s focus on tracing matter and energy through systems, "was, like, holy cow, you know, a whole 'nother way of looking at the world!" Ms. Eaton reflects, "I don't think I understood it at the beginning," sharing how "the first unit [was] super hard for me." However, Ms. Eaton recognizes her professional growth, saying, "I'm getting better ... it's important that people grow with their jobs." Ms. Eaton believes *Carbon TIME* "really is a better" approach for her students because "it gives them a much deeper understanding," adding, "even for me" as she notes, "it's been a long time since I took a chemistry class (laughter)."

Ms. Eaton's "vision for teaching and learning in my classroom is for students to ... make sense of what's happening around them" including "part[s] of their everyday life." She continues, students have "seen a plant grow ... they eat food all the time," but through *Carbon TIME* they "realize how much is actually happening that they don't really know ... [like,]... they had no idea what was happening inside their body when they were eating food." Ms. Eaton believes that "*Carbon TIME* really helps them make sense of the world around them," explaining how "we can really make sense of it, you know and they can get a deeper understanding, but not just because I'm telling them but because they're investigating it and ... they're having that aha moment of 'oh, my gosh!'"

Ms. Eaton's interview responses show a consistent orientation toward making sense of natural phenomena by tracing matter and energy through systems, both for herself and for her students. She is committed to scaffolding her students' mastery of *Carbon TIME*'s three-dimensional performances and their making sense of complex natural phenomena – such as growth of living things – even though her students, as middle schoolers, bring fewer school and canonical science resources with them into the classroom. Her high expectations and efforts to support her students are successful; her students show significant learning gains and their written explanations are some of the most detailed across our case study classrooms.

Ms. Eaton's classroom resources. Ms. Eaton recognizes that her vision for her science classroom as a place where her students "really make sense of" complex natural phenomena and master three-dimensional performances is significant and challenging for her students. She believes that her students are capable and willing to engage in efforts toward mastery, and she supports them by using *Carbon TIME* Tools as scaffolds. In addition, Ms. Eaton develops supplemental scaffolding. For example, she created "a list of 20 questions ... put together with very clear expectations" to support her students in constructing model-based explanations. We see Ms. Eaton's orientation toward three-dimensional goal performances for her students and her decision to structure their engagement in ways that support them in meeting such challenging learning goals. She says, "it's a little formatted in my class, but they are seventh graders and I think that's appropriate. I think it's an appropriate scaffold for them so that when they get to high school, they have that background information to help them be better scientific writers."

Further, though Ms. Eaton realizes that students sometimes grumble about the work that's involved in using the scaffolds, she believes that students recognize their value in supporting their mastery of challenging performances. She explains, "yes, [students] complain about [the Explanations Tools], but then at the same time when I say to them, 'You know, this is a graphic organizer that's going to help you, right? This is your resource for writing up your conclusion,' and then they're like, 'Oh, oh, yeah, I knew that.' I said, 'If you don't want to do it, you don't have to,' and then they're like, 'Oh, wait. No, I want to be, I know I need this,' you know. So, they get the connection."

Ms. Eaton understands that using *Carbon TIME* to reach three-dimensional performances "challenges [students] and that's hard for them," yet she does not accommodate them by reducing expectations. Instead, she believes, "they just – they're seventh graders. They don't [laughter] always want to work. So, they're like, 'Oh, I just don't want to do this again'."

Ms. Eaton identifies herself as "a big fan of kids writing in science," and focuses most of her interview discussing the cognitive apprenticeship involved in supporting her students' construction of explanations that trace matter and energy across scales, which – as we note in the Introduction's Table 2 (Anderson, 2020) – is something that *Carbon TIME* adds to an organizing framework for classroom practices. She shares how her students "can explain to me that matter does not turn into energy and yet, at the same time, they will tell me that food, you know, is your energy and that we use food for energy." In this comment, Ms. Eaton is assessing her students' understanding, and she goes on to share how she finds *Carbon TIME* to be "very scaffolded to help ... [students move] from where they are [to] get to where they need to be." Specifically, she describes how "the questions on the Explanations [Tools] don't change. 'How are the molecules moving? ... Where is the energy going to start? Where is the energy going to go?' I mean, the questions don't change. It's [students'] understanding that changes. ... I think it gets easier for them ... [and] it really helps them be better scientific thinkers."

Ms. Eaton also describes her role as a teacher in scaffolding students' thinking and progress: "I definitely scaffolded the Explanations Tool to ... [help students] write paragraphs ... [with] very clear expectations that they'll restate the question and ... explain ... what's happening because I just feel like ... kids struggle ... in science [to get] their ideas down." Further, as Ms. Eaton describes how "I always have to push them to explain," she also brings in ideas about how the classroom community can support students, "We talk a lot about it's super important to say what you're thinking, so that not only can I identify it, you [can] identify, and your neighbor [can] identify what you're saying." And, she connects this to students' self-assessment, "You consciously go, 'Oh, well, this is what I thought. This is what I now think,' and we spend a lot of time doing that. Like, 'What did you think was happening before? What do you know is happening now?' And so, just being really conscious about changing your mind." Ms. Eaton describes how she has students across the learning progression: "I've got the kid in the back of the room who's like, 'Uh-huh, uh-huh, I got this' ... but then there's the other kid who just has no idea and ... helping them get ... to the point where everybody is like, 'Yeah, we got this. We understand this,'" is something *Carbon TIME* provides.

This final comment, "Yeah, we got this. We understand this," highlights Ms. Eaton's commitment to a classroom community that *figures out* natural phenomena together alongside a commitment to truly helping all students reach rigorous learning goals. Overall, we see Ms. Eaton as a teacher who notices students' ideas and performances and responds to these through feedback or instructional decisions that scaffold all students toward more sophisticated performances. Her assessing and scaffolding occur within classroom communities in which

students are regularly sharing ideas with each other and assessing their own personal progress. Ms. Eaton recognizes that this work is labor intensive: “One of the things about *Carbon TIME* that I like and don’t like, all at the same time, is that the teacher is on 24/7. I mean you truly are on from the second I walk in the door to the second I leave.”

Ms. Eaton’s professional community and organizational resources. As with Ms. Callahan, Ms. Eaton describes approval and support from her school and district professional communities for using *Carbon TIME*, largely through perceived alignment among *Carbon TIME* goals and local norms and obligations. For example, the formal distribution of science content to specific grade levels in Ms. Eaton’s district coordinate with *Carbon TIME* learning goals. On this topic, Ms. Eaton says, *Carbon TIME* “line[s] up almost perfectly with my curriculum. I meet all of the standards without any trouble.” She perceives that her colleagues share her positivity, describing how “teachers at my school love *Carbon TIME* because it builds on ... sixth-grade physical science and helps prep the kids for eighth grade. So, my eighth-grade teacher is loving it and he feels like the kids are coming up so prepared for earth science.”

Further, Ms. Eaton feels supported by a district science administrator who “recommended *Carbon TIME* to me because she had already vetted it and she knew that it was going to work.” Ms. Eaton has found this administrator to be “really encouraging” around the use of *Carbon TIME* and Ms. Eaton expresses a perception that the district “really want[s] more teachers to do this type of program because they really feel like we’re not getting the resources [within the district] that we need to do good science.” Interestingly, we could look at this as a lack of material resources; Ms. Eaton admits that “our textbooks are from 2009. So, you know, it’s been a long time,” but she feels that “finding new ways to meet standards is super important and I think *Carbon TIME* is a perfect way to do that.” For Ms. Eaton, though the local context is not investing financially in science curriculum, this is not necessarily problematic because her perspective is that *Carbon TIME* is available to provide the support she needs.

Again – like Ms. Callahan – local norms for teacher autonomy around curricula selection, combined with being the sole teacher for her grade-level, lend great support to Ms. Eaton’s use of *Carbon TIME*. Ms. Eaton says, “I think it made it easier for me to choose to do [*Carbon TIME*] because I didn’t – I wasn’t dependent on anyone else.”

Ms. Eaton also has access to valuable human and social resources that support her use of *Carbon TIME* in meeting complex three-dimensional learning goals for students. From her perspective, “the most important thing ... is probably collaboration, having a team of teachers you can work with.” She goes on to explain how teachers need to hear “that they’re going through the same thing and ... you’re not alone, you know, and that the feelings you’re having about the curriculum are not new and that people have gotten, you know, strategies for how to get through it or how to do things.”

These human and social resources are being provided partly through Ms. Eaton’s local context (with her previously described colleagues who are big fans of *Carbon TIME*), as well as through her network of *Carbon TIME* connections, including her Case Study Coach and fellow network teachers. Ms. Eaton had a particularly close professional relationship with her *Carbon TIME* Case Study Coach, with the Coach spending more than the typical three lessons-per-unit in her classroom. Ms. Eaton says, “it’s easy to walk away when it gets hard and that’s the problem is that people may not be able to stick it out and if you want people to stick it out, you have to you know, tell them that there is, you know, light at the end of the tunnel. You know keep going. It’s going to be fine.”

MR. GILBERT helps students use science in the English language for personal sense-making and supports their classroom participation through teacher-mediated talk and writing.

As shared in Paper 4 (Covitt et al., 2020), Mr. Gilbert's classroom includes a large proportion of English language learners. His students engage with *Carbon TIME* materials in ways that support students' exposure to and use of science words in the English language. Mr. Gilbert mediates the classroom's talk and writing; he elicits small inputs from his students, then re-voices and expands on their language. Mr. Gilbert prioritizes personal relationships that support his students' acquisition and use of a new science language without inducing too much anxiety. He and his students enjoy a relaxed atmosphere that includes listening to music, joking, and engaging in relationship-building activities that foster community and comfort. Mr. Gilbert makes adjustments that modify target performances for students – particularly around writing – in ways that make the targets less difficult.

Mr. Gilbert discusses a vision for his science classroom that is aligned with an *NGSS, figuring out* approach: “We are looking more closely at specific phenomena and then working those out, from the phenomen[on] to the questioning to the guesses at what they think happened, and then spending the [unit] to solve the issues that we have.” Further, Mr. Gilbert recognizes a current shift toward “teaching huge scientific concepts” that is different from his previous work as a science classroom teacher. Like Ms. Callahan and Ms. Eaton, Mr. Gilbert links changes in his teaching practice to *Carbon TIME*: “It's really lent itself to teaching in a way that I wanted to teach for a long time but didn't know how.”

Mr. Gilbert also shares how he's become better at using *Carbon TIME* materials in his classroom. Now that he's taught the units for more than one year (this interview was at the end of the year following his Case Study Teacher data collection), he knows “where the kids are going to stumble, where they're going to have struggles, where [I'm] going to have struggles, things that could happen that could slow [me] up or make things not go as well and you already know how you're going to deal with those.” However, unlike Ms. Callahan and Ms. Eaton, Mr. Gilbert does not specifically discuss aspects of his professional growth that are oriented toward using *Carbon TIME* for fully three-dimensional goals. Nor does he elevate *Carbon TIME*'s approach to making sense of natural phenomena by tracing matter and energy through systems, an aspect of the curricula that both Ms. Callahan and Ms. Eaton highlighted.

Clearly, Mr. Gilbert's classroom discourse supports goals for environmental science literacy because he works to scaffold students' safe personal expression of ideas, even when this is difficult for his students because – as emergent bi/multilingual students – expressing their ideas in English is challenging. Mr. Gilbert makes intentional instructional decisions to bridge this gap, using additional scaffolding and teacher-mediation to help his students access and share their initial ideas. Yet, Mr. Gilbert's adjustments modify performance goals to be less complex and detailed than the highest-level performances in *Carbon TIME* units. Instead, supporting students to feel safe – so that they can share and develop their science ideas in English – seems to be Mr. Gilbert's primary classroom goal.

Mr. Gilbert's classroom resources. Mr. Gilbert's students include English Language Learners, students new to U.S. High Schools, and students who previously did not pass ninth grade Biology, so they bring with them fewer traditionally school-recognized resources than students in other *Carbon TIME* Case Study Classrooms. This is noticeable in their pretest scores, which are lower than Ms. Eaton's or Ms. Barton's middle school students.

Mr. Gilbert recognizes that his students “look at [the] class as being very difficult,” due in part to the fact that most of them are “trying to put together their thoughts into coherent sentences in English when it’s not their first language.” Mr. Gilbert also recognizes that his students’ difficulties relate to the more substantial *Carbon TIME* learning goals. He says, for example, that *Carbon TIME* is “something that’s different than a lot of classes that they’ve been taught, particularly in science ... they’re used to the multiple-choice regurgitation of information.” Mr. Gilbert recognizes that his students “learn more and have a better understanding of science at the end of it,” even though the students “probably have gone down a letter grade due to *Carbon TIME*.” Despite these challenges, Mr. Gilbert believes that his students “leave ... my classroom with a much better idea of how the earth works and the big picture” than before he was using *Carbon TIME*.

Like Ms. Callahan and Ms. Eaton, Mr. Gilbert’s orientation recognizes the value of students developing a “better understanding of science” through their use of *Carbon TIME* materials. Similarly, he also recognizes that making progress toward these learning goals requires effort on the part of his students. Mr. Gilbert indicates they “get a little worn out with the repetition” embedded in the units, though he says, “I believe the repetition is probably the most important thing for them.” So, Mr. Gilbert recognizes that learning goals with *Carbon TIME* are more complex than traditional science learning goals and that progress requires effort from his students and scaffolding and repetition from him. He even advocates for the use of three-dimensional assessment items: “I would tell teachers who are still teaching to tests that are multiple choice at the end of a unit, ‘Try [*Carbon TIME* assessments] and see how much more you think your kids get out of it.’”

Mr. Gilbert views *Carbon TIME* as a toolkit – “a great, strong curriculum with all of the tools and lessons put in place so that you can just follow along” – and feels that, as the teacher, he is “able to present ... lesson[s] with expertise, adding to it ... what I need to add in order to establish background knowledge for my EL students.” This idea about background knowledge is one that Mr. Gilbert discusses repeatedly. Related to the *Carbon TIME Ecosystems* unit, for example, Mr. Gilbert talks about taking “ten minutes out of your class and say, ‘This is a fox. This is what it does. This is a rabbit. This is what it does.’” He says, “you have to build a little bit of background knowledge and ... we have to call upon shared experiences.”

In these ways, Mr. Gilbert provides additional scaffolding that bridges his students’ backgrounds and experiences with the *Carbon TIME* units and upcoming classroom expectations, fostering his students’ capacity to share their personal ideas. Mr. Gilbert uses his language and leadership to mediate his students’ talk and writing, building on these through investigations and experiences. Mr. Gilbert recognizes how his students “get involved with the investigations” and “like to see something happening in front of them.”

One of the unique qualities of Mr. Gilbert is how he prioritizes developing relationships with and among his students: “We are constantly working on those relationships.” Mr. Gilbert explains, “with *Carbon TIME* and other *NGSS* curricula ... you need that relationship because there’s going to be a lot of open dialogue. And [students are] not going to openly speak ... unless they have a relationship with you or they feel comfortable.” He also relates how “there’s a million other things going on besides just that ... lesson presentation piece,” suggesting a sensitivity to the day-to-day experiences and lives of his students. He wants his students to recognize that “all answers are good answers and that they are valued.” Though we also note (as shared in Paper 4, Covitt et al., 2020) that there are times in the unit when Mr. Gilbert emphasizes canonically correct ideas and answers.

Mr. Gilbert describes his students as motivated to engage in the classroom when they find the content relevant to their lives and when they can have fun. Mr. Gilbert says, “They just have to see value in what I’m telling them. ‘So, how does this help me? When am I going to use this? What does it have to do with anything in my life?’” Mr. Gilbert feels that he is always able to make these kinds of connections in his Biology class. We also see this idea in his description of how his students “look at my class as being very difficult, but I think we have enough fun and we present it in a way that is meaningful enough to them that they are okay with it.” In these descriptions, Mr. Gilbert prioritizes an intrinsic value on learning (“meaningfulness”) as motivation for his students. This aligns with a *Carbon TIME* goal for environmental science literacy, though it is not the same goal as mastery of conventionally correct material, which Ms. Callahan and Ms. Eaton represent.

Mr. Gilbert seems primarily oriented toward a form of responsiveness that provides support and concern for his students – yet does not hold them accountable for the most complex individual performances, such as writing paragraph-length explanations of carbon-transforming processes. It is also worth noting that – unlike Ms. Callahan who talked about giving a “critical eye” to students’ explanations and Ms. Eaton, who said that “the teacher is on 24/7” – Mr. Gilbert suggests that he “can read a lesson in the morning ... and be able to present that lesson with expertise.” He says, *Carbon TIME* is “kind of dummy-proof. Now, you be the good teacher who ... facilitates the information in a way that is great for kids.”

Mr. Gilbert’s professional community and organizational resources. Similar to Ms. Callahan and Ms. Eaton, Mr. Gilbert describes perceived support from his professional communities for using *Carbon TIME*. Mr. Gilbert describes his district obligations in ways that align with the use of *Carbon TIME* in his classroom, focusing especially on the new *Next Generation Science Standards*. Mr. Gilbert describes this obligation partly through a comment about his administrators: “As far as administrators go, our[s] aren’t terribly strong in curriculum. So, they look at [*Carbon TIME*] and go, ‘Well, are we meeting the standards?’ Yes. ‘Okay, well, great, have fun.’” He also describes how, as he works with his colleagues to try “to figure out what we’re going to do to implement *NGSS* with some sort of fidelity,” he feels that *Carbon TIME* has provided the “backbone of a great, strong curriculum with all of the tools and lessons put it in place so that you can just follow along and ... it’s coherent for the kids and everybody is on the same page.” In these ways, Mr. Gilbert’s perception of his local obligations is in alignment with his use of *Carbon TIME* in his classroom.

Mr. Gilbert has colleagues teaching his course and grade with him and describes a sense of (group) autonomy or authority over his use of *Carbon TIME*. Mr. Gilbert describes how “we are kind of figuring out how *Carbon TIME* fits into [our school’s *NGSS*-implementation] right now.” He also explains how “the freshman campus [teachers], I can tell you, were very skeptical going into [this] year [piloting *Carbon TIME*] ... and then by the end of it, they really liked it.” Mr. Gilbert also shared how teachers are “trying out some different types of curriculum in order to be better informed when we’re trying to make our change.” These quotes – combined with his earlier description of administrators looking to teachers to evaluate whether or not science standards are being appropriately addressed through curricula – suggest a local context in which teachers are recognized with the expertise and authority to make their own standards- and curriculum-related decisions. These norms can support *Carbon TIME* being used toward students’ engagement with natural phenomena.

Considering teachers’ human and social resources, we see that the expertise and support teachers find from their colleagues is important in their perception of how *Carbon TIME* works

in the local context. Mr. Gilbert recognized this: “There’s three of us that have been around [*Carbon TIME*] for at least two years and then the rest of our freshman campus has done it for a year now and of course, one of the people at our freshman campus is [a *Carbon TIME* researcher, curriculum writer, and Case Study Coach now working full-time in the classroom]. So, you know, we are deep into the idea and we have great people to teach it and also to teach the teachers.”

Mr. Gilbert speaks of a specific colleague who is also a network teacher in his building. She “and I have been able to take a look at ... how [*Carbon TIME*] works with special populations. So, we are [English Language Learners] and special education and I would say that it’s excellent for both of those groups.” For Mr. Gilbert, his colleague has skills and expertise in teaching and thinking about specific populations of students, like those in the special education program, and in modifying *Carbon TIME* to meet the students’ needs. There’s also a cohesiveness with this colleague; they work together to explore how *Carbon TIME* meets the needs of their student populations, and we can infer that Mr. Gilbert trusts and appreciates this teacher.

MR. HARRIS prioritizes traditional science investigations and procedures while also recognizing problems with these one-dimensional approaches to “doing school.”

As shared in Paper 4 (Covitt et al., 2020), in Mr. Harris’ classroom, students engage with *Carbon TIME* Tools and related discussions in ways that allow students to identify and share initial ideas with each other and support them in completing investigations and assignments. Still, Tool use in Mr. Harris’ classroom does not support sustained sensemaking or reaching consensus around three-dimensional performances.

Like other Case Study teachers, Mr. Harris recognizes how “[using *Carbon TIME*] went better” during his second year (the year after our project’s case study data were collected): “Just like any time doing something the second time through. You just feel a lot more effective at how you’re able to deliver the material.” This recognition of professional growth over time, however, is not coupled with either increased student learning gains or a professional reorientation toward depth over breadth. Mr. Harris shares his related concerns: “I’m still worried about cutting content. Because I know *NGSS* talks about broad, and phenomena, and understanding conceptually, but even as I criticize others, I’m scared to cut content and spend more time going into depth, just because it’s a challenge.”

As he openly acknowledges, the ongoing classroom discourse that supports students’ three-dimensional mastery is hard for Mr. Harris. Additionally, he says, “Like, you don’t want to be the teacher that says, ‘Oh yeah. We didn’t get to - we didn’t get to that.’ Like, that just doesn’t sound good.” Unlike other teachers’ stories we’ve shared so far, Mr. Harris’ depicts a professional identity that is not in alignment with *NGSS* and *Carbon TIME* goals for deep understanding and three-dimensional mastery.

In his interviews, Mr. Harris’ descriptions of using *Carbon TIME* in his classroom match classroom observations analyzed in Paper 4 (Covitt et al., 2020). Though we hear Mr. Harris describe conceptual understanding (tracing matter and energy through living and non-living systems) as worthwhile for his students, he does not simultaneously describe goal student performances as fully three-dimensional. Instead, Mr. Harris tends to describe goals for student understanding separately from goals around student laboratory performances. In this way, he exhibits a more traditional approach to science teaching and learning in which science content knowledge is separate from science inquiry skills. Additionally, Mr. Harris does not seem to

believe that achieving deep understanding – or engaging in three-dimensional performances – is inherently motivating or interesting to his students. These orientations and classroom actions are sensible in a local context in which Mr. Harris and his colleagues have obligations to a common, one-dimensional course assessment and local norms for covering topics and doing labs.

Mr. Harris' case speaks to the differing experiences teachers have as they engage with *Carbon TIME* curricula and pedagogy. With Mr. Harris, we see a traditional science teacher's commitment to investigations without the coordinating classroom discourse that enables these to be three-dimensional engagement around natural phenomena and without the coordinating apprenticeship that supports students in mastering such significant learning goals. We hear Mr. Harris wrestle with both personal orientations toward "quick-and-snappy" teaching and with local obligations to cover content, neither of which align well with discourse routines that prioritize deep sense-making and "sticky probing."

Mr. Harris' classroom resources. Mr. Harris clearly distinguishes between facts and understanding – and breadth versus depth – yet his interview conversation doesn't suggest that he believes his students view conceptual understanding as a target worth mastering. Mr. Harris describes, for example, "not just shoving facts [at students, but] trying to get them to understand processes, and trying to get them and co-workers to realize that by knowing facts and by covering things, you didn't really cover things. You just checked them off a list." He elaborates as he compares his teaching of the *Carbon TIME Plants* unit with his colleagues' teaching: "And they're saying, 'Oh yeah. I did - I did photosynthesis last week, Wednesday.' And I'm like, 'Oh, we're doing it for three weeks!' You know. Like, 'What do you mean? I got - I did it last Wednesday?'"

In sharing his perspective on his students, Mr. Harris says, "I don't think you realize the benefit of *Carbon TIME* until you realize the students are so clueless." Even as this statement champions how *Carbon TIME* supports students' deeper learning, it nonetheless puts students in a deficit position. He also shares how he "realize[s] that kids do not have the endurance to think. They really think they should read [a test question] and put A, B, C, or D. Like, that's what they want to do, and if you have to think then ... they do not have endurance." Taken together, these statements suggest that Mr. Harris does not believe his students are motivated toward mastering deep learning.

This weak "motivation toward mastery" orientation is coupled with practical knowledge (Mr. Harris' experience-based understanding of teaching *Carbon TIME* in his classroom) that fails to connect students' personal sense-making with scaffolding three-dimensional performances. For example, Mr. Harris talks about eliciting students' ideas, providing time for students to discuss ideas with each other, and he suggests (though without specific examples) that students recognize their own ideas are changing. He also discusses some scaffolding decisions, though he does not connect these two purposes in ways that suggest he is using student ideas or responses to make instructional decisions.

For example, Mr. Harris describes two different situations in which his students express what our project calls "wondering" questions – questions that don't initially lend themselves to matter and energy tracing (which is a key "asking questions" practice in *Carbon TIME*). Though Mr. Harris notices the students' questions and expresses dissatisfaction with their lack of sophistication, he doesn't share how he could have used these questions to encourage more sophisticated questions or ideas. Specifically, the Evidence-Based Arguments Tools ask students to identify unanswered questions, which are questions that remain even after data has been

analyzed – questions that should prompt an exploration of what’s happening at the atomic-molecular scale.

Mr. Harris shares, “the kids are always saying things like, ‘Well, what’s - what are the chemicals in BTB?’ I’m like, ‘Okay, well, that’s not - that’s not what we’re going for.’” Similarly, within the *Plants* unit, Mr. Harris shares how students are surprised that the investigation design has plants growing without soil; “they’re like, ‘Wait, wait, wait! How are these going to grow?’” He wants the students to pay attention to “the actual data ... You really have to push for them to see that the data is any way connected.” He says, “And then, when they see it grow ... they don’t wait and say, ‘Well, let’s measure the mass.’ I wish. They should be, but they’re more just like, ‘Whoa, look! It grew and there’s no soil.’”

Mr. Harris is perceptive in his assessment of students’ questions, and their misalignment with unit goals, yet he doesn’t use this formative assessment information as a basis for instructional next steps in ways that move students toward unit goals. Based on these two examples, we recognize that Mr. Harris can identify particular problems in learning and instruction, but may not have the strategies to address them, and qualities of his professional communities (described below) do not support him in developing or using such strategies.

Finally, Mr. Harris talks about having his students “tak[e] the time to reflect, either verbally with their group or, you know, on paper, and then to go back and look at their old thought process and make revisions from that. So, having them say, ‘Oh, that’s what I thought; no, it’s this now’”. Yet he follows this up by saying, “[the students] can see that they were wrong and now they are right,” which does not reflect a perspective of guiding students toward more sophisticated understanding and performances over time. Instead, it suggests an almost fact-oriented interpretation of mastery for individual students. This can also be seen in Mr. Harris’ lack of discussion about his classroom as a community of learners.

Mr. Harris’ professional community and organizational resources. Unlike Ms. Callahan, Ms. Eaton, and Mr. Gilbert, Mr. Harris does not describe support from his school and district professional communities, nor does he perceive alignment between *Carbon TIME* goals and local norms and obligations. For Mr. Harris, local obligations to a Biology course common assessment present a powerful obstacle toward *Carbon TIME*’s goals for three-dimensional engagement with natural phenomena.

His personal approach “to try to help the [Biology] department” has been to suggest making the common assessments shorter, “which sounds bad, but the end goal is that then people would feel the freedom to try something worth students digging deep,” like students’ three-dimensional engagement around natural phenomena. He describes his idea: “Maybe where there are 50 multiple choice questions ... I’m saying ‘Hey ... let’s pick out 15 questions that we can all agree on that, no matter what ... we’re all going to cover these.’ And let’s eliminate a lot of these factual things.” Mr. Harris explains, “if we make our common assessments shorter, that allows you to cut [traditional content]. That’s - that’s the goal, [but] we have a common assessment that is very long, [and] you can’t cut. And when you can’t cut, you’re not going to be able to teach in new ways.”

Here, Mr. Harris describes a strong local obligation – the school’s course common assessment – that works against his use of *Carbon TIME* to support students’ three-dimensional engagement around natural phenomena. We agree with him, yet we also recognize how Mr. Harris himself doesn’t articulate a description of three-dimensional performances as a focus for assessment. Again, he sees limitations without finding what he needs to overcome these limitations.

Like Mr. Gilbert, Mr. Harris teaches in a local context with others teaching the same grade level and course. However, Mr. Gilbert is the only Biology teacher with an ELL-focused course, and Mr. Harris is one of eleven Biology A teachers! Across this large community, the “normal” way of decision-making and teaching are much less aligned with *Carbon TIME*’s focus on students’ three-dimensional engagement around natural phenomena. For Mr. Harris, the “normal” way of teaching in his department has a traditional, one-dimensional orientation: “We are all so very good at ... giving the notes, doing the lab, move on. And then you tell the kids, ‘Study the notes.’ And when they study the notes, look like, a test. They did well. And, not only that, but [teachers] can point to the test that [their] kids did for photosynthesis [and show how] they did well on [it].”

This traditional orientation includes covering content quickly: “And they’re saying, ‘Oh yeah. I did - I did photosynthesis last week, Wednesday.’” Mr. Harris points out how this makes shifting teacher practice “tricky, especially if ... all you’ve ever done is cover all these things.” A local teaching norm for “covering content” aligns with an obligation for a one-dimensional common assessment, creating a local context that is generally not supportive of using *Carbon TIME* to support students’ three-dimensional engagement with natural phenomena.

Mr. Harris’ local context has the potential to be rich with human resources, considering the sheer number of science teachers in his building: “We have eleven science staff but almost, I think, every one of us is certified for Biology,” but these resources don’t provide knowledge and skills that align with *Carbon TIME*. For example, Mr. Harris shares how his department has teachers “that have invested a lot of time and effort in the assessments we currently have, in the labs we currently have [so] trying to get things to change is - is really, really challenging.” This resistance – which acts against a vision for change toward *Carbon TIME*’s three-dimensional engagement around natural phenomena – is highly problematic for Mr. Harris.

MS. BARTON uses *Carbon TIME* materials for a version of “doing school” that emphasizes student talk and sharing ideas and devalues writing and mastery.

Ms. Barton’s eighth grade science classroom uses *Carbon TIME* materials in ways that promote broad sharing of ideas and engagement in experiences without coordinating work to move toward consensus, acquire canonical understanding, or master three-dimensional performances. She is attentive to her perception of students’ interests and engages with the class in ways that demonstrate care, including her consistent interactions with students during partner and small-group activities. However, as evidenced in both her classroom video and her interviews, Ms. Barton approaches classroom work as “quick and snappy,” and does not share an orientation toward “sticky probing.” Ultimately, Ms. Barton’s classroom discourse, professional orientation, and local context do not support students’ progress toward environmental science literacy goals; the class does not use atomic-molecular models to explain carbon-transforming processes and does not regularly invoke principles (such as conservation of matter and energy) as rules that guide sensemaking.

In fact, Ms. Barton expresses a professional orientation that is in opposition to students’ mastery of three-dimensional performances. Like other teachers, she recognizes that *Carbon TIME* is “a different way of teaching,” but (unlike Mr. Harris) she does not suggest that she recognizes the deeper understanding and three-dimensional nature of *Carbon TIME* teaching and goals for student learning. She does – rather like Mr. Harris – express personal challenges in devoting the sustained time and energy required for her classroom community to make progress toward mastery. She feels that *Carbon TIME* is “a lengthy thought process about one thing. The

amount is a struggle for me ... it's hard for me to stay with one thing for that amount.” Ms. Barton also indicates that she’s “really struggling with, like, student learning and looking at things in a deep way.”

And, unlike Mr. Harris (who discussed how using *Carbon TIME* “went better” during his second year) Ms. Barton indicates, “I just feel like I tried that, and I don't think it was exactly what I was looking for.” Ms. Barton doesn't indicate professional growth or improvement over time. Instead, we hear that Ms. Barton doesn't view *Carbon TIME* as a toolkit that she can take up and use in her classroom in ways that support her personal goals students' engagement and learning.

Ms. Barton's classroom resources. Ms. Barton's orientation affects her classroom decisions. For example, Ms. Barton indicates, “I just feel like I would rather have [students], like talk more and think more and, there's a finite amount that they're going to do and I have if I have to choose between talking and thinking or, doing a worksheet, I am going to choose talking and thinking more.”

We see this play out in Ms. Barton's modification of a lesson at the end of the *Animals* unit. Instead of engaging her students around constructing model-based explanations (writing on a worksheet), she asks them to talk together as they draw on whiteboards to represent their understanding of carbon-transforming processes in specific animals. Further, when students share these with the class, no criteria are used to evaluate the work and the class does not develop consensus around tracing matter and energy through living systems. Ms. Barton seems reluctant to engage the class in activities that support meaningful understanding and three-dimensional mastery and even puts writing in conflict to her classroom goals.

Ms. Barton perceives a similar reluctance in her students, discussing them as unmotivated (or not capable) of engaging in *Carbon TIME* work: “[*Carbon TIME* is] assuming that all kids want to learn or are interested in the topic or will do what they're asked to do and like I found with the Evidence-Based Arguments [Tool] that, like one key person would do it and everybody else would copy ... if like students did what was expected on those sheets, it'd be valuable.” She says, “I want [my students] to really think about it and maybe it's because they're in eighth grade and they are just like ‘ugh let's get this done,’ I don't know.”

At the same time, Ms. Barton notices that “the kids actually really like” the *Carbon TIME* online assessments (pre/posttests) because they're “somewhat entertaining” and that, specifically, “one of the kids pointed out, ‘well, they kind of keep asking us [the] same questions’.” This suggests that Ms. Barton's students may recognize how the assessments support their learning, and we notice – through classroom video – that Ms. Barton's students seem interested and motivated by *Carbon TIME* materials. But Ms. Barton doesn't seem to recognize or leverage this. For example, Ms. Barton says, “I hate giving the kids tests. Like I hate, I just hate it, because I just feel like you poor little kids, you're getting another test. I really wish *Carbon TIME* didn't have too many, I really just feel like there's too many tests.”

Ms. Barton's descriptions suggest that her classroom experiences are informing instructional decisions that run counter to *Carbon TIME* goals for assessing and scaffolding students' three-dimensional engagement. As the following examples show, however, it is not that Ms. Barton is too unfamiliar with *Carbon TIME* unit features or possibly unaware of the role that student ideas play in supporting students' science achievement.

For example, Ms. Barton has multiple years of experience using *Carbon TIME* in her classroom. In her interview, she shares how – in the preceding school year – she wondered, “were [students] really reading [The Three Questions]? Did they answer all the questions [on the

Process Tool]? ...they weren't really filling them out completely.” This coordinates with her quote (above) about students copying each other’s work to suggest that her understanding of her classroom experiences don’t support her making efforts to engage students in scaffolded practice to either share their initial ideas or to move toward more sophisticated performances.

Ms. Barton recognizes that “kids have a lot of hidden ideas that they're holding onto from past experiences ... and I think the Expressing Ideas or Predicting [Tools] do a really good job of helping the teacher get that out ... you're not like just putting some information into an empty bowl. You're building information with the information they're already carrying around and [you may] have to get rid of something or try to help them see that something that they are carrying around doesn't make sense.” However, she does not, in turn, view *Carbon TIME* as a toolkit that can scaffold her students toward more sophisticated understanding or performances. Nor does Ms. Barton seem to believe that class-level discussions will support shared understandings, noting her frustration around a perception that “[students are] not ... responding to each other's ideas.”

Finally, counter to *Carbon TIME*'s perspective on writing as a necessary endeavor for personal and group expression and consensus-seeking, Ms. Barton does not perceive writing as a meaningful form of engagement in science class. She says, “You know, what is the purpose of [writing]? Like, if you're going to write, if the student is going to write, why are they writing? And ... I don't always know the answer to that.” So, this school year, Ms. Barton says, “I'm doing fewer of [the Process Tools].” Instead, she has her students “draw things and then show their partner” in an effort to “get more things out that way, where ... I'm hoping that it's doing the same thing but more, like, quickly.” This description provides insight into Ms. Barton’s perspective that writing neither helps students express their authentic ideas and experiences nor supports them in developing more sophisticated understanding.

Ms. Barton’s professional community and organizational resources. Like Mr. Harris, Ms. Barton does not describe support from her school and district professional communities, nor does she perceive alignment between *Carbon TIME* goals and local norms and obligations. However, Mr. Harris clearly articulated points of tension between one-dimensional teaching norms and obligations in his local context and *Carbon TIME*'s goals for deep understanding. Differently, Ms. Barton does not note differences between *Carbon TIME* goals and her local obligations.

For example, as Ms. Barton describes it, her local obligation toward the *Next Generation Science Standards* doesn’t align with *Carbon TIME* perspectives on the *NGSS* as a set of three-dimensional student learning goals. Ms. Barton indicates her local context is “standard[s]-focused [so] that anything that varies from” the standards is problematic. For example, she explains how her required “‘I Can’ statements all have to be *NGSS*-referenced, you know, with the actual standard – the code – on there.” This shaped her request to modify *Carbon TIME* tools so that the correlating *NGSS* standards were provided for each student activity – “like, right there ... underneath the activity title.” Though using *Carbon TIME* to support students’ three-dimensional engagement around natural phenomena is aligned with the *NGSS* expectations, providing activity-level connections to specific standards may misrepresent the goals of the *NGSS* by suggesting that multi-dimensional standards can be met through single activities.

Further, Ms. Barton’s description of working with her department emphasizes quantifying and separating the standards: “We've been, you know, really talking about [the *NGSS*] in our department because, there's less standards ... we have [only] 22 standards total in eighth grade.” Discussions like Ms. Barton’s that organize standards into courses can be

necessary and appropriate, given that the *NGSS* middle school standards are provided in grade-bands (not assigned to specific grade-levels). However, in combination with Ms. Barton's other comments around the *NGSS*, this particular description of departmental work suggests that her local context is not interpreting the *NGSS* in ways that support their complex, multi-dimensional design.

Certainly, as described by Ms. Barton, her local context offers few resources that support assessing and scaffolding students' three-dimensional classroom performances. Moreover, Ms. Barton perceives her local context lacks organizational resources in general. She shares how "we really don't have a science curriculum ... the last time that we worked on a science curriculum and actually wrote it [was] about ... 1997." But Ms. Barton (unlike Ms. Eaton, who described a similar experience) does not continue by elevating *Carbon TIME* as a potential answer to her district's problems. Instead, she relays how "I might look at that [Project JASON] book and say 'okay, well, here's an activity that meets the standard,' I'm not going to do the whole book, you know, like it's really, the onus is on the teacher to develop the curriculum in such a way that students can make meaning."

Further, she provides few examples of human or social resources in her school or district. Though – like Ms. Eaton and Mr. Harris – Ms. Barton was the only *Carbon TIME* network teacher in her district, she did not describe human resources in her local context (Ms. Eaton described a strong working relationship with her Case Study Coach and support from her colleagues, while Mr. Harris described the resources of his other ten Biology teachers). Instead, Ms. Barton described professionals outside of her local context (for example, work she did with a science researcher through a university extension site). Though she uses the word "us" in discussing her department's work to transition to *NGSS*, there's no other evidence in her interview that she shares affective qualities such as trust or cohesiveness with her local colleagues.

Research Question 3: Relating Findings Across Papers 3, 4, and 5

The above findings describe – in narrative fashion – how each teacher describes their classroom resources and professional communities and organizational resources. Our final research question relates to *how these descriptions relate to observed classroom discourse and student learning outcomes* (Covitt et al., 2020; Lin et al., 2020). We find consistency across these papers: Teachers whose students show the highest learning gains are those who are engaging in rigorous and responsive classroom discourse and are the same teachers who describe high levels of resources at the classroom and organizational levels.

These results are based on deep analysis of just five Case Study Teachers, so the observed patterns are not statistically significant. However, these case studies provide insight into the causal mechanisms connecting our classroom-level and organizational-level variables with patterns in classroom discourse and student learning outcomes. Continued analyses of classroom and interview data from all 17 Case Study Teachers will allow us to further refine these variables and explore more deeply the mechanisms that connect student learning outcomes and patterns in classroom discourse with classroom and organizational resources.

Discussion

Our Paper Set helps us consider and describe the goals for achieving three-dimensional learning in secondary science classrooms, the challenges for accomplishing this, and causes for these challenges. In this Paper's findings, we shared narratives of five *Carbon TIME* Case Study

Teachers, detailing their orientations toward three-dimensional learning goals and instruction, the extent to which their understanding of their classroom work aligns with these learning goals, how they perceive their local professional communities and related organizational resources, and how all of this corresponds to success as measured by *Carbon TIME* student learning gains.

What stands out in our combined analyses of these five teachers is the alignment among a teacher's classroom learning gains (Paper 3; Lin et al., 2020), their patterns of classroom discourse (Paper 4; Covitt et al., 2020), as well as their understanding and beliefs about teaching and learning with *Carbon TIME* and perceptions of their local contexts (this Paper 5). Across these classroom cases, we generally see Ms. Callahan, Ms. Eaton, and Mr. Gilbert as having high resources, enacting "3D doing school" classroom discourse, and their students experiencing three-dimensional learning outcomes. In contrast, we see Mr. Harris and Ms. Barton as having lower resources, enacting "1D doing school" classroom discourse, and their students experiencing one-dimensional learning outcomes.

As we make sense of this pattern, we recognize that our teachers are sharing with us rational stories; they are describing their experiences with their students and with *Carbon TIME* in their local contexts in ways that are logical. So, we would expect some alignment in their stories. For example, we aren't entirely surprised that a teacher like Ms. Eaton – in a high learning gains classroom, with a strong orientation toward her students being "motivated toward mastery" – might perceive her local context as adequately resourced because of her access to *Carbon TIME*, even when (as is the case) there isn't funding for textbooks. Similarly, we notice that local obligations and norms that do not align with *Carbon TIME* goals for three-dimensional engagement around natural phenomena are challenging for teachers like Mr. Harris to circumvent. They are likely affecting his perception of students being "motivated toward mastery," as his local context seems to only support motivation toward one-dimensional (fact-oriented) performances.

Patterns in Classroom Resources

We described and identified teachers' classroom resources – their professional identities, practical knowledge for using *Carbon TIME* in their classrooms, and orientation toward students' motivation and mastery. Though there are differences across individual teachers, we notice patterns among teachers in higher learning gains classrooms – Ms. Callahan, Ms. Eaton, and Mr. Gilbert – that are different from patterns among teachers in lower learning gains classrooms – Mr. Harris and Ms. Barton.

First, teachers in higher learning gains classrooms – Ms. Callahan, Ms. Eaton, and Mr. Gilbert – describe professional identities that align with *Carbon TIME* goals for rigorous and responsive teaching and that include both growth-oriented mindsets and a recognition for their own professional growth in using *Carbon TIME* to support students' three-dimensional engagement. Ms. Callahan and Ms. Eaton also describe personal orientations toward deep understanding of science phenomena.

In contrast, teachers in lower learning gains classrooms – Mr. Harris and Ms. Barton – describe professional identities that are not in alignment with *NGSS* and *Carbon TIME* goals for deep understanding and three-dimensional mastery. Mr. Harris stands apart from Ms. Barton in how he wrestles with this misalignment, recognizing his own orientation toward "quick-and-snappy" teaching as conflicting with *Carbon TIME* goals that he also indicates are important.

Second, the same teachers in higher learning gains classrooms describe developing experience-based understandings of teaching with *Carbon TIME* – their practical knowledge (van Driel, et al., 2001) – in ways that align with *Carbon TIME*'s goals for students' three-

dimensional engagement with phenomena. Ms. Callahan and Ms. Eaton – in the highest learning gains classrooms – stand out in how they describe specific scaffolding decisions in response to their assessment of specific students’ ideas and questions. Mr. Gilbert similarly describes scaffolding decisions, though these respond more to his students’ diverse backgrounds and limited experiences with science in the English language than they do to students’ specific initial ideas.

In contrast, Mr. Harris – in one of the lower learning gains classrooms – describes both students’ ideas and his instructional decisions but does not discuss these in conjunction with each other. For Mr. Harris, assessing and scaffolding do not seem to be intertwined instructional purposes. Uniquely, Ms. Barton, in the lowest learning gains classroom, describes how her classroom experiences inform instructional decisions that run counter to *Carbon TIME* goals. This is especially apparent when she discusses students’ writing and talk as not mutually reinforcing activities and her related decisions to reduce writing in favor of talk.

Finally, teachers in higher learning gains classrooms perceive their students’ engagement as “motivation toward mastery” while teachers in lower learning gains classrooms discuss students as motivated by things besides mastery (such as novelty, variety, and a fast pace), presenting students as either not capable of reaching or not motivated to reach significant learning goals.

Patterns in Professional Communities and Organizational Resources

We also identified qualities of teachers’ professional communities and organizational resources in their local contexts, including the teachers’ perceived alignment across local norms and obligations and *Carbon TIME* goals as well as the availability of material, human, and social resources. Again, though there are differences among individual teachers, we notice similar patterns across teachers in higher learning gains classrooms (Ms. Callahan, Ms. Eaton, and Mr. Gilbert) as compared to those in lower learning gains classrooms (Mr. Harris and Ms. Barton).

Specifically, we find that teachers in higher learning gains classrooms – Ms. Callahan, Ms. Eaton, and Mr. Gilbert – perceive support from their professional communities for using *Carbon TIME* and alignment among local norms and obligations and *Carbon TIME* goals for three-dimensional engagement and mastery. All three teachers describe support and enthusiasm from other science teachers at their school, as well as support from school or district administrators. All three also perceive that *Carbon TIME* helps them to fulfill their obligations as science teachers in their schools. Additionally, all three teachers discuss the value of important human resources related to the *Carbon TIME* program (Case Study Coaches or other network teachers), as well as their perception of support and other social resources available in their professional environments.

In contrast, Mr. Harris and Ms. Barton describe misalignment between *Carbon TIME* goals and expectations and local norms and obligations. As we’ve mentioned, Mr. Harris is particularly articulate about the challenges he perceives existing in his local context, with norms for teaching in traditionally oriented ways and obligations to one-dimensional, fact-based common assessments. Additionally, neither Mr. Harris nor Ms. Barton describe significant human or social resources supporting their use of *Carbon TIME*. This is especially surprising in Mr. Harris’ school, which has eleven certified Biology teachers with whom he regularly communicates.

Finally, the consistency of these patterns is particularly striking when we take into account other demographic factors that are the same for teachers in different classroom learning gains groups. For example, Ms. Eaton (higher learning gains classroom) and Ms. Barton (lower

learning gains classroom) are both middle school teachers in classrooms where students enter with fewer science classroom experiences. However, being in a middle school or high school was found to have no statistical effect on students' learning gains (Paper 3; Lin et al., 2020). Additionally, Mr. Gilbert (higher learning gains classroom) and Mr. Harris (lower learning gains classroom) are similar demographically in that both teach in schools with large science departments and multiple Biology teachers. Yet – as we've seen – they have strikingly different classroom discourse patterns and student learning outcomes. These examples suggest that factors we've highlighted in this paper – teachers' professional identities, orientations, and practical knowledge, along with aspects of their local contexts including norms and obligations and organizational resources – have more influence than demographic variables on eventual student outcomes.

Implications

Overall, we perceive the *Carbon TIME* project's design efforts to create a "toolkit" that can be used to support students' three-dimensional classroom performances as successful. As shared in Paper 3 (Lin et al., 2020), student learning gains across diverse classrooms suggest that *Carbon TIME* is working; even in lower learning gains classrooms, students are learning more than they do without *Carbon TIME*. Paper 3 also reports that learning gains in *Carbon TIME* classrooms improved over time. We changed professional development and curricular materials in response to cases like Ms. Barton's and Mr. Harris's, which occurred in the first year of the project, and the evidence is that those changes were helpful.

However, as detailed in Paper 4 (Covitt et al., 2020), students in some classrooms are still engaging more deeply and their classroom teachers are able to support more rigorous and responsive classroom enactment. This Paper's exploration of *why* classrooms differ reaffirms points outlined in the Paper Set's Introduction (Anderson, 2020): Teaching for three-dimensional mastery is *expensive* in terms of demands on classroom resources, and different classrooms have different resources. Supporting more teachers in engaging in rigorous and responsive classroom discourse and supporting more students in productive disciplinary engagement that leads to three-dimensional mastery requires enhancing or developing resources at both the classroom and organizational levels.

At the classroom level, students and teachers need quality research-based curriculum materials with aligned, three-dimensional assessments – resources that the *Carbon TIME* project has designed and iteratively developed (Anderson, 2020; Anderson et al., 2018). Though necessary, this toolkit is not sufficient in helping teachers go beyond doing school in one-dimensional ways (Covitt et al., 2020). Additional classroom resources that are necessary include teachers' professional identities, the resources their students bring with them, and their own skills and knowledge. We know this from the compelling patterns across these classroom-level resources, classroom discourse (Paper 4; Covitt et al., 2020), and eventual student outcomes (Lin et al., 2020).

Further, there are continued patterns across organizational-scale resources, meaning that the local obligations and norms of teachers' school professional communities and the material, human, and social resources of the teachers' departments, schools, and districts are also relevant to classroom discourse and student outcomes. In other words, teachers' orientations and their local contexts are relevant to what they're actually doing in their classrooms, which has real consequences for students.

This suggests a strategy for supporting three-dimensional classroom discourse: Align resources across classroom and organizational scales. Mr. Harris is a case-in-point; his local organizational context has little alignment with classroom-level three-dimensional goals. We can imagine different outcomes if, instead, the “normal” way of doing school in Mr. Harris’ context was three-dimensional engagement with natural phenomena, and if – instead – his obligations to doing school were to students’ three-dimensional performances (versus one-dimensional expectations). We recognize that actually aligning goals and resources across scales is no easy endeavor, but we believe this kind of alignment is a way to increase resources in an educational reality that can feel resource poor.

A second implication of our work highlights teachers’ orientations and professional identities as important classroom resources. Classrooms like Ms. Callahan’s and Ms. Eaton’s, for example, illuminate how “sticky-probing” approaches (Hess & Azuma, 1991) can be personally meaningful and worthwhile for teachers while also meeting needs for students’ motivation and interest. As noted in Table 4 of this Paper Set’s Introduction (Anderson, 2020), developing these orientations and professional identities likely involves overcoming norms for privacy around classroom discourse (Little, 1990) and instead linking this professional discourse with colleagues through sharing and analyzing student work, analysis of classroom recordings or through peer observations. It also likely requires supporting the development of teachers’ professional growth orientations so that, as Ms. Callahan notes, we “continue to grow . . . in all [our] years of teaching.”

Conclusion

We are proud of our *Carbon TIME* project’s design and research efforts to Teach for Science Literacy at Scale. In this paper we have shared the compelling patterns that connect classroom and organizational scale resources with classroom discourse and student learning gains. In this Paper Set, we have described the difficulty and complexity of teaching for science literacy through “3D doing school” approaches, while recognizing that other teachers’ “1D doing school” still meets teachers basic needs and obligations in ways that work for teachers with fewer classroom resources.

It will be hard for less-resourced teachers – like Mr. Harris and Ms. Barton in this Paper Set – to individually become more like higher-resourced teachers, because aspects of the teachers’ local professional communities and contexts play an important role in what happens inside classrooms. All five of our Case Study teachers participated in *Carbon TIME* Networks that were outside of their school and district professional communities. Though we know that these networks were valuable to our teachers, we also know that they were not designed to identify local obstacles for using *Carbon TIME* to reach three-dimensional learning goals, nor to support the extended work that is required to align organization-scale expectations with classroom-level goals. We see new research-practice partnerships at the district and union level as future opportunities to apply and extend our learnings.

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This research is supported in part by a grant from the National Science Foundation: Sustaining Responsive and Rigorous Teaching Based on *Carbon TIME* (NSF 1440988). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Appendix A: Carbon TIME Network Teacher Interview Protocol

<p>1. Describe your vision for teaching and learning in your science classroom.</p> <ul style="list-style-type: none"> a. What unit that you teach best exemplifies that vision? <ul style="list-style-type: none"> i. (if <u>not</u> a CTIME unit) How is it like or different from <i>Carbon TIME</i> units? ii. (if a <i>Carbon TIME</i> unit) What is it that makes it closer to your vision than other units? b. In what ways does <i>Carbon TIME</i> help you reach your vision? <ul style="list-style-type: none"> i. How has implementation of <i>Carbon TIME</i> in your classroom been similar to/different from your vision for teaching and learning of science? c. What obstacles (if any) do you encounter in using <i>Carbon TIME</i> to meet your vision? 	<p>General Questions to Ask Anytime to Probe for More Information</p> <p><i>Can you tell me more about that?</i></p>
<p>2. How do your students feel about <i>Carbon TIME</i> ?</p> <ul style="list-style-type: none"> a. What do they like the most? least? 	<p><i>Can you give an example of that?</i></p>
<p>3. How does <i>Carbon TIME</i> fit into your local context: your department, school, district, and/or community?</p> <ul style="list-style-type: none"> a. In what ways is <i>Carbon TIME</i> a good (helpful) fit? In what ways is it problematic (a mis-fit)? b. Are there other people in your school/district who are teaching <i>Carbon TIME</i>? <ul style="list-style-type: none"> i. probe: Does this or would this make it a better fit? c. Do you have other colleagues or administrators who are strong advocates (or strong opponents) of <i>Carbon TIME</i>? <ul style="list-style-type: none"> i. probe: What do they like/oppose? 	<p><i>What do you mean by ___?</i></p>
<p>4. Is there anything else you related to your <i>Carbon TIME</i> perspectives or experiences that you would like us to know now?</p>	
<p>FOR YEAR 2 ONLY</p>	
<p>5. Are you planning to participate in <i>Carbon TIME</i> Year 3 data collection?</p> <ul style="list-style-type: none"> a. Why or why not? 	
<p>FOR YEAR 3 ONLY</p>	
<p>6. How has your vision and implementation of <i>Carbon TIME</i> changed over time?</p>	

Appendix B: Carbon TIME Network Teacher Coding Framework

- a) Organizational Resources
 - 1. material
 - 2. human/social
- b) Obligations & Norms
 - 1. obligations
 - 2. norms
- c) Practical Knowledge
 - 1. T assessing
 - 2. S self-assessment
 - 3. grading
 - 4. scaffolding/IM (Instructional Model)
 - 5. pragmatics
- d) Teacher’s Frames
 - 1. motivation/mastery
 - 2. teacher’s story

a. Organizational Resources (material, human, social) of the teachers’ schools and districts	
<i>Attributes</i>	<i>Definitions</i>
1. Material	<p>Things that money could buy (even if it’s free in this specific case) – from teachers’ school or district</p> <ul style="list-style-type: none"> • Technology (availability and ease of access) • Professional development, including time for PD/PLCs • Professional/out-of-classroom time; people going to trainings • Textbook/curricula <p><u>What it’s not:</u> CTIME-provided materials (unless it’s about having more than the project provided)</p>
2. Human / Social	<p>Specific skills/capacities of specific adults that the teacher has access to</p> <ul style="list-style-type: none"> • knowledge and skills of specific colleagues or specific others • specific support from an administrator <p>Also includes “negative” resources</p> <ul style="list-style-type: none"> • lack of skills of a colleague • lack of colleagues <p><u>What it’s not:</u></p> <ul style="list-style-type: none"> • skills, etc., of students <p>Affective aspects of relationships among teachers/others in the school system. There will be some overlap with norms; but this describes the strength/importance of the norm more than content of the norm.</p> <ul style="list-style-type: none"> • ties among colleagues • Collegial cohesiveness • trust • openness <p>Also includes “negative” resources</p> <ul style="list-style-type: none"> • arrogance • lack of trust • isolation

b. Norms and Obligations of teachers' school professional communities	
<i>Attributes</i>	<i>Definition</i>
1. obligations	<p>formal expectations: department, school, district level expectations</p> <ul style="list-style-type: none"> • teacher evaluation • common student assessments or grading expectations • Standards (NGSS, MSS) • other areas of focus (ex: rubrics) • district-adopted curriculum
2. norms	<p>informal expectations from colleagues/administration and/or “normal” methods for group interaction, decision-making, ways of teaching. (content of norms).</p> <ul style="list-style-type: none"> • autonomy: freedom to decide about what Ts teach or do • ways of making decisions • collaboration • traditional ways of teaching
c. Practical Knowledge (teachers' developing practical knowledge [and practical constraints] of how (and why) to teach <i>Carbon TIME</i> units)	
<i>Attributes</i>	<i>Definition</i>
1. T assessing	<p>Teacher discusses student ideas</p> <ul style="list-style-type: none"> • student ideas are important • student ideas should be elicited/used • specific examples of student ideas related to this/other curriculum • examples of formative assessment • students' prior knowledge • may also relate to NGSS dimensions: students' practices (asking questions, etc.) or CCC (matter/energy; scale)
2. S self-assessment	<p>Teacher discuss students' knowledge of/use of their own ideas</p> <ul style="list-style-type: none"> • student self-assessment • students' recognition of their changing ideas • students' metacognition • can be negative (Ss don't know they're learning)
3. Grading	<p>Teacher discusses points/grades</p> <ul style="list-style-type: none"> • Discussion of points/grading • Discussion of “fairness”
4. Scaffolding/IM	<p>Teacher discusses 3D/Figuring out and/or CTIME vision, Instructional Model and/or recurring features</p> <ul style="list-style-type: none"> • 3-dimensional/figuring out • phenomena • Instructional Model (triangle, map) • Process Tools, other repeating activities • Discourse Routines • scaffolds • includes not CTIME-aligned: <ul style="list-style-type: none"> ○ 1D activities ○ repetition ○ activities/worksheets looking the same

5. Pragmatics	<p>Teacher discusses pragmatics of implementing and managing units/activities</p> <ul style="list-style-type: none"> • managing student talk • student grouping • lab preparation • materials management • classroom/instructional time • planning time
d. Teachers' frames for the quality and purposes of students' engagement	
<i>Attributes</i>	<i>Definition</i>
1. Motivation/ Mastery	<p>Teacher's description of what motivates Ss</p> <ul style="list-style-type: none"> • Students approaches to classwork • Students approaches to learning • Students likes/dislikes • Students' affect or feelings <p>Teacher's description of learning goals and performances</p> <ul style="list-style-type: none"> • CTIME-aligned: tracing matter & energy (3D) learning goals <ul style="list-style-type: none"> ○ can be meta-level; does <u>not</u> need to include the specific content/practice/CCC that is the goal or performance • not CTIME-aligned (lower value): <ul style="list-style-type: none"> ○ other content goals (macromolecules) ○ importance of vocab ○ goals are to prepare kids for college/ AP/ standardized tests
2. Teacher's story	<p>Teacher's description of his/her own orientation/learning; a story of past/future trajectories</p> <ul style="list-style-type: none"> • Growth-mindset • Idea of shifting his/her practice (or not) • What am I like as a T? • What have I been like or done? And what do I want to be like/do differently?

Appendix C: Carbon TIME Network Teacher Interview Evaluation Matrix for Coding Variables

<i>Motivation toward Mastery</i>	<p>Ss are unmotivated or unable to master 3D performances ←————→ Ss can be motivated to master 3D performances</p>		
	<p>Students: T says that Ss</p> <ul style="list-style-type: none"> • don't or won't complete work • are lazy, without "endurance" • are interested in investigations/hands-on/activities • get bored; don't like CTIME over time <p>Performances: T describes</p> <ul style="list-style-type: none"> • non-3D performances (vocabulary, activities, hands-on, practice w/o content) 	<p>Students: T says that Ss</p> <ul style="list-style-type: none"> • find work repetitive • find work hard/challenging • are interested in new phenomena, novel experiences <p>Performances: T describes</p> <ul style="list-style-type: none"> • content and practice performances (though not together as 3D) • superficial 3D (connections) 	<p>Students: T says that Ss</p> <ul style="list-style-type: none"> • find personal value in the work <ul style="list-style-type: none"> ◦ "they see the reward in it" • find work repetitive/hard • engage as questioners, investigators, and/or explainers <p>Performances: T describes</p> <ul style="list-style-type: none"> • 3D performances as worthwhile • repetition as valuable • Ss engaged as questioners, investigators, and/or explainers
<i>Practical knowledge</i>	<p>1D, task-oriented engagement ←————→ 3D engagement with natural phenomena</p>		
	<p>Carbon TIME as a toolkit:</p> <ul style="list-style-type: none"> • T describes changes made that don't support Ss 3D engagement • T may describe CTIME as a script <p>Assessing & Scaffolding:</p> <ul style="list-style-type: none"> • T may describe assessing Ss ideas/questions • T may discuss Ss sharing ideas • T may describe scaffolding • T does not provide examples of using Ss ideas/questions to make instructional decisions <p>Ss Self-Assessment:</p> <ul style="list-style-type: none"> • T does not describe Ss self-assessment <p>Grading/Pragmatics:</p>	<p>Carbon TIME as a toolkit:</p> <ul style="list-style-type: none"> • T describes changes that may support Ss 3D engagement <p>Assessing & Scaffolding:</p> <ul style="list-style-type: none"> • T may discuss eliciting Ss ideas and questions • T may indicate Ss share ideas • T may provide examples of scaffolding • T does not provide examples of using Ss ideas/questions to make instructional decisions <p>Ss Self-Assessment:</p> <ul style="list-style-type: none"> • T may describe Ss recognizing their own ideas are changing <p>Grading/Pragmatics:</p>	<p>Carbon TIME as a toolkit:</p> <ul style="list-style-type: none"> • T describes changes that support Ss 3D engagement <p>Assessing & Scaffolding: T describes</p> <ul style="list-style-type: none"> • eliciting and using Ss ideas and questions • Ss sharing ideas • Ss build ideas/understanding together – as a community • T using Ss ideas/questions to make scaffolding decisions • T provides examples of scaffolding • T provides feedback to Ss <p>Ss Self-Assessment:</p>

	<ul style="list-style-type: none"> grading may be highly problematic pragmatics/implementation may be highly problematic 	<ul style="list-style-type: none"> Grading may be a problem to be solved Pragmatics/implementation may be a problem to be solved 	<ul style="list-style-type: none"> T describes Ss recognize their own ideas are changing <p>Grading/Pragmatics:</p> <ul style="list-style-type: none"> grading does not negatively impact 3D engagement pragmatics/implementation strategies are not problematic
<i>Teacher's Story</i>	<p>T does not describe professional growth ←————→ T orientation toward professional growth</p>		
	<p>T orientation</p> <ul style="list-style-type: none"> T describes value of non-3D/other performances (vocabulary, activities) <p>Professional growth:</p> <ul style="list-style-type: none"> T does not describe professional growth T may describe continued areas of weakness T may describe failures (that didn't lead to improvement) 	<p>T orientation:</p> <ul style="list-style-type: none"> T may/may not believe 3D performances are worthwhile T provides unclear/vague descriptions of 3D <p>Professional growth:</p> <ul style="list-style-type: none"> T descriptions specific to CTIME – more experiences w/ CTIME make them better CTIME Ts T may list additional aspects they want to incorporate (phenomena/inquiry) 	<p>T orientation:</p> <ul style="list-style-type: none"> T believes Ss 3D performances are worthwhile T describes specific aspects of <p>Professional growth:</p> <ul style="list-style-type: none"> T describes changes in teaching practice toward engaging Ss in 3D T could include new focus on tracing matter and energy (not necessary)
<i>Obligations & Norms</i>	<p>lack of alignment with 3D engagement ←————→ alignment with 3D engagement</p>		
	<p>Alignment with Carbon TIME:</p> <p>T does not describe alignment w/ CTIME</p> <ul style="list-style-type: none"> NGSS may be misrepresented local focus on 1D/vocabulary <ul style="list-style-type: none"> through teaching norms through common assessments T may not perceive authority to make classroom decisions 	<p>Alignment with Carbon TIME:</p> <p>T describes some alignment w/CTIME</p> <ul style="list-style-type: none"> T may describe additional local obligations T may describe colleagues with non-3D goals or implementation 	<p>Alignment with Carbon TIME:</p> <p>T describes alignment w/ CTIME</p> <ul style="list-style-type: none"> NGSS standards or course/grade topics/content T (individual or group) autonomy and authority for classroom and curriculum decisions T's colleagues share similar 3D goals or similar 3D implementation
<i>Organizational Resources</i>	<p>lower support for students' 3D engagement ←————→ higher support for students' 3D engagement</p>		

	<p><u>Material resources:</u></p> <ul style="list-style-type: none"> • difficult to access or use • CTIME may not provide locally needed curriculum/support <p><u>Human/Social Resources:</u></p> <ul style="list-style-type: none"> • colleagues do not have or share experiences/expertise • T may describe isolation • T may describe negative affective aspects (arrogance) • T may not describe any human/social resources 	<p><u>Material resources:</u></p> <ul style="list-style-type: none"> • may be challenging to access or use • CTIME may provide locally needed curriculum/support <p><u>Human/Social Resources:</u></p> <ul style="list-style-type: none"> • colleagues may or may not have experience/expertise • colleagues' expertise is something other than CTIME or 3D • leadership may be lacking 	<p><u>Material resources:</u></p> <ul style="list-style-type: none"> • easy to access, easy to use • CTIME may provide locally needed curriculum/support <p><u>Human/Social Resources:</u></p> <ul style="list-style-type: none"> • colleagues with specific, relevant (CTIME or 3D science) experience and/or expertise • colleagues work together and/or make decisions together
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