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Integrating Power to Advance the Study of Connective and Productive Disciplinary Engagement in Mathematics and Science

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ABSTRACT

Engle and Conant's *productive disciplinary engagement* (PDE) framework has significantly advanced the study of learning in mathematics and science. This artilce revisits PDE through the lens of critical education research. Our analysis synthesizes two themes of power: *epistemic diversity,* and *historicity and identity*. We argue that these themes, when integrated into PDE, strengthen it as a tool for design and analysis of disciplinary learning in relation to power and personhood, and describe the broadened framework of *connective and productive disciplinary engagement* (CPDE). By comparing and contrasting the use of PDE and CPDE in relation to two cases of classroom learning—for science, Warren et al.'s *metamorphosis* and for mathematics, Godfrey and O'Connor's *measurement*—we demonstrate how CPDE surfaces issues of history, power, and culture that may otherwise be overlooked by PDE alone. In particular, we analyze how CPDE makes visible unseen identities and generative resources of disciplinary knowing and doing among minoritized students. We discuss how the revised framework redresses epistemic injustice experienced by minoritized learners held to the narrow rubric of western epistemologies and compels close attention to the diversity of human activity in mathematics and science. Further, we elaborate how it provides a structure for teachers, teacher educators, and researchers to design and analyze learning environments as safeguarding the rightful presence of minoritized learners in STEM classrooms and beyond.

Among its many contributions, the learning sciences has progressed our understanding of students' disciplinary engagement in and out of school. Within this body of research, Engle and Conant's (2002) productive disciplinary engagement (PDE) has made an indelible mark as a framework of design and analysis of disciplinary learning in relation to cultural and linguistic diversity (Engle, 2012). It emerged through the study of science learning in Fostering Communities of Learners classrooms (Brown & Campione, 1990, 1994), the Cheche Konnen Project (Rosebery, Warren, & Conant, 1992), and Hypothesis-Experiment-Instruction studies (Hatano & Inagaki, 1991). Since then, PDE has impacted research across various disciplines in and beyond the United States (Forman, Engle, Venturini, & Ford, 2014; Mortimer & de Araújo, 2014; Nolen, 2017; Schoenfeld, 2014) and has also been adapted in contemporary technology-rich learning environments (Hickey & Rehak, 2013; Zhang, Scardamalia, Reeve, & Messina, 2009).

Disciplinary engagement in classrooms, however, also rests upon social relations and dynamics of power and ideology (e.g., neoliberalism, racism, patriarchy, colonialism; Esmonde & Booker, 2016; Politics of Learning Writing Collective [PLWC], 2017) that studies of learning and instruction have increasingly engaged with since the inception of PDE. Research that reflects this shift wrangles with the political and ethical complexities of what disciplinary knowledge and practices are valued, whose ideas are valued, and toward what ends disciplinary learning is mobilized

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(Philip, Bang, & Jackson, 2018). In mathematics and science education, for example, this involves problematizing normative conceptions of the disciplines, engaging the cultural histories of children studying those disciplines, and attending to the diversity of epistemologies and ontologies they invoke. And yet, the PDE framework does not explicitly animate the political and ethical dimensions of disciplinary learning.

In 2012, Engle outlined clarifications and future directions for the development of PDE with an eye to the advances in research taking place since her initial framing. She invited scholars to more consciously attend to the notion of "disciplinary" (p. 184), the role of material artifacts in mediating human activity, and the collective processes of learning to address the "differential opportunities to participate that are experienced by individuals" (p. 187). Engle noted that PDE was only a beginning towards fully engaging issues of inequities. In this paper, we take up Engle's charge to extend the reach of PDE by proposing a framework of *connective and productive disciplinary engagement* (CPDE). CPDE explicitly asks what knowledge is and who has claims over it to broaden the normative perspectives on disciplinary learning. By rearticulating the PDE framework in relation to the sociopolitical and ethical dimensions of learning and learners, CPDE makes a significant contribution to the integration of power in studies of disciplinary engagement. In what follows, we (a) identify two interrelated and recurring themes of power in critical mathematics and science education studies, (b) reinterpret PDE with closer attention to the power themes and introduce the rearticulated CPDE framework, (c) apply the framework to previously published empirical studies of science and math learning, and (d) discuss the implications of CPDE for research and practice.

Two Themes of Power

Drawing on studies of disciplinary (math/science) learning from a range of theoretical perspectives including social practice theory, discursive theories of identity, intersectionality, feminist and Indigenous epistemologies of science, and critical race theory, we treat power as a historical and sociopolitical formation that privileges certain forms of knowing (epistemologies) and being (ontologies) over others (e.g., Esmonde & Booker, 2016). We translate these insights into two themes of power—*epistemic diversity,* and *historicity and identity*—by which to reinterpret the PDE framework.

Epistemic diversity

Institutionalized in artifacts, activities, and discourses that span across time and place, privileged power precipitates epistemic injustice in the disciplinary lives of minoritized learners by systematically discrediting their claims to knowledge (Dotson, 2014; Fricker, 2007). Fricker (2007) explained that such epistemic injustice occurs at individual and societal levels. For individuals, it occurs when a person's idea or experience is undercut because of pernicious ideologies associated with their race, gender, or class. For societies, it occurs when dominant ideologies of race, class, gender, and even the disciplines (e.g., scientism) treat communities and their cultural knowledge and practices as incomprehensible. The use of *injustice* is deliberate in this literature—as Sullivan (2017) argued, restricting epistemic diversity is "a harm done to the flourishing of a human organism, rather than [simply] an unfair exclusion from a process of pooling of knowledge" (p. 205). Denying epistemic diversity in school mathematics and science as a *pragmatic* or *realistic* choice is, therefore, a *de facto* injustice that denies not only what people may know or how they come to know, but also the very real history of math and science as disciplines that have evolved in relation to a diversity of human thinking, the world over. Thus, in thinking about how to engage power and ideology in disciplinary learning, a focus of our work became redressing epistemic injustice by engaging epistemic diversity.

Epistemic diversity refers to heterogeneity in knowing and doing a discipline—e.g., perspectives, meanings, practices, values—that are historically and culturally constituted. In mathematics and science education, identifying disciplinary knowledge and practices beyond those legitimated in schools (i.e., canonical western knowledge) has a relatively long and storied history (e.g., Cole, 2002; Civil, 2007; Lave, 1988; Warren & Rosebery, 2011). This body of research finds multiple epistemologies and a wide repertoire of everyday sense-making practices as necessary resources for children's disciplinary engagement. As Bang and Medin (2010) asserted, "Day-to-day practices are the sites at which epistemologies and epistemological stances are implicitly brought to life, learned, and infused with meaning" (pp. 15–16).

Scholars have called into question how theories of learning often reflect assimilation or erasure of epistemic agency of minoritized people to know and do the disciplines in favor of western epistemologies (Bang & Vossoughi, 2016; Gutiérrez, 2017; Gutstein, 2006; Martin, 2013). By contrasting cases of mathematicians that make visible epistemic injustice and the absence of it, Rittberg, Tanswell, and Van Bendegem (2018) imagined how injustices inherent in folk theories of a discipline and, interactionally, among people emerge in schools. To wit, education researchers have demonstrated how minoritized learners within schools can experience epistemic injustice (e.g., Bang, Warren, Rosebery, & Medin, 2012; Warren & Rosebery, 2011). As one example, an African American middle school student named Jonathan questioned why the sun was nonliving in a conventional classification activity. Jonathan asked, "If the sun is nonliving, then how does it produce the flowers, if it's like not real? 'Cuz like if you think about it, if something's dead, how does it help another thing out?" (Warren & Rosebery, 2011, p. 103). Jonathan's relational view of life rendered the sun (and, later, water) as living, for their capacity to nurture other life. His perspective, distant from western science but reflective of Indigenous epistemologies of science, was not taken up as a legitimate line of inquiry. Therefore, whether demonstrated in cases of professional scientists and mathematicians or children in schools, the risk of epistemic injustice should be of central concern in studies of learning.

Feminist scholars of science also argue the foreclosure of knowing and being as an injustice. Harding (1991) located western science as a project of White Bourgeoisie masculinity that systematically ignores feminist epistemologies of science. This, in turn, denies children deeper and more diverse opportunities for disciplinary learning. Consider, for example, Haraway's (1989) discussion of Dr. Jane Goodall, a White female primatologist, who offered novel methodologies to study the communication and survival activities of primate life. Arguing that Dr. Goodall relied on feminist epistemologies, Haraway describes how Dr. Goodall produced new and necessary knowledge related to the nature of primate culture than was readily known, accepted, or even imagined at the time. Across this diverse body of research, links between epistemic diversity and the diversity of people and their histories became clear, and evidenced the need to articulate a second theme of power—historicity and identity—by which to reinterpret the PDE framework.

Historicity and identity

Historicity and identity concern *being* and *becoming*—a recognition of learners as, simultaneously, persons in the moment and as shaped by social, cultural, and political history over time. The temporality of who a learner is, how she came to be, and who she is becoming, matters a great deal in how she positions or is positioned in relationship to her peers and the discipline. This idea frequently arises in mathematics identity research (see Herbel-Eisenmann, Wagner, Johnson, Suh & Figueras, 2015; Langer-Osuna & Esmonde, 2017) where *within the scene* identities telescope power and injustice *beyond the scene* to reveal the relationship between, for instance, Blackness and mathematics excellence (e.g., Gholson & Martin, 2014) or femininity and rationality (e.g., Mendick, 2006). These and similar studies elucidate how minoritized children are often at risk of being undervalued and underestimated in learning mathematics and science.

Racial narratives and ideologies visited upon minoritized bodies are profoundly consequential for disciplinary learning (Gholson, 2016; Larnell, 2016; Leyva, 2017; Shah, 2017). This is especially true as teachers are seldom systematically supported to engage ideologies of race, class, and gender in direct relation to their disciplinary work (Dyches & Boyd, 2017; Sengupta-Irving, Tunney, & Macias, in press). Philip, Olivares-Pasillas, and Rocha (2016) offered a generative example of how attunement to ideologies of race matter in disciplinary learning. Within the context of data analytics, they focused on a whole-class conversation where students were interpreting data displaying movie popularity in relation to neighborhoods. In conjecturing a relationship between the racial composition of movies and that of neighborhoods, a student described Black neighborhoods as *ghetto,* a typically derogatory term associating race (Blackness) and class (working class or poor). In response, an African American male student named William defended racial solidarity in the Black community as an alternate interpretation of the data. William's argument was not, however, valued by the teacher, who instead advanced a rationale related to marketing. The authors argued that the dismissal of William's cultural agency and his contribution to the topic were not only racially hostile, but also foreclosed on opportunities for students to develop a disciplinary capacity to be "racially literate about data" and "data literate about race."

Drawing upon this body of work, we contend that learning approaches that ignore historicity and identity of students and their epistemic diversity in the discipline sustain disparities of race, class, and gender, and promote epistemic injustice. Imbuing two themes of power in reinterpreting the PDE framework recognizes the histories and personhoods of minoritized learners and the diverse epistemic, cultural, and ideological terrain of disciplinary learning. We imagine, then, that the substantive contribution of rearticulating PDE through these themes of power is its potential to create and assess epistemically curious and disciplinary rigorous learning environments that simultaneously engage with the sociopolitical and ethical dimensions of learning and its consequences.

Researcher Positionality

We come to these questions of culture and power as a consequence of our histories in person, and we come to mathematics and science learning having observed and experienced its promises and perils from multiple standpoints. As women of Asian Indian ancestry, we are at once on the margins and in the main of STEM learning discourses—outside by virtue of patriarchy and racism, and inside by virtue of White supremacy's need for a model minority. As mothers who know firsthand that the excellence and ingenuity of children of color are always put at risk in and beyond schools, we see our work as seeking to safeguard their dignity and personhood to think, act, and be. So, as learning scientists, we draw on sociocultural and critical theories to foreground the influence that heterogeneity of contexts, histories, and identities play in disciplinary learning.

Connective and productive disciplinary engagement

At its core, the CPDE framework problematizes the notion of "disciplinary engagement," what Engle and Conant (2002, p. 403) described as "contact between what students are doing … and the issues and practices of a discipline's discourse" by surfacing the diversity of epistemologies and ontologies that sustain human knowing (Bang & Vossoughi, 2016). Warren and Rosebery (2011) eloquently advocated for recognizing the "very real ways [that] socio-historically structured inequities live in present-day, moment-to-moment interactions" (p. 98). Implicit here is a call to make visible connections between past and present, individual and structure. The press of CPDE is very much the same; a recasting of disciplinary engagement that is fundamentally *connective* engagement—connecting past with present; disciplinary ideas with a heterogeneity of ways to

know and be; mathematics and science with a diversity of cultural practices that shape them; and students to one another and their histories-in-person (Holland & Lave, 2001)—all of which work to clarify learning as a cultural and political endeavor. Next, we present the framework and subsequently, the guiding questions in applying this framework, as an interpretive lens on disciplinary learning.

The framework

Figure 1 describes the four principles of the CPDE framework. Reading left to right, each principle is paraphrased from Engle's (2012) articulation and redefined in relation to the themes of power. Following Figure 1, we discuss how CPDE leverages and extends each of the principles of the original framework.

Problematizing refers to the identification and resolution of disciplinary uncertainties about solution paths, conclusions, or justifications by students (Engle, 2012). Problematizing is fundamental to PDE, as opportunities to problematize engage students in productive struggle, where they grapple with ideas yet unclear but within reach (Hiebert et al., 1996). It prioritizes students' demands for resolution of uncertainties that stand to deepen their fluency in the disciplinary content and practices. Instances of problematizing include, for example, students expressing uncertainty about a procedure; about the affordances or constraints of a tool; or about a solution that raises new disciplinary questions. Uncertainty related to surface features of a task—e.g., missing information, a misstep in procedure—are not typically demonstrations of problematizing.

We extend the focus on students' curiosities and demands for resolving disciplinary quandaries by considering how problematizing likely favors disciplinary uncertainties aligned with the academic content and outcomes considered normative. We therefore explicitly expand what is seen as *disciplinary* to protect against the assimilation or erasure of uncertainties (as well as knowledge,

	Connective and Productive Disciplinary Engagement (CPDE)	
Principles of PDE (Engle, 2012)	**Epistemic Diversity**	**Historicity & Identity**
Problematizing: Take up and seek resolution of disciplinary uncertainties together with peers and the teacher	Take up and seek resolution of disciplinary uncertainties with peers and the teacher, including the epistemic or cultural assumptions that give rise to the uncertainties, and the sociopolitical dimensions the assumptions surfaced	Learners' identities and histories are treated as legitimate bases from which to raise uncertainties or to identify the sociopolitical dimensions of them
Authority: Take up of intellectual agency to share their ideas; are recognized as authors of the ideas; contribute to others' ideas; and, gradually develop into local intellectual authorities	Take up of epistemic or cultural agency to share a diversity of perspectives on disciplinary ideas; diverse ideas be seen as valued contributions	Learners are recognized as having ideas informed by (but not limited to) their social locations, identities, and histories; recognized as authors and contributors in relation to those ideas; and as gradually developing into local intellectual authorities
Accountability: Justifying ideas by making sense of them to oneself; to peers; to internal and external authorities; and to the discipline	Justify ideas (to self, peers, others) in relation to epistemic and cultural knowledge that can be recognized by internal and external authorities as generative to the discipline, past and present	Justify ideas (to self, peers, others) in relation to culturally and historically constituted identities and social realities of people (self, peers, others)
Resources: Any resources that support students' overall disciplinary work and the embodiment of the other principles in the learning environment	Any resources that support a diversity of epistemologies and the sociopolitical dimensions surfaced in students' disciplinary work and their embodiment through the other principles	Any resources that support a diversity of identities and histories to surface and shape students' disciplinary work and its embodiment through the other principles

Figure 1. The four principles of connective and productive disciplinary engagement.

practices, histories, and identities) that are disciplinary, but are often disregarded as tangential, inconsequential, or irrelevant to normative western epistemologies and identities. This can include students drawing upon Indigenous or feminist epistemologies to consider the historical dimensions of scientifically accepted facts, engaging multiple modalities of counting and measurement, and arguing in ways that make contact with social or political realities.

Authority refers to students gaining intellectual agency to share their ideas; getting publicly recognized by the teacher or other students as authors of those ideas; becoming contributors to the ideas of others; and gradually being positioned as a local authority on disciplinary topics (Engle, 2012, p.170). Engle predicted the strength of PDE depended on how far learners traveled up the intellectual authority scale, which then influenced their inclination to engage in problematizing. When learners are positioned as authors or contributors to others' ideas but are not authorized to share "what they actually think" (p. 170), such instances do not reflect intellectual authority.

We reconceptualize intellectual agency by amplifying the epistemic and cultural nature of the *intellectual* work. We see encouraging intellectual agency as also encouraging learners' epistemic or cultural expressions of reasoning by inviting them to draw on their history of experiences with disciplinary ideas beyond schools. This explicitly elevates students' unfettered thoughts and contributions, particularly when distant from what is normatively defined, without undoing their potential as local intellectual authorities. This protects against silencing what students actually think (legitimated epistemic diversity) and who they actually are (legitimated histories and identities). This could include students challenging classification systems in science as informed by their social locations or their questioning the truth-value of what state-sanctioned internal authorities (i.e., the teacher, textbook) or normative external authorities (i.e., scientists) deem disciplinary knowledge and knowing.

Accountability refers to learners justifying their arguments in relation to others' ideas and the discipline. The expectation of explanation supports students in being "disciplinarily grounded and productive" (Engle, 2012, p. 171) while also allowing for critique and revision. Accountability provides an important balance to authority where, for example, accountability to the discipline can mitigate the uptake of misconceptions by an influential peer. Engle (2012) recommended building the "inside-out accountability" (p. 172) as one way to ensure balance—i.e., account to oneself, to a peer, to internal and external authorities, and, finally, to the discipline (norms, practices).

In focusing on students' accountability to the discipline and others' ideas, we broaden the disciplinary basis for their accounting and the breadth of people to whom they may be accountable. Amplifying cultural and epistemic heterogeneity in the discipline expands the modalities and logics students use in disciplinary justification. This protects against the misidentification of students' attempts at accounting for ideas as having no disciplinary basis when they are simply culturally distant from normative conventions. As a balance to authority, accountability also explicitly expands how students' identities and histories influence who is asked to account for their thinking (or not), and to whom they are held accountable (others). For example, this would extend inside-out accountability to include students accounting for ideas in relation to community elders or social movements (e.g., environmental justice, Black Lives Matter).

Resources refers to time, space, technological tools, cultural artifacts, institutional support, classroom norms, scaffolding, and anything else that helps actualize PDE and the other principles. Resources provide an important balance to problematizing: Although insufficient resources may cull students' efforts to resolve disciplinary uncertainties (problematizing), too many resources may oversimplify a problem space and foreclose on opportunities to problematize. So, resources must advance but not overwhelm the embodiment of other principles.

We expand upon the forms and functions of resources to also include those resources that enliven cultural and epistemic diversity while inviting students' identities and histories into

disciplinary work. Examples of this could be resources that make silenced identities and ideologies visible (Nasir & Cooks, 2009; Nasir, 2012), such as material resources like technology-based epistemic scaffolds (Sandoval & Reiser, 2004); relational resources that animate a diversity of identities and histories (Middleton & Jansen, 2011); and/or ideational resources like teachers' discursive positioning of students and their ideas (Cohen & Lotan, 2014; Hand, Penuel, & Gutiérrez, 2012).

Guiding questions in using CPDE

In this article, we apply CPDE as an interpretive framework in studying children's learning in science and mathematics. We begin by offering example questions that analysts might pose in using CPDE (Figure 2).

Although Figure 2 reflects the use of CPDE as an interpretive framework (how we will use it here), CPDE (like PDE) is intended as a framework for analyzing as well as designing learning environments.

Applying CPDE

In this section we apply the CPDE framework (Figure 1) to two previously published case studies of classroom-based disciplinary (math/science) learning. In each case, PDE was not the original analytic frame, but sufficient empirical and descriptive information (e.g., design of settings, norms, conversational flow) was available for reanalysis. We found each to be a moderate to strong case of PDE. Selection of these cases came as a consequence of reading nearly 150 case

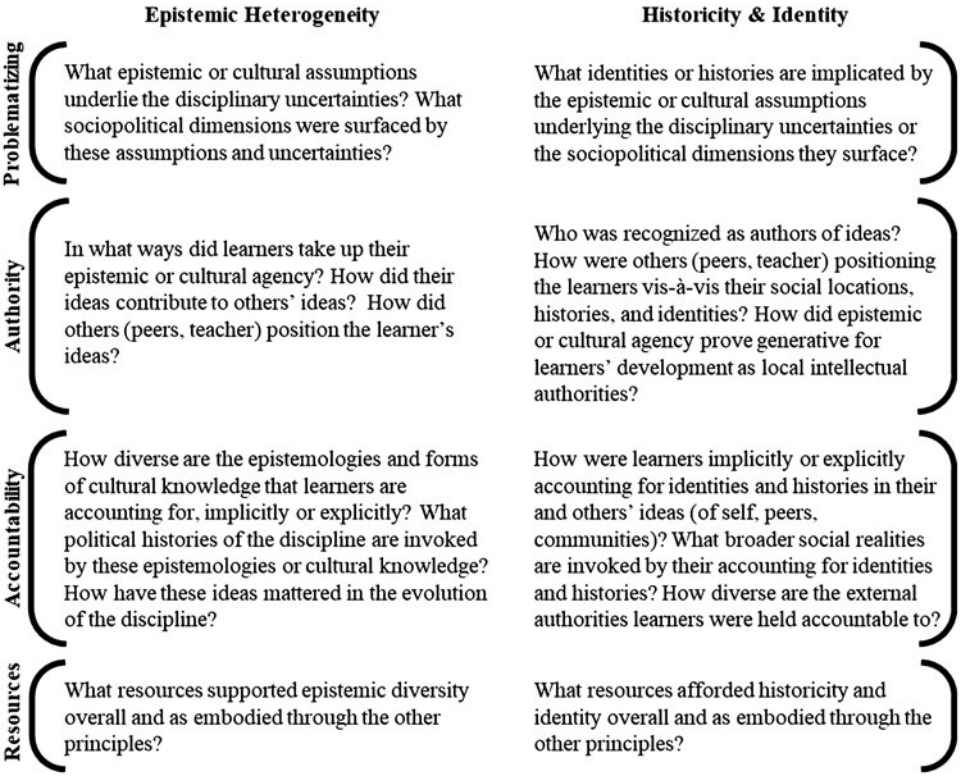

Figure 2. Guiding questions in using the CPDE framework.

studies of children's mathematics or science learning in schools, with the vast majority being eliminated from consideration due to lacking detail about the turns of talk among children, or because disciplinary uncertainties that diverged from normative expectations were redirected, assimilated, or ignored too quickly to be taken up. In contrast, in the cases selected, the disciplinary uncertainties students raised were given some space to take hold, reflected cultural and epistemic heterogeneity, and carried the potential for relating to the identities of the children. However, the cultural and academic histories of children were not always included in the original analyses, as is desired of the CPDE framework, prompting us to reach out to some authors and seek additional information. Further, the sociopolitical dimensions of the uncertainties were directly implicated in the history of the disciplines, and the assimilation or erasure of minoritized epistemologies and ontologies in their becoming settled knowledge. Even though both the cases included several aspects of what we refer to as building blocks of CPDE, we also describe ways in which further resources and accountability structures would have allowed for the connective aspects of the learning to take hold more explicitly and for students to deliberately investigate them vis-à-vis disciplinary uncertainties.

In what follows, we provide a synopsis of the original analysis, ways in which each case represented PDE and a background on the cases to be used for CPDE. We then apply the CPDE framework, drawing particular attention to how the themes of epistemic diversity in the discipline and historicity and identity of students surfaced in each case, and with what import in deepening the understanding of students' disciplinary engagement as productive and connective.

Case 1: metamorphosis

This case reflects insights from the Learning-in-Practice after-school seminar of the Cheche Konnen Center as described in Warren, Ballenger, Ogonowski, Rosebery, and Hudicourt-Barnes (2001). Drawing on a case of Haitian American students engaged in argumentation to make sense of insect metamorphosis, Warren et al. (2001) illustrated students' "scientific sensemaking as encompassing a varied complex of *resources*" (p. 532), including students' everyday experiences, cultural practices such as their embodied imagining, and the use of Haitian Creole (a language often dismissed as unscientific) to describe their sense-making. As a case of PDE, the four principles were evident in the ways students deemed a straightforward metamorphosis demonstration problematic, took up their intellectual agency and authority to forward multiple views on a question posed by a peer, and were accountable to themselves, their peers, and the discipline in grappling with the topic of metamorphosis. Among other resources supporting their engagement were the use of student-centered science circles, shared text, and prior academic activities.

Context

The case concerns a mixed-grade (5–8th) bilingual class of recent immigrant students. The students and their families had few opportunities for formal schooling prior to immigration. The debate over insect metamorphosis occurred during a *science circle*, which was an opportunity for students to read, question, debate, and share ideas. Over several weeks, the students had been observing mealworms move through the stages of metamorphosis. The case begins when Manuelle poses a question (Line 1) after reading a text aloud about how much larvae eat before becoming pupa. The authors described the ensuing discussion and debate by highlighting the following exchanges:

Epistemic diversity

In applying CPDE, there were three epistemic assumptions that surfaced in students' problematizing of metamorphosis, which we refer to as *ecological*, *human supremacy*, and *unity of life*.

1	Manuelle	Why, if people eat and eat, don't they change their skin, don't they transform, the way insects do?
2	A student	[*Asserts that human skin also peels.*]
3	Manuelle	But we don't transform.
4	Fabiola	God did not create us like insects.
5	Raoul	If you play basketball, you get dirty: when you bathe, your skin comes off with the dirt.
6	Marianne	It's not all people who do that. [*She embodies an old person walking; implying they do not play hard, get dirty, and go through skin-peeling*]
7	Jean	[*Says human skin rubs off inside of clothes, as learned from TV*]
8	Stefan	People and animals aren't the same thing.
9	Jean-Charles	Manuelle, skin changes. It's like, the larva, when it was inside the egg, you, like when you were inside your mother's stomach. It's like, when you were a little baby, when you were born, when you were a little baby, you had hardly any hair. Didn't that change? Don't you have hair?
10	Manuelle	Not all babies are born without hair.
11	Marianne	We grow, we don't change.
12	Jean-Charles	When you were a baby, your eyes were closed.
13	Joanne	[*Argues that Manuelle today and Manuelle as a baby did not look the same; implies we do change*]
14	Manuelle	Do I change my skin like this, *vloop, vloop*? [*Embodies the unzipping of skin and climbing out*]

Furthermore, what students found perplexing about metamorphosis arguably carry the sociopolitical weight of questioning, asserting, or rejecting the nature-culture divide (Bang & Medin, 2010), respectively.

Manuelle's contributions (as supported by Marianne) represented an ecological stance in problematizing the eating behaviors of larvae as represented by the text she was reading ("how much larvae eat before becoming pupa"). In Manuelle's question (Line 1), we see a reach to not take this fact for granted and a desire to understand the relation between the eating behaviors of insects with their unique stages of change and transformation more clearly, and in parallel equivalence to that of humans. This question also carried forward the sociopolitical history of science in which ecological knowledge authored by women and Indigenous peoples has long been assimilated, erased or ignored. Consider, for example, renowned naturalist Maria Sibylla Merian (1647–1717), whose work demonstrated plants as hosts for specific insects. This and other original scientific revelations in her work were not widely recognized until the late 18th or early 19th century (Etheridge, 2011). Argued by some as the *first ecologist* (Etheridge, 2011), the profound influence of her pioneering work on naturalists and scientists remains elusive in modern science classrooms. Thus, asking after the parallel equivalence in food consumption of insects and humans and in considering the relationship between eating and insect transformation, Manuelle's question not only invites epistemic assumption (i.e., an ecological assertion), but also invokes an associated sociopolitical history of ecology in science.

The second epistemic assumption (human supremacy) that problematized metamorphosis was voiced by Fabiola and Stefan. Manuelle's opening question positions insects as unique, but perhaps behaviorally parallel to humans, which Fabiola and Stefan seemingly reject (Lines 4, 8). Instead, they assert the nature-culture divide with culture (humans) as superior to nature (insects, plants). Fabiola's retort to Manuelle invoking God seemed to suggest a faith-based epistemic stance by which, even if God created humans and insects, insects are not humans. Stefan's words make this an even more explicit stance ("people and animals aren't the same"), albeit without similar reference to religion. The nature-culture divide, according to Medin and Bang (2014), draws a "psychological distance between humans and the rest of nature" (p. 2), allowing humans to see themselves as outside of ecosystems rather than as a part of or related to them. Discussing the nature-culture divide in a framework of faith not only invites epistemic assumption, but also invokes a sociopolitical history of deep contemplation (and sometimes conflict) among people of faith and science, over the natural world. Noticeably, although Manuelle attempted to refute every other response that contested her question, she did not or could not counter Stefan or Fabiola's response (and perhaps implicitly, the charge that science cannot answer everything).

We refer to the third epistemic assumption that problematized metamorphosis as *unity of life*, one way to reject the nature-culture divide. Jean-Charles (along with Raoul, Jean, and Joanne) compared humans with insects in a way that may reach past Manuelle's ecological perspective to instead assert similarity, if not sameness (Lines 9, 12). He identifies multiple ways two species that look very different may, in fact, be quite similar (e.g., coming out from mother's womb and hatching from an egg; change in body features in humans and insects). This perspective reflects a unity of life that scientific research has also considered—the transformation of insects in pupae is not markedly different than that of human cells in a womb (Jabr, 2012a, 2012b). Before hatching, worms develop cell tissues for the adult body parts—like wings, antennae, legs, and eyes—that lay dormant or exist as tiny rudimentary parts until the pupa stage. Once a pupa, those tissues go through rapid cell division required to form the wings and other features of an adult winged insect. Zooming out further, the sociopolitical dimensions of rejecting the nature-culture divide, as Jean-Charles does, brings forward the great debates primatologist Dr. Jane Goodall engaged in rejecting the inferiority of chimpanzees and their social worlds to that of humans.

Several features speak to the principles of authority, accountability, and resources, but we limit our discussion to a few that make contact with epistemic diversity, specifically. As Warren et al. (2001) shared, the science circle, as a participation structure, was a critical resource designed for the children to reason scientifically together through personal experiences, embodied imagining, and home-language practices, which created opportunities for multiple students to be seen as local intellectual authorities. In the science circle, students could also hold one another accountable in a variety of ways. When God was invoked, for example, neither the teacher nor the students treated such an instance as having violated authority or accountability; that is, faith as an epistemic stance mattered in expanding with what agency children could speak and also what authority they could hold one another's reasoning accountable to, within a scientific debate. Although their disciplinary uncertainty about the nature-culture divide remained unnamed, the discussion also evidenced an expansive range of ways in which children could invoke their agency and hold one another accountable. That said, the children lacked accountability structures and resources that would have allowed them to further pursue the epistemic assumptions and sociopolitical histories related to metamorphosis or science more broadly. Broadening the science circle to include external authorities like local etymologists, naturalists, farmers, theologians, or community elders could be one way of providing resources to support the scientific uncertainties raised.

Historicity and identity

The shared history of the students as recent immigrants and speakers of Haitian Creole mattered a great deal to their disciplinary engagement and to the original analysis. Specifically, the case makes evident how conversational norms (e.g., posing a question while reading aloud), embodied imagining (e.g., vloop vloop gesture), invocation of personal experiences (e.g., playing basketball), and the use of Haitian Creole (see especially the focus of original analysis on Jean-Charles' use of Haitian Creole in an interview), shaped what was possible for disciplinary engagement. Further, the norms of the science circle legitimated the children's rights to invoke histories and personal identities (e.g., as people of faith) in the midst of academic discourse. With the teacher's relative silence in these turns of talk, except for an invitation for students to engage with Manuelle's question, we can say little about how he positioned students and their ideas beyond the freedom he allowed positioning themselves and others as knowers in the circle.

From the original article, we know most about Jean-Charles's identity in the local context. He was ascribed the institutional labels of being a special education bilingual student with particular difficulties with language. As Warren et al. (2001) discussed, such labels belie his sophisticated mobilization of Haitian Creole to evidence a nuanced understanding of metamorphosis. In an interview, for example, he chose a creative Haitian Creole phrasing—"whereas both 'become,' one

becomes big and one becomes something else" (p. 537)—to preserve his epistemic stance (i.e., unity of life) while also honoring the metamorphic change that Manuelle and Marianne were suggesting (Lines 11, 14). As such, his labels did not undermine his standing as an intellectual authority in the circle, nor was he positioned apart in holding himself or others accountable to the disciplinary uncertainty. This is to say, the sociopolitical and historical acquisition of children like Jean-Charles (immigrant, racially minoritized, bilingual) by deficit institutional labels like *special education* (Blanchett, 2006; McDermott, 2001) is directly relevant to the analysis of disciplinary engagement in this case.

Case 2: measurement

This case reflects research from The Algebra Project Transition Curriculum (Moses, 1992) as presented by Godfrey and O'Connor (1995). The authors described how students develop "communicative authority" (p. 342) by using mathematical language within the constraints of a complex activity. Rather than depend on the authority of textbooks or the teacher, each student team created their own measurement unit, its symbol, and its meaning. As a case of PDE, the task set students up to problematize what counts as a unit measure and how to represent it. As the authors argued, the process of choosing a symbol is quite arbitrary but also conveys a mathematician's authority over symbol creation, its meaning, and application within a local problem space. Here, students could demonstrate their local intellectual authority on the topic of measurement and symbolization. Moreover, the participation structure (team → whole-class → team) created opportunities for students to be accountable to the discipline and peers. During whole-class presentations, students were encouraged to solicit and respond to questions, and revise their work. Among the resources supporting problematizing, authority, and accountability were classroom norms (as inferred by teacher and student activity), the participation structure, and physical materials.

Context

Sixteen sixth-graders worked in small teams in a unit designed to move them from first-person understandings of measurement (i.e., nonstandard) to formal or standardized measures. In the task, teams had to compare the heights of two team members without using standard measuring units. One team (KND-Team: Kadeem, Noel, Daria) used Kadeem's hand (tip to palm) as the unit of measure to compare Noel and Daria's heights. They created a six-fingered hand, the *Kadeem hand span*, to denote their measure. During whole-class presentation, peers asked for clarifications, some of which led to a revision of their thinking. When a subsequent group (A-Team: Elliot, Brandon, Justin) presented, other students objected to the use of a standard measure (inches) in their work as contradicting the task. In response, the A-Team referenced a shared experience of the gym teacher measuring their heights in inches. After some debate, the A-Team agreed to revise their work. When the KND-Team later presented their revisions, a student asked if one of them had six fingers like the symbol they chose. Kadeem clarified "it was a symbol," to represent their measure and not an actual hand (p. 334). A-Team member Elliot took issue with *hand span* as the distance from fingertip to palm, arguing instead it is "like wingspan—from tip to tip." After Kadeem turned to the teacher to confirm that the task invited new meanings for words, the teacher asked: "Do you all think this is an okay thing to do in this class? Is it okay to create new definitions for old words?" In the ensuing discussion, students felt it was possible in this task but suggested *vertical hand span* as an alternative name for the unit. Elliot, however, maintained that that defied the conventional meaning of *hand span*. The teacher ended the discussion by asking the KND-Team to consider their peers' feedback. The next day, KND-Team announced they had retained the symbol but would call it the *vertical hand span*.

Epistemic diversity

In applying CPDE, debating symbolic notation—e.g., using a six-fingered hand span as a symbol—not only afforded problematizing and authority; it also afforded students' participation in a gateway conversation about mathematics as a canon of cultural knowledge (Dyches & Boyd, 2017; Martin, 2013). As such, in students problematizing A-Team's inches and KDM-Team's hand span, we see evidence of students expressing their epistemic agency to make sense of the sociopolitical dimensions of mathematical language, including symbolic notation as expressing (or digressing from) western conventions (though without additional data the extent to which this was explicitly discussed is unclear).

Historicity and identity

The task, as designed, sets students up to express their epistemic agency and left ample space for students to draw on personal histories or cultural expressions in defining measurement units and symbols. Indeed, the only cultural conventions and expressions disallowed by this task were those that would replicate the history of standardization in western mathematics. Consider how the A-Team, which consisted of all middle-class White male students (O'Connor, personal communication), were inclined toward maintaining western or institutional authority in accomplishing the task: asserting a normative measure (inches), drawing on institutional authority to defend their decisions (i.e., gym teacher), and challenging KND-Team's repurposing of *hand span* from its conventional meaning. In this way, the episode evidences a decentering of western cultural authority through an assertion of nonstandard knowledge and practice of measure as the norm. We contend this legitimated the epistemic or cultural agency of teams like KND—comprised of an African American male student (Kadeem), a biracial female student whose father was African American (Daria), and a White student Noel (O'Connor, personal communication)—to assert their authorship and intellectual authority over mathematical language and symbol usage.

From the perspective of accountability, the study of measure invites an understanding of mathematics as a culturally situated endeavor, where a unit such as pre-19th century *cow's grass* or a tailor's forearm suggests that measure/measuring is responsive to the social realities of people and communities. In context, what is a standard measure of length can thus be justified based on the social realities of she who is measuring. So, when KND-Team revised their thinking as both accommodating the language of *vertical* but also maintaining *hand span* (and its six-fingered notation) their justification was responding directly to the political dimensions surfaced through student problematizing, as discussed (i.e., who gets to shape representations and symbol conventions, or who determines truth in mathematics). Here, much as Engle and Conant (2002) explained of PDE, we see how the principles of authority and accountability work closely together by which KND-Team could justifiably depart from settled practices of western conventions, and experience mathematics as a *connective discipline* of person and practice achieved through active interpretation, representation and authorship.

Discussion

CPDE is one way to press on the generative power of the PDE framework (Engle, 2012). In revealing the disciplinary diversity in what children know, do, and express, CPDE creates opportunities for epistemic justice and repair. It begins with actively disrupting epistemic fundamentalism to form expansive notions of disciplinary learning and learners in and beyond schools. In that sense, the CPDE framework draws inspiration from scholarship that seeks the *rightful presence* of minoritized people as a project of not only future possibility but inclusivity in the present (Calabrese Barton & Tan, 2019; Tedesco & Bagelman, 2017; Vrasti & Dayal, 2016). CPDE argues for a legitimate membership of children in classrooms vulnerable to the epistemic injustice that

comes with assimilating, mistaking, or ignoring the Jonathans, Manuelles, Mariannes, Jean-Charles, and Kadeems in our midst. As a framework that engages the political and ethical dimensions of learning, CPDE stands to be most restorative for minoritized children's experiences of mathematics and science in schools. At the same time, it has the potential to allow every student to grapple with the cultural, political, and ethical reach of mathematics and science in our worlds (e.g., Esmonde, 2014; Philip, Gupta, Elby, & Turpen, 2018; Vakil, 2018).

As an interpretive framework, the power of the CPDE hinges on the descriptive depth with which students' curiosities can be traced over time. CPDE interprets when, how, and by whom disciplinary uncertainties or perplexities surface, are sustained and pursued, and with what sense of resolution. CPDE also requires amplifying student voice to ascertain what they actually think about disciplinary ideas and debates. In particular, microethnographic and microanalytic techniques that focus on the embodied and discursive acts of learners is essential to this work, much as we have seen in studies of minoritized children's identity development (e.g., Bishop, 2012; Langer-Osuna, 2016; Ritchie, 2002). For this reason, beyond mainstays of ethnographic inquiry like observations and interviews, CPDE also invites contemporary methods like Family Forest Walks (Marin & Bang, 2018) and Photovoice (Harper, 2017) to amplify the diversity of perspectives children may have of their immediate environments. Methods like these create opportunities for students to represent what they think about disciplinary ideas, narrate their meaning, and make visible the cultural and relational terrain from which those thoughts emerge (e.g., Tzou & Bell, 2010). Seeking evermore creative ways of understanding how identities and histories matter in the evolution of disciplinary uncertainties moment-to-moment and over longer periods of time, will further advance the power of CPDE as an analytic tool.

As a design framework, there is much still to be known about CPDE. In particular, the principle of resources is perhaps articulated least in this article. This reflects our own uncertainties about the specific material, relational, or ideational resources that make way for a diversity of epistemologies and ontologies to take root in learning environments. We conjecture, however, that this uncertainty will find resolution when we look closely at learning environments that already reflect CPDE (e.g., Cheche Konnen Center), as well as by conducting future studies that will actualize the framework's ideas.

Teachers are essential for creating the conditions by which connective and PDE can emerge. In particular, we suspect that teachers wanting to address the education debt (Ladson-Billings, 2006) that shadows minoritized students in schools will find a new foothold for their practice in CPDE. The political clarity of teachers, that often characterizes teachers of color in particular (Kohli, 2009; Kohli & Pizarro, 2016; McKinney de Royston, Vakil, Ross, Givens, & Holman, 2017), positions them as "gate openers" (Koerner & Hulsebosch, 1995, p. 9; see also Beauboeuf-Lafontant, 1999) to new academic possibilities for minoritized students. We see CPDE as dependent, in part, on the political work of teachers willing to deepen and diversify their students' experiences of mathematics and science, while also engaging humanizing pedagogies that allow children to bring forth their whole-selves (Gutiérrez, 2013). As Dyches and Boyd (2017) explained, teachers need to understand school subjects as curated and privileged subsets of a much broader disciplinary knowledge terrain. They should make transparent the "controversies in a discipline, the centrality of some topics at the exclusion of others … [so that] content becomes not a taken-for-granted entity that is immutable but rather something that has been canonized" (p. 486). We conjecture that when teachers learn the sociopolitical controversies, histories, and new directions of their disciplines along with the histories and identities of their students across time and space, they are better prepared to amplify the disciplinary ideas their students raise.

Epistemic and cultural heterogeneity is endemic to human (disciplinary) learning and progress. Anthropological studies have demonstrated how modern mathematics and science has culminated through cumulative contributions of diverse civilizations over centuries and is continuing to do so (Katz, 2007; Toulmin, 1967). In fact, ways in which the disciplines of mathematics and science

embody cultural and political worldviews of people and the role that social context (societal needs, wars, etc.) and human practices (such as aesthetics, care, arts, storytelling, metaphors, and intuitions) play in its knowing are being increasingly investigated and accepted (Ascher, 2017; Cobern, 1996; Closs, 1986; Harding, 1998; Haraway, 2006; Hottinger, 2016). By foregrounding the significance of epistemic assumptions and their sociopolitical dimensions in designing and analyzing learning environments, CPDE thickens the intellectual substrate in which disciplinary curiosities and uncertainties can find root. Hence, what may seem a momentary discursive aside ("If something's dead, how does it help another thing out?") can now be seen as seeding rich opportunities for students to connect disciplinary ideas to a root system of great diversity epistemically, in cultural form, identity, history, and ideology.

This more connective learning environment problematizes what counts as disciplinary and, by extension, who and whose ideas count. This is not an easy ask of teachers or researchers, who may be as vulnerable as the novice learner to erase or assimilate ideas that seem distant from normative disciplinary displays. CPDE, therefore, works to recognize the heavy lifting of expanding our own epistemic horizons. As Dotson (2014) wrote:

> Epistemic oppression … can only begin to be addressed through recognition of the limits of one's overall epistemological frameworks. This generally means that one's epistemic resources and the epistemological system within which those resources prevail may be wholly inadequate to the task of addressing the persisting epistemic exclusions that are causing epistemic oppression. (p. 116)

Expanding our reach toward the diversity of epistemologies and ontologies that have long sustained human learning will require that we learn anew: learning about the disciplinary histories in relation to the cultural and political contexts of their progressions both told and forgotten, and imagining what mathematics and science could be learned and claimed in schools.

As such, beyond a tool of design or analysis, CPDE is a call for "collective political action" (Fricker, 2007, p. 174) of researchers, educators, and other agents of education working together to build and transform disciplinary learning environments. It invites novel design partnerships recruiting teachers and researchers working alongside youth, families, and communities to reconstruct possibilities of who and how we benefit from diverse thinking rooted in cultural ties with the world (e.g., Bang, Faber, Gurneau, Marin, & Soto, 2016; Cammarota & Fine, 2008). It flows within a growing current of work seeking to connect disciplinary learning with the diverse practices, histories, and worldviews of minoritized communities (e.g., Bang & Vossoughi, 2016; Booker & Goldman, 2016; Gutiérrez & Jurow, 2016). This seemingly more intrusive and collaborative approach to the study of disciplinary learning will require politicized trust, a trust that "actively acknowledges the racialized tensions and power dynamics" of research relationships (Vakil, McKinney de Royston, Suad Nasir & Kirshner, 2016, p. 199). By proposing and refining interpretive tools of design and analysis, a more expansive, rigorous, and responsive understanding of human learning draws evermore within reach.

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