

Teacher learning about the integration of energy and equity: A case study

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Multicultural education invites teachers to support students in critiquing the foundations of a given discipline, with the aim of reimagining that discipline and the purposes it serves. In this paper, we present a series of cases in which high school physics teachers who are enrolled in a summer professional development course expressed vexation as they tried to integrate equity with the physics concept of energy and in which one teacher made significant progress in this integration. These cases serve to illustrate what teacher learning about multicultural education might look like in physics and what resources may support this learning. These cases also point us to some of the ways in which physics as a discipline and schooling as a system make it difficult for teachers to critically examine the canon.

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I. INTRODUCTION

Critical Race Theory names that white supremacy¹ is endemic to all aspects of U.S. society, from the law to employment to schooling [2–8]. This endemism means that structures and institutions reify and uphold white supremacy, embedding it not only in policies and practices but also in ideas and values. We observe this in educational settings as we examine the history of schooling, where enslaved children were prohibited from schooling; schooling has been and in many ways continues to be racially segregated; school resourcing and discipline policies are racialized; and the school curriculum valorizes and centralizes knowledge constructed by white European men [9–11].

Critical scholars have responded to the reality and the permanence of racism in education by developing a framework for multicultural education, which recenters a multiplicity of ways of knowing and being in the classroom, rejecting the notion of (Eurocentric) epistemic superiority [12,13]. Often misunderstood as limited to curricular change [13], the framework for multicultural education (MCE) developed by Banks and colleagues in fact draws on five dimensions—content integration, knowledge construction, equity pedagogy, prejudice reduction, and empowering school culture—to recreate school culture toward more equitable and just teaching. Some of these dimensions focus on action at the classroom level, others on the action at the school and departmental levels; both are needed for change to happen. The goal of MCE is for “all students—regardless of their gender and social class and their ethnic, racial, or cultural characteristics—[to] have an equal opportunity to learn in school,” acknowledging that schools are “currently structured” to give some students “better chance[s] to learn” than others. Consistent with Critical Race Theory, MCE also acknowledges that due to the permanence of racism, the full vision of MCE can never be fully attained; MCE is something educators do and continue doing, not something they accomplish.

Importantly, for this paper, MCE encourages teachers to support their students in *critiquing* mainstream academic knowledge—as Critical Race Theory has done for the law—by situating knowledge in its historical context, considering whom mainstream knowledge serves and what purposes it advances, and dreaming about how academic

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¹In contrast to a meaning of white supremacy that focuses on overt acts of racialized hatred, when we use the term “white supremacy,” we mean the everyday enactments of “the systematic maintenance of the dominant position that produces [w]hite privilege” [1]—the multitude of mechanisms by which whiteness stays at the center.

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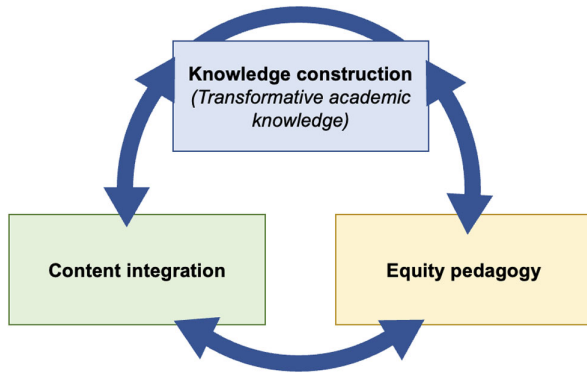


FIG. 1. Mutually reinforcing nature of the knowledge construction, content integration, and equity pedagogy dimensions of MCE.

disciplines might be transformed for liberatory purposes. Our project team is designing a professional development (PD) experience that aims to support high school physics teachers in coming to see *energy in physics* as a sociopolitically and historically situated concept. Although energy seems to be among the most purely abstract concepts in physics, in fact, the concept of energy, like all science concepts, was constructed at a specific historical time and place, for the advancement of specific causes [14–17]. Present-day physics energy concepts were shaped primarily in the Industrial Revolution when Britain was establishing coal-powered factories to process goods from its global trading empire, which were brought to England on steamships [18,19]. Thus, physics instruction about energy emphasizes work, heat, power, and efficiency: those concepts constructed to characterize and improve the engines in those factories and steamships [19]. These concepts carry not only the economic values that were prevalent in Britain in the 1800s but also the moral values [17–19]. Efficiency, for example, was a theological concept, referring to the idea of maximizing the usefulness (e.g., processing and manufacture) of divinely provided natural resources [18].

The design and aim of our PD draw on elements of multicultural education to support teachers in developing “transformative academic knowledge” in the context of energy, where “transformative academic knowledge” is defined as understandings that “challenge mainstream academic knowledge and expand and substantially revise established canons, paradigms, theories, explanations, and research methods” [20]. In Banks’ theory, the development of transformative academic knowledge is supported by all five dimensions of MCE; here we highlight three (Fig. 1) that allow teachers to make local, classroom-level changes to their instruction:²

²Other professional development programs focus on supporting teachers in working for structural change by, for example, building networks of change (e.g., [21,22]). This has not been our focus, though our theory of action does assume that teachers will become change agents in their schools and departments.

- Equity pedagogy “exists when teachers modify their teaching in ways that will facilitate the academic achievement of students from diverse racial, cultural, gender, and social-class groups.” For example, “using a variety of teaching styles and approaches that are consistent with the wide range of learning styles within various cultural and ethnic groups.
- Knowledge construction “relates to the extent to which teachers help students to understand, investigate, and determine how the implicit cultural assumptions, frames of reference, perspectives, and biases within a discipline influence the ways in which knowledge is constructed within it.”³ For example, students can ask questions about “whose point of view or perspective does this concept reflect” and “how might a (e.g., Lakota Sioux historian) describe this period in U.S. history” and “what are other ways of thinking about and describing” this.
- Content integration is “the extent to which teachers use examples and content from a variety of cultures and groups to illustrate key concepts, principles, generalizations, and theories in their subject area or discipline.”

In Banks’ framework, the construction of transformative academic knowledge—knowledge that challenges and expands established (Eurocentric) canons—is supported by (and supports) content integration, or, as above, “the extent to which teachers use examples, data, and information from a variety of cultures and groups to illustrate the key concepts, principles, generalizations, and theories in their subject area or discipline,” by disrupting the hegemony and centrality of Eurocentric content and expanding what the discipline means (and thus what is taught). The equity pedagogy dimension, which includes using teaching strategies that support students in engaging with multicultural, transformative content, encourages critique and expansion of what is thought of as knowledge. In this way, MCE is accountable to Critical Race Theory by (i) making apparent the ways in which school knowledge and knowledge-generating processes have reified white supremacy and (ii) expanding the possibilities of what instruction can look like, changing the kinds of knowledge that are produced in classrooms and the opportunities that students have to learn.

Banks and colleagues describe a variety of forms of knowledge that can be cultivated by schooling (Table I) and a variety of ways in which teachers have attempted content integration (Table II). We would argue that the transformation and social action approaches to content

³Notably, “knowledge construction” has had many meanings in physics education research, including meanings that are consistent with a cognitive interpretation of constructivism. Banks and colleagues’ interpretation of “knowledge construction” is consistent with a sociocultural approach to learning, wherein learning is influenced by social and cultural factors, including racialized, gendered, and classed power dynamics [6].

TABLE I. Forms of knowledge in Banks *et al.*'s framework [20].

Knowledge type	Definition, according to Banks and colleagues	Example from energy
Personal or cultural	The concepts, explanations, and interpretations that students derive from personal experiences in their homes, families, and community cultures.	We get energy from eating food. "I have lots of energy right now!" Energy is a life force.
Popular	The facts, concepts, explanations, and interpretations that are institutionalized within the mass media and other institutions that are part of popular culture.	Alternative energy sources
Mainstream academic	The concepts, paradigms, theories, and explanations that constitute traditional Western-centric knowledge in history and the behavioral and social sciences.	Conservation of energy The first law of thermodynamics
Transformative academic	The facts, concepts, paradigms, themes, and explanations that challenge mainstream academic knowledge and expand and substantially revise established canons, paradigms, theories, explanations, and research methods. When transformative academic paradigms replace mainstream ones, a scientific revolution occurred. What is more normal is that transformative academic paradigms coexist with established ones.	Situating energy in its sociohistorical context and understanding ways that this context shaped the substance of the concept—e.g., the emphasis on work as a byproduct of the Industrial Revolution An expansive view where different notions of energy can be in conversation without needing to appropriate or exclude one another—e.g., Western and Eastern notions of energy as a substancelike quantity or as Qi
School	The facts, concepts, generalizations, and interpretations that are presented in textbooks, teachers' guides, other media forms, and lectures by teachers.	Energy bar charts Lists of energy forms

integration, which include critiquing and expanding what is thought of as knowledge within the curriculum, provide a context for the development of transformative academic knowledge. In this way, content integration and knowledge construction mutually reinforce and sustain one another.

Studies on MCE in STEM, including physics, have been limited, largely focusing on equity pedagogy and content integration [24–26]. In this paper, we explore teacher learning about energy and equity in the context of our summer PD, using MCE as an analytic lens. We noticed that when teachers in the first iteration of our PD were asked targeted questions designed to support them in integrating physics energy concepts and notions of equity, they often expressed confusion or vexation [27,28].

Because this integration was a central aim of our PD program, we pursued this as a line of inquiry, asking questions like, "What do teachers identify as vexing as they try to integrate energy and equity and are there any clues as to why teachers feel stuck?," and, "When teachers get unstuck or make progress, what does this progress look like and what might facilitate it?" In the remainder of this paper, we use case study methods to explore these questions using the lens of multicultural education, situating teachers' sensemaking about the integration of energy and equity (including their vexation) as part of the development of transformative academic knowledge. Our work adds to the physics education research literature by illustrating dimensions of multicultural education within physics, defining

TABLE II. Types of content integration in Banks *et al.*'s framework [23].

Approach to content integration	Description
Contributions approach	"the insertion of ethnic heroes and heroines and discrete cultural artifacts into the curriculum selected using criteria similar to those used to select mainstream heroes and heroines and cultural artifacts."
Additive approach	"accomplished by the addition of a book, a unit, or a course to the curriculum without substantially changing the curriculum."
Transformation approach	"changes the basic assumptions of the curriculum and enables students to view concepts, issues, themes, and problems from several ethnic perspectives and points of views."
Social action approach	"includes all elements of the transformation approach but adds components that require students to make decisions and take actions related to the concept, issue, or problem studied in the unit."

and illustrating teacher learning about energy efficiency within a multicultural education framework, identifying what may support physics teacher learning in this framework, and discussing ways in which physics teaching and learning reify white supremacy.

II. RESEARCH METHODS AND CONTEXT

A. Professional development context

The data for this analysis come from the first offering of a one-week-long, virtual teacher PD workshop designed to support high school physics teachers in integrating physics energy content and principles of equity education. The PD designers were guided by a principled epistemological stance: that science concepts are neither culture-free nor socially neutral ideas, but rather are concepts created and sustained by people in specific times and places for the purposes of (i) addressing specific social needs and (ii) empowering or oppressing people or groups of people. The primary goals of the PD include supporting teachers in building an understanding of energy as a historically and politically situated science concept and supporting them to develop instructional materials that teach energy to their students in this way.

1. Participants

Twenty-three high school physics teachers enrolled in the PD course which is the focus of our analysis. Twenty-two were from the United States and one from Canada. Fifteen participants identified themselves as female, six as male, and two as nonbinary. Eighteen teachers used the descriptors White or Caucasian, two Black or African American, one Asian, three Latinx or Hispanic, and one multiracial to characterize their race and/or ethnicity. Ten teachers taught in Western states (including one teacher from British Columbia, Canada), seven in the Northeastern region of the United States, three in the Midwest, and three in Southern states. Fourteen of the teachers described their student population as majority Students of Color while the other nine teachers described their student population as majority White. These educators applied to take part in the PD and all were eager to incorporate equity into their classrooms. Though not a representative or even a typical sample, case studies that examine specific local contexts for the purposes of defining and illustrating broader frameworks such as MCE do not require representative samples; in fact, case studies like ours are especially good for identifying features of the particular context that may shape local instantiations of theory [29–31].

2. Overview of the workshop

The PD included both synchronous and asynchronous parts. Teachers met synchronously for three hours each day on Zoom and worked asynchronously on activities designed by workshop facilitators that were posted on a

learning management system. Asynchronous activities were a mix of (i) recorded presentations and public lectures that teachers were asked to watch and (ii) written assignments and prompts that teachers were asked to complete and submit. Synchronous Zoom sessions included presentations from workshop facilitators, whole group discussions, and smaller breakout discussions and activities. There was a different featured guest facilitator each day of the workshop. Three regular facilitators—one physics faculty, one equity and organizational leadership facilitator, and one teacher facilitator with substantial experience integrating equity into physics teaching—were present every day.

The workshop was designed to support teachers in learning to integrate physics energy content with equity education frameworks. As detailed in Table III, day 1 focused on introductions and definitions of equity; day 2 focused on our team’s model for energy; day 3 on energy equity and climate justice; day 4 on identity and intersectionality; and day 5 on parts of the Underrepresentation Curriculum [32].

B. Data collection, selection, and analysis

1. Data collection and selection of cases

Synchronous Zoom meetings of the PD course were observed in real time by researchers, who took field notes and video recorded both large group and breakout room conversations. The video recordings were transcribed by an artificial intelligence transcription service and corrected by research team members. Asynchronous activities were archived in a project database, and pre- and post-surveys designed by the research team and external evaluators were collected.

Throughout the PD, researcher and first author A. D. R. was particularly attentive to teacher discourse during activities designed to support the integration of energy and equity (e.g., “explore a new vision...” on Day 1), as this was a central goal of the PD (and a central interest for A. D. R. as an original co-author of the grant funding the PD). In the breakout rooms and large group conversations that A. D. R. observed in real time, she noticed that teachers were often overtly stating their confusion about how the physics concept of energy—and in particular, canonical definitions and formulas—could be integrated with equity. In these same conversations, teachers named places where they *could* see the integration of energy and equity (e.g., energy resources and their distribution), the integration of equity and their energy curriculum (e.g., in the examples used), and the integration of equity with their science or physics lessons more broadly (e.g., in images of who becomes a physicist). A. D. R. was captivated by a sense in which the physics canon seemed “untouchable” with respect to equity frameworks—as though the canon were “above” or “separate from” equity considerations—which connected to her understanding of theory from MCE, particularly the knowledge construction dimension.

TABLE III. Structure of professional development.

Day	Theme	Synchronous discussion prompts	Asynchronous activity themes
1	Introductions, equity	• Introductions • Large group: What is equity to you? How do you think about equity? • Breakout: Compare and contrast equity and anti-racism. Explore a new vision of energy instruction that connects energy and justice.	• Introduction to the energy model • Energy Tracking Diagrams [33]
2	Physics model for energy	• Large group: Overview of model for energy and Energy Tracking Diagrams (ETDs) • Breakout: Advantages and disadvantages of this model for energy for your students. Are there any other questions or concerns? • Breakout: Teacher-generated questions ranging from modeling time in ETDs to energy in communities	• Sociocultural nature of energy model • Additional ETDs • Energy equity and climate justice • Student ideas about energy
3	Energy equity and climate justice	• Large group: Difficulties in integrating energy and equity • Large group: Climate and energy • Breakout: Discuss and compare teachers' ETDs for two different cars • Large group: Discussion of the sociocultural nature of energy efficiency • Breakout: The energy idea came from a time and place. If this idea were developed in the present, would likely focus on energy renewal. How would you re-situate the energy concept, knowing energy inequity is an issue?	• Energy tracking • Efficiency (traditional and novel definitions) • Positionality introduction and slide-making • (Personal) philosophies of education
4	Positionality or identity	• Large group: Positionality introduction • Breakout: Share intersectionality slides • Large group: You see things differently based on your positionality. How do you work with students who see things only one way, or who see things differently? • Breakout: Which parts of your identity (SES, race, gender, religion, education) play the biggest role in your life? Which parts impact how you see energy?	• Positionality and teaching philosophy • Resources for positionality and identity • Underrepresentation curriculum and racism
5	Underrepresentation curriculum, wrap-up	• Large group: Next steps, Energy and Equity Portal • Large group: Is physics objective or subjective? • Breakout: Definitions of racism, intent vs. impact, individuals vs systemic • Breakout: Goals moving forward	• Implementation plans for classroom instruction

After the PD, A. D. R. and the author team searched for segments of discourse in which teachers discussed their uncertainty or confusion about the relationship between physics energy and equity frameworks and selected the examples in Sec. III from these cases. Additional selection criteria for the examples in Sec. III included that the dialogue between participants include more than one talk turn, offering more opportunity for analytic depth and

situating of participant perspectives than brief comments made by single participants that were not taken up by the group.

As we discussed and identified examples of teachers expressing confusion, we recalled one teacher participant, pseudonymed Rebecca, who on day 5 described a lesson she planned to implement that *did* integrate the energy concept of efficiency with principles of equity education.

(This is not to say that Rebecca was the *only* participant who accomplished this during the workshop.) This contrasting case [30,31] felt like it had the potential to help us articulate what we, as a project, might do to support the kind of teacher learning that the PD was designed for. Thus, we searched the video transcripts and asynchronous activity records for Rebecca's utterances and submissions throughout the week and constructed an arc of her thinking, from expressing confusion about the integration of energy and equity to articulating a clear plan for her students' engagement with it.

2. Data analysis

Our research questions and claims in this paper draw on multiple concepts and frameworks, including dimensions of multicultural education (MCE), sensemaking, and cognitive theories of learning. In particular, we focus on the following:

1. Teacher confusion about the integration of physics concepts of energy with equity frameworks. We draw from the literature on *sensemaking* to analyze our data, claiming that the confusion teachers express reflects their reaching a vexation point [27], an important step in the sensemaking process. We highlight that though teachers are expressing vexation as they are invited to develop transformative academic knowledge about energy, they do reach for and use other dimensions of knowledge in the MCE framework.
2. Progress in teacher thinking about the sociopolitical nature of the concept of energy efficiency, toward transformative academic knowledge and a social action approach to instruction. In investigating this, we draw extensively from the literature on MCE, and we layer on *cognitive theories of learning* to define learning within MCE and to hypothesize about what resources may have supported one teacher's learning.

In this section, we briefly describe each of these (italicized) concepts and frameworks, as relevant to our analysis, and we name the positionalities we each bring to this work.

Identifying discourse as sensemaking.—Literature on instructional reform frames sensemaking as *triggered by ambiguity and uncertainty* and as *a process that aims toward resolution* [34–38]. Resolution need not be a definitive or final stance on an issue; it may be more a feeling of clarity or a step in the “continued redrafting of an emerging story” [38]. Sensemaking is further framed in this literature as *an active process of meaning construction* that involves selecting relevant features of a situation to attend to, and interpreting and creating meaning from these features in interaction with existing ideas, prior experiences, etc. In science education, sensemaking is represented as a (cognitive) process of trying to “‘fit’ new knowledge into our existing knowledge frameworks, which

are built out of ideas that we have learned or gathered from our experiences” [28]. Odden and Russ [27] argue that “[w]ithin this sensemaking process, a critical moment occurs when students attend to and articulate an inconsistency or gap in their understanding, the thing that doesn’t ‘make sense’ to them.” Odden and Russ define such moments as “vexation point[s].”

Many of the uncertainties teachers expressed about the relationship between (i) the energy concept as defined in physics and (ii) equity frameworks were expressed as confusing, not making sense, or inconsistent. That is, in expressing confusion, teachers spoke in ways that suggested that equity frameworks do not or cannot “fit” (or be integrated) with their understandings of physics definitions and representations of energy. In most cases, these vexation points triggered more sensemaking, which often led teachers to other forms of integration that they seemed to feel more clear about—e.g., integrating equity frameworks with physics instruction more broadly, such as by introducing female scientists or Scientists of Color to their students. In Rebecca's case, the vexation became “resolved” over the course of the PD, in the context of energy efficiency.

Operationalizing dimensions of multicultural education and learning within MCE.—In Sec. I, we gave an overview of three dimensions of MCE that are relevant to our analysis: equity pedagogy, knowledge construction, and content integration. We use Banks and colleagues' definitions of these dimensions to code selections of Rebecca's discourse and course submissions, for the purposes of illustrating her learning. For example, we coded as *equity pedagogy* instances in which Rebecca describes efforts to make her classroom practice or lessons more inclusive. We coded as *knowledge construction* instances in which Rebecca is situating an energy concept in its sociopolitical history or issuing critiques of mainstream definitions of energy concepts. In each case of knowledge construction, we sought to identify the *type* of knowledge Rebecca was discussing, using the definitions in Table I. We coded as *content integration* instances in which Rebecca described efforts to include in her curriculum examples or content outside mainstream white, masculine culture. As with knowledge construction, we sought to identify what *type* of content integration Rebecca was describing, using definitions from Table II.

Identifying resources for teacher learning.—For the purposes of this analysis, we define learning in terms consistent with cognitive theories [39–41], situated within MCE: evidence that Rebecca has learned is in her deployment of *more* dimensions of MCE as she discusses energy and energy instruction and in her deployment of dimensions of MCE consistent with *more transformative* instruction. In Sec. IV B, we hypothesize about some of the resources that may have supported Rebecca's learning. Cohen, Raudenbush, and Ball [42] describe resources as “facilitators or inhibitors” of (learning about) particular instructional aims or approaches. Believing that learning is

shaped by context [43,44], we expect these resources will include both personal resources that teachers activate in given situations and environmental resources present in different contexts. This sense of “resources” is consistent with but broader than what PER has called “resources theory”—a framework that asserts that “resources” are cognitive elements that are activated in and by context and serve as input for learning and growth [39,45]. In the case of Rebecca’s learning within MCE, we claim that she brings and activates cognitive resources and also that there are environmental resources that facilitate her learning. Using a process theory of cause [46,47], in which cause is inferred from a sequence of events—event A precedes B, which preceded C..., where the events have a plausibly causal link—we identify resources using analytic markers such as *proximity* (e.g., resource *x* precedes the emergence of a new idea for Rebecca) and what we call *fingerprints* (e.g., we see evidence of resource *y*’s impact in the language Rebecca uses).

Positionalities of author team.—Robertson (first author) is a chronically ill and disabled, physics-Ph.D.-holding, straight and cis-gendered, thin wealthy white woman. Robertson spent most of her life ignorant of the current material landscape of white supremacy, an ignorance encouraged by white supremacy and enabled by her dominant position as a white woman. She approaches equity analyses centered on race with the positionality of a learner theoretically informed by Critical Race Theory, and her writing necessarily reflects (at least in part) the scaffolding she needed (and still needs) as a learner. At the same time, Critical Race Theory (which motivated MCE), while centering race and the dismantling of racism, has a “larger goal of eliminating all forms of subordination” [48] and thus speaks broadly to the experience (and dismantling) of systemic marginalization. Importantly, Critical Race Theory has informed Robertson’s analysis of ableism in her own life, and her experiences of marginalization as a disabled and chronically ill woman inform her understanding of Critical Race Theory. She sees her scholarship, including scholarship on the impacts of white supremacy in physics teaching and learning, as deeply personal and as part of a collective struggle for liberation [49,50].

Huỳnh is an able-bodied, physics-Ph.D. holding, Asian migrant woman who was born and raised in a middle-class family in Vietnam and is the first generation in her family to go to college and pursue higher education. Growing up, while sexism, classism, and colorism were central to her lived experiences, she was not conscious of global white supremacy and racism, in part due to her living in a racially homogenous geography and her privilege of identifying with the majority ethnicity. Not until she came to the United States did her lived experiences start centering around racism and discrimination against Asian migrants. Entering PER work around physicist identities, Critical Race Theory and antiracist work by Scholars of Color have helped her to

define and make sense of her experiences. Her learning journey is filled with struggles to abolish her assimilated mindset, unlearn what has been normalized, and make a connection between western scholars’ work and her experiences as a Vietnamese migrant. The work in this paper intimately resonates with her own experiences where she found that it has been made very difficult to begin to uncover systemic structures and epistemologies that uphold social hierarchies and to battle assimilation.

As a researcher, Mathis’ experience as a former physics teacher from a multicultural population gave him insight into issues of multiculturalism and equity within physics teaching. As an African American male who is a former high school and community college physics teacher, Mathis’ experiences helped him analyze physics teachers’ approach to implementing equitable practices in the classroom. As a Person of Color, Mathis has experienced aspects of whiteness projection that impact how he views and navigates physics spaces. In the past, he has taught physics to students of various cultural backgrounds and used different forms of instruction. Through his experience, Mathis believes most physics teachers disregard issues of equity in their development and assessment of curricula. Through this study, Mathis seeks a better understanding of ways to help teachers maximize students’ resources to effectively teach physics.

Bauman is a young, cisgender, white woman. She was born and raised in a privileged, upper-middle-class family in Canada. She grew up in a homogeneously white, race-evasive context where positionality, privilege, and oppression were rarely discussed. She has been heavily shaped by her positive experiences in educational spaces and her insatiable curiosity. She received her bachelor’s degree from a small liberal arts college that valued an interdisciplinary curriculum because she wanted to be embedded in an extremely tight community and wanted to learn as much as possible about a little bit of everything. Although she primarily studied physics, it was during this time she took courses and was immersed in a community that encouraged her to think more critically about her own positionality, privilege, and marginalization across dimensions of race, gender, ability, and class in a deeply unjust world. She recognizes her position as primarily a learner in this space and strives to approach this role with curiosity, honesty, commitment to reflection, and self-awareness. She sees this work as part of her continued commitment to learning, amplifying the voices and lived experiences of others, and supporting equity-oriented work in all parts of life.

Scherr is an able-bodied cisgender woman. Her identity as a white-passing Jewish person has contributed to her awareness that schooling and popular culture normally ignore or tokenize nondominant cultures. As a leader of the Energy and Equity Project that provides the context for this paper’s research, her efforts include creating a model for secondary science teacher development centered on

understanding energy as a historically and politically situated science concept, as well as striving to support a culturally diverse team to construct knowledge that integrates their race, ethnicity, nationality, gender, religious commitments, social class, ability status, and other features of social identity that may be important to them.

III. INTEGRATING ENERGY AND EQUITY: TEACHER VEXATION POINTS

This section explores the question, “What do teachers identify as vexing as they try to integrate energy and equity and are there any clues as to why they feel stuck?” We offer a number of examples of vexation points, and we speculate about some of the ways in which physics culture and the U.S. system of schooling reify these vexation points, making it difficult for teachers to critically examine canonical definitions and representations.

A. Vexation points

As reflected in Table III, teachers were asked multiple times over the course of the PD to reflect on the relationship between energy and equity. On day 1, they were invited to explore (together) a new vision of energy instruction that connects energy and justice; on day 3, they were asked to resituate the energy concept, given what they were learning about its sociohistorical roots and present-day inequities; and on day 4, teachers were encouraged to consider how their positionality shapes their energy instruction. What we noticed is that as teachers engaged with these questions, they often expressed confusion or vexation, particularly in relation to canonical energy definitions and representations, and their conversations often then moved in a direction of connecting equity to curricular examples, energy resources (e.g., distribution of energy), or representation of women and people of color in physics or science. We reflect on these examples in terms of Banks and colleagues’ framework for MCE and the science education literature on sensemaking.

The first example comes from a discussion on day 3, in a breakout room with three teachers: Tim, Elena, and Josh.⁴ The teachers have been asked to resituate the energy concept. This group of three expresses some confusion about the task and then begins discussing their student populations and some of the things they do in their schools and classrooms to try to make instruction inclusive. Tim eventually jumps in, saying:

Tim: It also feels, so like it’s still energy, but like, I don’t under—, I don’t know yet. I don’t see yet how to use the energy imbalance in the developed versus the developing world, or use the, uh, where do I get my energy from? How do I take that content—, which

does feel valuable, but at the same time, I don’t see myself getting kinetic energy equals one-half mv squared out of that discussion or that project. And that piece is where I—, I flounder, I suppose.

Elena: Yeah. I’ve been having the same, like how do you actually incorporate this stuff into the curriculum? Because the things within, like a lot of the stuff that’s been discussed [in this PD] would fit really well in like an environmental science context, or even within a unit of biology, but—, or even within the context of what’s discussed in physics. You know, like we talk about gravitational potential energy or whatever it is, you know, like these different things and the, how does that incorporate into the things that we’ve been discussing? Like the curriculum doesn’t lend itself so much to connect the things that we discussed in our [physics] class with what we’re discussing right now [in this PD].

Tim leads this exchange by referring to a variety of discussions and activities the teachers have been engaging with: energy access across the globe (“energy imbalance in the developed versus the developing world”) and energy backtracking, where teachers consider whose ancestral lands provide the energy that they use in their homes (“where do I get my energy from”). He acknowledges that these are “still energy,” but also that he is struggling to see the connection to canonical representations of energy (“one-half mv squared”), which he is accountable to.

Elena affirms Tim’s feeling, saying that this PD content, which integrates energy and equity, seems more relevant to environmental science or biology. She hedges a bit, saying “even within...physics,” but proceeds to name that she does not see how these things are tied to “gravitational potential energy”—again, the canonical concepts she is accountable to.

In this example, we hear Tim and Elena expressing a vexation point: they can sensemake about the relevance of equity to certain aspects of energy, but they cannot make it fit with canonical representations and definitions. In the context of the types of knowledge in Table I, it is relatively easy for Tim and Elena to see the relationship between equity and *popular knowledge* about energy (i.e., equity and energy resource distribution), but it is more difficult for them to see a connection between equity and *school knowledge* about energy. They seem willing to integrate popular knowledge into their curricula (approximating an additive approach, Table II), but unsure as to how to participate in a transformation approach to content integration, and/or how to develop transformative academic knowledge in the context of energy. Importantly, though, they are *naming* this uncertainty; they seem to be aware that there is something just outside their grasp.

Similar to the dialogue between Tim and Elena, Lori and Maggie have an exchange on day 1, in a breakout room with four teachers, including themselves, Megan, and

⁴All teacher names are pseudonyms.

Leslie. The group has been prompted to both (a) compare and contrast antiracism and (b) explore a new vision of energy instruction that connects energy and justice. The teachers begin sharing ways that they are already connecting energy and justice in their *astronomy* instruction, including highlighting female scientists and scientists of color and discussing the injustices of the Thirty Meter Telescope on Maunakea in Hawaii [51]. Lori brings up the inequitable distribution of energy resources as one direction they could go, saying

Lori: ...Um, when I was thinking about this question, I was thinking about just energy, you know, that by the law of conservation, that there's a fixed amount of energy, like, is that kind of how we look at our, um, our resources, right? That's a fixed amount. So everybody is a part of energy resources. Um, I was trying to put those two together in my head about how, um, how do we distribute energy according to need, how do we [inaudible]. Do you have any thoughts about what a new vision of energy education would look like?

Maggie: That part? I honestly didn't really know where to go with, like energy in particular. I can kind of think about how to incorporate some equity and justice issues in physics teaching in general, but energy in particular. I guess if you think of energy in a more practical way, like they were talking about. Well, I was thinking about like, who has the energy resources? Like, where does your energy come from? Where do they build the power plant? And which people are the most affected by the power plant or the pipelines or all of that infrastructure that's involved in getting electrical energy to different places? I was learning recently—, I'm up in Northern California, and there's a project I hadn't heard about until recently that is a natural gas pipeline that they want to get from Colorado through to the Oregon coast. And when they, I guess there's a, the hub that they need to build. And when you look at which town they pick to build it in, you're like, 'Oh yeah, that's, that sounds about right.' It's the, like, a poor⁵ community, um, all the, all the usual criteria that you figure of who's

on the margins and whose—, whose communities aren't as respected by the people who make those decisions.

As with Tim and Elena, Maggie names that she reaches a vexation point when she tries to connect equity and “energy in particular,” which we interpret as *school energy* (Table I). In conversation with Lori, Maggie identifies that she can see connections between *popular energy*—in particular, the distribution of energy resources, which she narrates as “energy in a practical way”—and equity, in terms of which communities are impacted by the energy industry, offering an example from her local context.

Our third and final example comes from a discussion between Rebecca, Lisa, Tim, and Kelsey—answering the same prompt as Lori and Maggie—to explore a new vision of energy instruction that integrates energy and justice. Rebecca says:

Rebecca: I feel like—, I feel like I'm woefully ignorant in this and it's always been something that I've been wanting to do. Like I think often I teach content and then like, like social justice, kept almost separately by like bringing up, um, hidden figures and like talking about women in physics and, um, People of Color in physics and LGBTQ in physics and space travel and that sort of thing. Um, but it's not like interwoven into the curriculum. So I'm like, here's these people and then here's physics. And I'm really excited to learn ways to, to like actually engage students in—, through learning physics, while also talking about social justice and I think that'd be really, really cool.

Lisa: Yeah. I feel the same in terms of having social justice and physics as two separate schools of thought in my mind. And I feel like, I don't know why I never thought to put them together. And, um, I was thinking about this, I read an academic paper, I can't remember the name of it. Um, but it's on culturally relevant pedagogy and it was talking about having, like, your goal to be that students—, like, they feel welcome, and their culture is welcome in the class, but then also they're questioning systems and it kept talking about that. And I was like, what can we question in energy? And I like—, there's such an energy, um, like, inequity issue in America. And I feel like we have a big space to talk about that in physics. Um, and you can talk about the structures that are in place and the history of it. I think I just don't really know how to like, tangibly turn that into lesson plans for high schoolers, but I'm like, I have the big ideas I think. That's kind of where I'm at.

Tim: Yeah. Similar—, similar to both Rebecca and Lisa, uh, the exposure piece, I feel very comfortable with, um, working to bring alumni back

⁵The word “poor” is value-laden; it uses language of quality to describe a group of people, often cues a charity model, and evades structural analyses. Though not the way it is being used here, “poor” has also been reclaimed, sometimes in intersections with other marginalized identities, as an act of resistance. For example, Chicano art scholar Ybarra-Frausto reclaimed the term “rasquache”, historically used as a classist slur, to develop a “rasquachismo” aesthetic and a worldview—“the view of the underdog, which combines inventiveness with a survivalist attitude”, a view that is both “defiant and inventive” [52].

into my classroom, giving them exposure to women in physics or in engineering so that they have those—, those role models. But I don't know how to bring it into like the lesson plan as you said. And that—, that—, that's the part that I'm really interested in and why I'm so curious as to why they picked energy, which is such a difficult topic. And I find so interesting that they—, they use that—, they want to tackle it through energy. Um, and that that's really what I'm excited for, because I don't know how—, how they're going to do that. Um, I'm really curious to see if—, what the expectations are in terms of, what does it look like to have an equitable classroom that is learning energy? Is it—, is it changing the—, how, you're just—, how you're presenting the physics? Is it changing the language you're using, how the students are interacting? What—, what is it that brings that equity through energy?

In this exchange, Rebecca discusses her dissatisfaction with her (current) additive approach to content integration (Table II), saying that it feels like in this approach, the content and social justice are “kept almost separately,” whereas she would like to do something where equity content is “more interwoven in the curriculum.” She describes herself as “woefully ignorant in this” but very eager.

Lisa follows up, drawing on theory from culturally relevant pedagogy [53] to lay out a vision consistent with the development of transformative academic knowledge, which “question[s] systems,” and with a transformation or social action approach to content integration. Lisa then names a vexation point, saying, “What can we question in energy?” Though it does not seem like she reaches resolution—she says that “she doesn't know how to tangibly turn that into a lesson plan”—she does begin to speak about the integration of popular knowledge and equity when she brings up energy inequities in the United States.

Tim then affirms both Rebecca and Lisa's commentary, describing his comfort with the contributions approach to physics instruction (“I feel very comfortable with...working to bring alumni back into my classroom, giving them exposure to women in physics or in engineering”) but names vexation in integrating school knowledge and equity (“I don't know how to bring it into the lesson plan”). As with Rebecca and Lisa, he is eager to resolve this vexation and begins imagining possibilities consistent with equity pedagogy and knowledge construction, though the group does not explore these possibilities in depth.

B. Connections to broader literature, culture of schooling, and discipline of physics

In all three of the exchanges we presented in this section, high school physics teachers express vexation as they try to fit equity with school energy, particularly with canonical

definitions and examples. In all three cases, teachers name ways that they *do* see a fit between energy or physics instruction and equity—in integrating popular knowledge about energy with equity or in changing the curriculum to highlight the contributions of marginalized groups. They also express dissatisfaction, feeling that there *should* be a way to integrate equity and school knowledge about equity. This was not only evident in the video but also in the course, post-survey responses: only ~15% of the participants report feeling very confident in their ability to explain how energy concepts reflect culturally specific values.

These conversations reflect themes from the literature on multicultural education. In particular, the contributions and additive approaches to content integration—where teachers insert “ethnic heroes/heroines and discrete cultural artifacts into the curriculum” and add “a book, unit, or course to the curriculum without substantially” changing it, respectively [23]—are often more accessible than the transformative and social action approaches. For example, teachers in our PD describe including women and People of Color in their examples of scientists—bringing in alumni, highlighting “hidden figures”—but name difficulty when it comes to integrating equity with the energy canon. Integrating popular knowledge into the classroom (e.g., around the distribution of energy resources) is intuitive, but developing transformative academic knowledge is countercultural [54–58].

The difficulty of constructing transformative academic knowledge and enacting the transformative and social action approaches to content integration may be even more pronounced in physics, which is often storied as objective, neutral, and value-free [14,16]. In fact, it is on the basis of its objectivity, neutrality, and aculturality that physics considers itself epistemically superior. Grosfoguel argues that though the canon is “based on the knowledge produced by a few men from five countries,” and thus is “based on the social/historical experiences and sensibilities as well as world views of particular spaces and bodies...,” the situatedness and cultural specificity of the canon “is disguised under a discourse about ‘universality.’” Grosfoguel [11] argues that this disguise is made possible in part by Cartesian thought—“I think, therefore I am,” or the notion that the “mind [can be] undetermined, unconditioned by the body” and thus can produce a “God's-eye-view” of the world through careful thought. Cartesian epistemology produces a “‘subject-object’ split,” where “objectivity [is] understood as ‘neutrality’” and a body can “produc[e] unbiased knowledge unconditioned by its body or space location.” To question the physics canon, then—to situate physics *content* in bodies, times, and places, and to critique the role it has played in power relations—is not only to challenge hundreds of years of Westernized thought but also to challenge the basis on which physics considers itself epistemically superior. This is less true of popular knowledge, which, though deeply entangled with the canon, is often framed by physicists as “applications” of physics knowledge and “not physics itself.”

Layered on to this, schools play a central role in the reproduction of power relations. According to Bourdieu and Passeron [59], educational systems produce and maintain power relations by instilling values and knowledge that align with the dominant culture and by perpetuating the conditions under which the arbitrariness (as contrasted with meritoriousness) of this dominance goes unrecognized. Further, they create *institutional structures* that support this work, such that the arbitrariness is further hidden in policies and practices that become “the way things are” in school and thus in society more broadly. Teachers, in this model, are the “agents recruited and trained to carry out” the instilling of mainstream knowledge and values; Bourdieu argues that teachers must “operate within institutional conditions...[that] preven[t] them from performing heterogeneous or heterodox” schooling, and that this prevention happens through “standard training and standardized, standardizing instruments” [60]. In other words, the system is deeply invested in constraining teacher agency, in service of reproducing existing power structures. To challenge school knowledge is to challenge the very nature of what it means to be a teacher, in Bourdieu’s analysis.

All of this is to say that *it is no wonder* that teachers struggle to see the fit between equity and canonical definitions and representations of energy; there is so much in the way, so much that would need to be challenged, and such big consequences for doing so. At the same time, the teachers in our PD, including Tim, Elena, Maggie, Rebecca, and Lisa are identifying vexation points as they sensemake, and we know that vexation (even frustration) is a critical and generative part of learning [61]. This was indeed the case for Rebecca; we will turn to her learning next.

IV. INTEGRATING ENERGY AND EQUITY: TEACHER PROGRESS IN THE CASE OF REBECCA

In this section, we return to the question, “When teachers get unstuck from vexation points or make progress, what does this progress look like and what might facilitate it?” We present a case study of Rebecca’s learning, detailing her progress through the week of PD and then hypothesizing about some of the resources that may have supported her learning. As we go, we highlight the dimensions of MCE that we observe in Rebecca’s written reflections and discourse. Equity pedagogy is abbreviated as EP, content integration as CI, and knowledge construction as KC. When possible, we identify the specific types of knowledge construction shown in Table I and the types of content integration shown in Table II.

A. Rebecca’s progress

Over the course of 5 days of our summer PD, Rebecca moves from a place of expressing vexation around the relationship between energy and equity; to beginning to

question the objectivity of physics and wondering about who shaped the development of canonical energy concepts; to critiquing the energy concept of efficiency; to designing a lesson plan that invites her students to construct transformative academic knowledge in the context of energy. We describe this development in chunks to highlight Rebecca’s learning, not to suggest that transformative academic knowledge of this type develops along a predictable progression.

1. Day 1: Rebecca expresses vexation

At the very start of the PD, as teachers were asked to say what equity means to them, Rebecca shared that for her, equity is not only about ensuring her students have access to the curriculum but also about creating a classroom space where they feel included and heard. She says

When I first started teaching, I think I thought equity was more about content and making sure that every student had access to the material or access to being able to learn the material. And I think, um, some evolution in my thoughts since I started teaching have been that equity is also about getting kids to that table. I really liked that table analogy of everyone has a seat at the table with dignity and their voices are heard. And I think, um, every kid needs something different from me to get them to that table sometimes. Um, and whether that looks like just reaching out to a student more than another, or not more than another student, but like noticing the kid who’s sitting in the corner and reaching out to the kid, that’s sitting in the corner to fold them into the, the table.

Here, Rebecca describes a shift in her thinking, from a more equality-focused lens where all students are given equal access, to a more equity-focused lens where she differentiates her approach based on specific needs [62]. Though she does not share specific pedagogical strategies, her teaching principles reflect the equity pedagogy (EP) dimension of MCE.

Later on day 1, Rebecca joins the discussion we captured in Sec. IV, describing her current approach to integrating physics and equity, which we interpret as a contributions approach to content integration (CI contributions):

I feel like—, I feel like I’m woefully ignorant in this and it’s always been something that I’ve been wanting to do. Like I think often I teach content and then like—, like social justice, kept almost separately by like bringing up, um, hidden figures and like talking about women in physics and, um, People of Color in physics and LGBTQ in physics and space travel and that sort of thing. Um, but it’s not like interwoven into the curriculum. So I’m

like, here's these people and then here's physics. And I'm really excited to learn ways to—, to like actually engage students in, through learning physics. We're also talking about social justice and I think that'd be really, really cool.

Later, she added

Um, [doing this] has made my kids recognize that I am at least trying to be an ally, um, which has then made them like more comfortable in my classroom or like seek me out sometimes. Um, I feel like my classroom is a safe space because they see that I'm actively trying. And I think by discussing that issue, I think, like, one, it'll get kids interested, like, 'wait, this is a real thing that's happening to us right now.' And then to the fact that I'm like actively trying to like bring those points across might help. Like just kids recognize that I am an ally.

Here, Rebecca elaborates that her goal in sharing the contributions of women, People of Color, and LGBTQ folks in physics is to create a safe and inclusive environment for her students. We see this as further evidence of EP. Rebecca shares that as a result of this, her students are connecting their classroom experiences to racism ("wait, this is a real thing that's happening to us right now"), which we see as a precursor to a social action approach to content integration (CI social-action precursor).

Rebecca's contributions on day 1 illustrate that although she has been integrating some aspects of equity into her physics classroom, she encounters a vexation point as she tries to integrate equity with canonical physics content, saying, "I feel like I'm woefully ignorant in this and it's always been something that I've been wanting to do."

2. Day 2: Rebecca begins to question who shapes the construction of canonical energy concepts

In Rebecca's asynchronous submissions on day 2, we observe her beginning to resolve the vexation she names on day 1, as she begins to critique the story of objectivity in physics and situate energy in its sociopolitical origins. In particular, in a written response to a short lecture given by one of the workshop instructors about the sociopolitical nature of the energy concept, Rebecca expresses

I can't believe I never thought about this before but it makes so much sense! Energy is just a construct so of course the people who constructed the idea shaped it toward their thinking patterns and societal goals. It makes [me] think about how much richer, deeper, and more profound science could be if we had made room at the table for more diverse people to be involved. What

understandings did we miss out on by not hearing all of the voices that could have had so much to contribute?

In this reflection, Rebecca's affect suggests a breakthrough in her thinking—"I can't believe I never thought about this before!"—as she begins to situate physics content as sociohistorical. She implies that physics knowledge—particularly the concept of energy in physics—may be different had more and different people been valued and invited, drawing on the imagery of a table from her earlier reflections. Here, Rebecca is engaging in her own knowledge construction, particularly around mainstream academic knowledge (KC mainstream academic knowledge).

On the same day, Rebecca submits a reflection on her role as a physics teacher in light of Pichon Battle's talk, "Climate change will displace millions. Here's how we prepare" [63]. The prompt for teachers asks

As physics teachers, we often teach about energy as though the energy stories that we construct, or others construct for us, are value-neutral and objective. In doing so, are we unintentionally complicit in spreading what Colette Pichon Battle describes as "the arrogance to think that technology will save us?"

Rebecca responds in writing:

Yes I think I am unintentionally complicit. I do teach energy like it is all about technology and I think I do accidentally spread the concept that everyone benefits from energy equally and that it does not have consequences that affect the poorest communities. I think this comes from me not realizing that the social construct of energy was made by white rich factory owners at the turn of the century! I think that teaching kids about the fact that the rich are benefiting and the poor are having the consequences might help them make better energy choices and also might get them involved in energy politics.

In this reflection, Rebecca names that her current approach to teaching energy is "all about technology," and she begins to name a different, sociopolitical reality that the energy concept as it is currently taught centers some and marginalizes others. This shift in her thinking is made possible in part, she says, by her realizing that "the social construct of energy was made by white rich factory owners at the turn of the century"; it is almost as though this sociohistorical situating supported Rebecca in naming the social and political impacts of energy in the present day.

Again, here, there are glimmers of a social action approach to content integration (CI social action precursor). In her written reflections submitted on day 2, Rebecca

seems to make progress from acknowledging that she treats social justice and energy content as separate (day 1), to locating inequity in energy use and distribution, on the basis of an emerging critique of the energy concept. Questions that primed her critique in this stage include who creates and shapes energy concepts and who benefits from the concept of energy.

3. Days 2 and 3: Rebecca critiques the energy concept

On day 3 of the summer PD, a guest facilitator presented on energy injustice and climate change. One of the asynchronous activities that preceded the presentation (to be completed on day 2) asked teachers to investigate the efficiency of automobiles and invited them to rethink their definitions of efficiency. This topic closely relates to one of the projects that Rebecca has already been giving her students, where they build a matchbox car and create a car commercial to explain their car's efficiency.

As Rebecca engages with the asynchronous activity, she begins to apply her critique from the previous section to energy efficiency, exploring ways in which this concept has been used to unequally benefit different populations. For example, in a reflection on her vision of the integration of energy and equity at the end of day 2, which asked teachers how they envision energy equity and/or energy justice at multiple scales, from local to global, Rebecca responds by locating energy inequities in the energy industry, noting who profits and who suffers:

I think energy equity is about who profits from the energy and who is harmed by the energy, and who is “screwed over” by the energy. So often the —, who profits is Americans, often in the richest most white areas. Often big oil tycoons profit. I think climate change does a lot of harming to not-rich communities, communities that live off the land. When I taught climate change we looked at a Native population in Alaska that relied on ice fishing and was not able to feed their families because the ice that normally stayed year round was melting and no longer year round. There is also the “screwed over” group. Native peoples were the first people on this land but white people are the people benefiting from owning oil wells and hydroelectric plants. [continued below]

Here, we see Rebecca beginning to integrate school and popular knowledge, toward transformative academic knowledge: If energy, as a concept, was constructed by “white rich factory owners,” then they will be the ones who “profi[t] from energy,” while others are harmed. Rebecca offers a specific example of people who have been harmed: Indigenous communities who are not only dispossessed of their homelands but also do not benefit from the sale of resources from this land and are disproportionally affected by the

consequences of the energy industry. Here Rebecca is engaging in her own process of transformative knowledge construction (KC transformative academic). She continues,

[continued] I’m also thinking about the word efficiency a lot. Efficiency is, I think, how I will connect equity to physics because it is such a huge construct and depending on who you are and what your personal goals are you might define efficiency differently. I am excited to try to allow my students to define it! I am thinking about introducing the “standard definition” and then telling them that it is antiquated because now we have different ideas about what is efficient. I think I want to do a project where the end results are that students try to sell a car to each other based on their group’s created definition of efficiency. That gives me an in for teaching about energy equity issues so that they can take those concepts into consideration for their own definitions of efficiency! I should also mention that this is a pre-existing project that my students really love. They have to create a matchbox car and then a car commercial and justify why their car is the most efficient. All I have to add to this project is that we will no longer be using a fixed definition of efficiency!!!!

In this second half of her reflection, Rebecca interrogates the universality of the mainstream definition of efficiency, situating the process of defining a concept in the goals and bodies of the definers. Though she does not yet offer a substantive critique of the concept of efficiency, she begins to describe a project that she plans to adapt to allow students to define efficiency for themselves, aligned with the social action approach to content integration within MCE (CI- social action).

On day 3 of the PD, one of the facilitators reiterated the sociopolitical origins of the energy concept in physics and asked teachers how they might resituate an energy concept today. As Rebecca works with her breakout group to complete this task, the teachers express some confusion about what they are supposed to be doing. One of the course facilitators joins the discussion and asks them what they teach when they teach energy, as a way (we think) to concretize the discussion. The teachers name a variety of concepts, including efficiency, and the course facilitator asks what equity questions are tied to efficiency. Rebecca answers

I guess what is efficient? So we said efficiency. So like, what is efficiency, right? Whose definition of efficiency? Efficient for whom, right?

This series of questions mimics exemplars of knowledge construction (KC-transformative-academic) described in

Banks and colleagues' work [20]. Here, Rebecca is resting firmly in an awareness of the situatedness of the efficiency concept and naming it as not-neutral—as serving particular aims (in this case, the aims of those in power).

In the asynchronous activities following instruction on day 3, teachers are asked to name aspects of vehicle sustainability that are not captured in the conventional definition of efficiency and to brainstorm ways of quantifying vehicle efficiency outside of the conventional definition. In her written response, Rebecca redefines energy efficiency in a way that is personally relevant to her, writing:

I think having an efficiency per person would take into account carpooling. So your efficiency should double if you have two people in the car. Another aspect of efficiency that I am thinking about is how often you use your car. I bike everywhere and I only use my car to go to the mountains in the summer or for road trips. Recently my car broke down and I am going to try to live for 1 year without a car. In the meantime I am looking into my options for what I want when [I] do get a car. I was thinking of getting an electric car but that would not serve my purposes at all. I need something that is good for going long distances without having to recharge and I need something that can get me around on rocky roads. So I think the overall efficiency of my car plus my general biking habits have to be taken into account together.

In this response, Rebecca articulates criteria for a new definition of efficiency that takes into account the relationship between the car and the people who use it. Here, she offers to herself what she says she wants to offer her students, integrating her developing ideas about efficiency with personal and cultural knowledge (KC-personal/cultural).

On days 2 and 3, we observe Rebecca gaining momentum toward connecting equity and physics energy content. Guided by the instructors of the PD, Rebecca focuses on one concept of energy—efficiency. First, she names unequal benefits accrued and harm done by the energy industry, linked to her emerging critique. Then she describes an expansive, social-action-oriented approach to instruction about efficiency. She goes on to embody knowledge construction by asking questions about the nature of the efficiency concept and whom it serves and articulates a new definition of efficiency that is personally relevant.

We see this work as interconnected in the ways that MCE would predict: As Rebecca comes to see physics concepts as historically and socially situated—not objective or absolute but local and situational—it becomes more possible for these concepts to be resituated and redefined.

4. Day 5: Rebecca develops a lesson plan to support the development of transformative academic knowledge

Ending day 3 with a new definition of efficiency (efficiency per person), Rebecca continues to refine and solidify her lesson plan to integrate equity and energy. On the last day of the PD, Rebecca shares her brainstorming for her lesson on efficiency with her group. Compared to her written reflection on day 2, by day 5, Rebecca has constructed a detailed plan, writing

I am really excited about teaching about efficiency as a construct that a certain group of people created for a certain purpose. I want to first define efficiency that way I always do in my energy unit. Then, I want to have students design a matchbox car and design an experiment to measure the classical definition of efficiency for their car using the energy diagrams. Then I want to talk about who those people were and why they created efficiency that way. Then I want to tell students that they are a car company and that they have to redefine efficiency based on their values. I think I will show some TED talks about energy consumption harming the environment and who is harmed. Also maybe show some stuff about generational poverty and racism in property ownership (so along the lines of who can afford a car). I like the idea of who[se] land we are using for the energy resources (i.e., white people are benefiting from land that we stole from [N]atives). I want to maybe provide some more readings and research that students can choose to look into for their own definitions of what is “efficient”. I also want my student[s] to make their company’s values statements before they define efficiency. I think this will be well received! I teach many [S]tudents of [C]olor and at the beginning of the year in my introduction powerpoint I said “I believe [B]lack lives matter and our society has to work to figure out how to make sure all people can be safe. I feel like it is time for white people like myself to figure out what they can do in the world to make it more equitable for everyone.” I also said that this concept is very important in physics because it is one of the most inequitable fields. My white students gave no push back and also wrote to me saying that they agree! So, similarly to you, I need to establish a safe space for a project like this but I do that by talking about female scientists and [S]cientists of [C]olor and LGBTQ scientists who should have been more famous and more celebrated but who have not really been heard of (I do hidden figure of the week every Friday).

TABLE IV. MCE codes in excerpts from Rebecca's written work and discourse across the PD.

Day 1	Day 2	Days 2 and 3	Day 5
EP, CI contributions, C social change precursor	KC mainstream academic, CI social-change precursor	KC transformative- academic, KC personal/cultural, CI social action	KC transformative academic, CI social change, CI transformative, EP

Then, after break, I will launch into this actual project that I think will let students delve deeper down the rabbit hole!

In this description of her lesson plan, Rebecca invokes all three dimensions of MCE that we outlined in the introduction—knowledge construction, content integration, and equity pedagogy—and she engages in the knowledge construction and content integration dimensions transformatively. She names that efficiency is a “construct” created by “a certain group of people,” “for a certain purpose” (KC transformative academic). She describes herself as wanting to situate this further for her students: she not only wants them to know *that* this is true but she also wants them to know “who those people were and why they created efficiency that way” (KC transformative academic). She describes a lesson in which students are not only engaging in critique (CI transformative) but also defining efficiency for themselves and being held accountable for the impacts of their definitions (CI social action). She names the importance of this kind of work for creating an inclusive classroom space (EP), and the importance of fostering an inclusive, safe space beforehand *so that* students can engage fully with this transformative content (EP), again illustrating the interconnectedness of these dimensions within MCE.

5. Evidence for Rebecca's learning

In Sec. II B. 2, we defined teacher learning within MCE as the deployment of more dimensions of MCE over time, and/or the deployment of dimensions of MCE more consistent with transformative instruction. We see evidence of both in Rebecca's work across the week. Table IV collates the codes we applied to her discourse and written reflections.

B. Resources that may have supported Rebecca's progress

In this section, we offer hypotheses about some of the resources that may have supported Rebecca's learning. As we say in Sec. II, we define resources here as both cognitive and environmental “facilitators” [42], and we rely on a process theory of cause [46,47], wherein cause is inferred from an observable sequence of events (rather than, say, from a controlled experiment).

Resource: Mutually reinforcing nature of the dimensions of MCE.—It feels somewhat odd to say that the nature of

MCE facilitates the learning of MCE. And yet the data suggest this: Rebecca's commitment to equity pedagogy right from the start—and her drive to deepen this commitment to include canonical content—appears to have been a resource for her engagement in transformative content integration. Further, Table IV (and the progression of the case) suggests that Rebecca's engagement in knowledge construction sparked more transformative work in content integration: we notice that after the KC code appears, more transformative codes also appear.

Resource: Rebecca's frustration.—Literature on the role of affect in learning science names confusion and frustration as generative for learning—a resource that can propel learners forward and sustain their engagement [61]. Rebecca's dissatisfaction seems to do just that in this case. Her affect at the start of the workshop is one of vexation: she is dissatisfied with her current approach but does not know how to get what she wants. As she starts to make progress, her affect shifts to excitement (“I can't believe...!!!” and “I am really excited about...”). Though we do not have evidence that Rebecca's frustration *sustained* her through specific challenges, it did seem to play a role in her engagement.

Resource: Rebecca's activation and use of tenets of Critical Race Theory, which pervade Rebecca's talk and writing from day 1. In particular, Critical Race Theory [2,7] contends⁶ that

- Racism is permanent.*—Racism is endemic, hegemonic, and permanent, and therefore difficult to change [2,4,64]. We see evidence of this in Rebecca's naming the relevance of racism for her students (“this is a real thing”) and in her growing awareness of and willingness to accept the pervasive power dynamics in the energy industry.
- Whiteness is property.*—U.S. jurisprudence has played a role in reifying racism [3]. In the United States, whiteness carries legal property rights and interests that nonwhites are not allowed to claim. White identity confers tangible and economically valuable benefits and is guarded as a valued possession, allowed only to those who meet a strict standard of proof. Rebecca names multiple instantiations of whiteness as property,

⁶Critical Race Theory also contends that progress happens through interest convergence and that those living at the intersection of multiple forms of oppression are multiply marginalized. However, we do not see evidence of these in Rebecca's reflections.

from the dispossession of Indigenous lands to the power conferred to those controlling the energy industry.

- c. *Counterstorytelling is resistance.* Counterstories aim to cast doubt on the validity of accepted premises or myths, especially those held by the majority. Majoritarian narratives are recognized as stories and not assumed to be facts or truth [65]. Rebecca leads with her efforts to counter mainstream images of scientists as only white men, and her emerging plans for instruction about efficiency resist dominant narratives.
- d. *Liberalism must be critiqued.*—Liberalism fails to consider race and racism in the examination of laws, policies, and practices, and their implications for Communities of Color [2,64,65]. Critical Race Theory issues a critique of basic notions embraced by liberal ideology, including race evasiveness, meritocracy, and neutrality of the law. Rebecca expresses delight and ease in challenging the objectivity and neutrality of physics. When she says she “can’t believe [she] never thought of this” as she names energy as a construct, we infer that she *has* thought about this in other contexts.

Importantly, these tenets of Critical Race Theory are entangled with the development of transformative knowledge and curriculum for Rebecca. This is not surprising, as MCE is a *response* to the realities named within Critical Race Theory. Our analysis concretizes this entanglement in the context of physics teaching.

Resource: Rebecca’s familiarity with the concept of efficiency.—On day 2, Rebecca writes about a lesson she had previously developed, in which students compete to design the most efficient matchbox car. Implicit in her description is some flexibility in her definition of efficiency—notably, students “justify why their car is most efficient”; they are not said to “apply a pre-determined definition of efficiency.” During the PD, Rebecca at first describes small-scale changes that she plans to make to this lesson and then more substantive ones. Rebecca’s access to this lesson seems to have cued her focus on efficiency and eased the content integration work that she went on to do. This raises questions about the role of content knowledge and/or teaching experience in teachers’ flexibility and capacity to engage in learning MCE.

Resource: Instruction in the PD course.—Rebecca’s learning about MCE was situated in the context of a PD designed to invite the development of transformative academic knowledge, and the activities and prompts shaped Rebecca’s discourse and writing. Particularly influential for Rebecca seemed to be specific examples offered by workshop facilitators. For example, one guest instructor offered a short video lecture about the sociopolitical nature of energy, including the ways in which Industrial-Revolution-era values shaped an emphasis on work and efficiency. This video prompted Rebecca’s “I can’t believe I never thought of this” reflection and seems to have influenced subsequent reflections in which Rebecca refers to ideas coming from a

particular time and place. Likewise, a second PD facilitator offered an Easy Bake Oven as an example of how one might define efficiency differently: though the light bulb in an Easy Bake Oven is inefficient as a light, it is very efficient as a heater. This example seemed to affirm Rebecca’s growing expansiveness around the definition of efficiency.

Summary.—Rebecca’s learning about MCE seems to have been shaped by a variety of cognitive and environmental resources, including the mutually reinforcing nature of the dimensions of MCE, her frustration, Critical Race Theory, her familiarity with the concept of efficiency, and instruction in the PD course. Though necessarily local in nature, the resources Rebecca draws on help us to formulate hypotheses that could be explored further in future studies, including the possibility of the following supports for teacher learning:

- Attending to opportunities to connect dimensions of MCE within teacher discourse.
- Encouraging and supporting productive frustration.
- Supporting teachers in learning about and designing instruction on the basis of tenets of Critical Race Theory. This is particularly relevant in the current, politically charged climate around Critical Race Theory in schools.
- Directing teacher attention to opportunities for modifying existing lessons on energy.
- Developing examples that highlight the sociopolitical nature of physics concepts or that offer expansive definitions of physics concepts.

V. DISCUSSION

In this paper, we have used the lens of Banks’ multicultural education to analyze teacher discourse and written work in the context of a PD designed to support the integration of physics energy concepts and equity. We hope this paper offers unfamiliar readers a theoretical and situated introduction to MCE, which has been one powerful response to the reality and permanence of racism in education [2,6,7]. One of our goals has been to illustrate what MCE can look like in physics, with the aim of generating community dialogue around this framework.

We have shown, first, that high school physics teachers encountered vexation points [27,28] as they sought to integrate equity into physics energy concepts, saying things like, “I don’t see myself getting kinetic energy equals one half mv squared out of that [equity-oriented] discussion,” and, “I feel like I’m woefully ignorant in this” even though “it’s always been something that I’ve been wanting to do.” The substance of these vexation points highlights the difficulty of developing transformative academic knowledge [13,20,57] in relationship to canonical definitions and representations of energy. We suggest that developing transformative academic knowledge is *made* difficult by the discipline of physics and the US system of schooling, both of which are significantly invested in maintaining existing power structures and

narratives of epistemic superiority. In physics, epistemic superiority is premised at least in part on knowledge-building practices believed to ensure (or approximate) objectivity and neutrality—to produce “‘unbiased’ knowledge unconditioned by its body and space location,” and thus “beyond any particularity” [11]. These framings—and the enlightenment-era values and philosophies they rely on—mask the cultural specificity of physics knowledge and knowledge-building practices. Instead, they support a powerful story: that the physics canon represents universal truths about the natural world, arrived at through rigorous (objective and neutral) methods. This story—combined with the cultural and political capital of physics in mainstream U.S. culture, the “rightful” (and enforced) role of teachers as “agents recruited and trained to carry out” the instilling of mainstream knowledge and values [59,60], and the current political climate around the critiquing of dominant ideas or ideals in schools [66]—creates an environment in which teachers are understandably confused about how to integrate canonical energy concepts with equity.

Rebecca’s case offers some insight into how teacher educators who want to support the development of

transformative academic knowledge might intervene. In particular, for Rebecca, observing a PD instructor critique and sociopolitically situate physics energy concepts was transformative (“I can’t believe...!”). Her transformation was further supported by invitations to issue her own critiques in the context of the physics concept of efficiency. In this example, physics instructors who specifically and substantively address the sociopolitical origins of physics concepts “broke the script” around the objectivity and neutrality of physics, opening new pathways for Rebecca to develop transformative academic knowledge.

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- [1] D. Battey and L. A. Levy, A framework for understanding whiteness in mathematics education, *J. Urban Math. Educ.* **9**, 49 (2016), <https://jume-ojs-tamu.tdl.org/JUME/article/view/294>.
 - [2] K. Crenshaw, N. Gotanda, G. Peller, and K. Thomas, Introduction, in *Critical Race Theory: Key Writings that Formed the Movement*, edited by K. Crenshaw, N. Gotanda, G. Peller, and K. Thomas (The New Press, New York, NY, 1995), pp. xiii–xxxii.
 - [3] C. I. Harris, Whiteness as property, *Harvard law review* **106**, 1707 (1993), <https://harvardlawreview.org/print/no-volume/whiteness-as-property/>.
 - [4] V. Vélez and D. Solórzano, Critical race spatial analysis: Conceptualizing GIS as a tool for critical race research in education, in *Critical Race Spatial Analysis: Mapping to Understand Address Educational Inequity*, edited by D. Morrison, S. A. Annamma, and D. D. Jackson (Stylus Publishing, LLC, Sterling, VA, 2017), pp. 8–31.
 - [5] D. J. Connor, B. A. Ferri, and S. A. Annamma, *DisCrit: Disability Studies and Critical Race Theory in Education* (Teachers College Press, New York, NY, 2016).
 - [6] E. R. Carlton Parsons, Interfaces between Critical Race Theory, and sociocultural perspectives, in *Power, and Privilege in the Learning Sciences*, edited by I. Esmonde and A. N. Booker (Routledge, New York, NY, 2017), pp. 28–49.
 - [7] R. Delgado and J. Stefancic, *Critical Race Theory: An Introduction* (NYU Press, New York, NY, 2017).
 - [8] M. Alexander, *The New Jim Crow: Mass Incarceration in the Age of Colorblindness*, revised (The New Press, New York, 2020).
 - [9] G. Gay, *Culturally Responsive Teaching: Theory, Research, and Practice*, 2nd ed. (Teachers College Press, New York, 2010).
 - [10] D. B. Martin, P. G. Price, and R. Moore, Refusing systemic violence against Black children: Toward a Black liberatory mathematics education, in *Critical Race Theory in Mathematics Education*, edited by J. Davis and C. C. Jett (Routledge, New York, 2019), pp. 56–74.
 - [11] R. Grosfoguel, The structure of knowledge in Westernized universities: Epistemic racism/sexism and the four genocides/epistemicides of the long 16th century, *Hum. Archit.* **11**, 73 (2013), https://www.niwr.org/sites/default/files/images/resource/2%20The%20Structure%20of%20Knowledge%20in%20Westernized%20Universities_%20Epistemic.pdf.
 - [12] J. A. Banks, Multicultural education: Characteristics, and goals, in *Multicultural Education: Issues and Perspectives*, edited by J. A. Banks and C. A. McGee Banks, 6th ed. (John Wiley & Sons, Hoboken, NJ, 2007), pp. 3–30.
 - [13] J. A. Banks, Multicultural education: Historical development, dimensions, and practice, *Rev. Res. Educ.* **19**, 3 (1993), <https://education.uw.edu/sites/default/files/Review%20of%20Research%20AERA.pdf>.
 - [14] S. Traweek, *Beamtimes and Lifetimes: The World of High Energy Physicists*, revised (Harvard University Press, Cambridge, MA, 1992).

- [15] S. Harding, Why ‘physics’ is a bad model for physics, *Whose Science? Whose Knowledge?: Thinking from Women’s Lives* (Cornell University Press, Ithaca, NY, 2016), pp. 77–102.
- [16] S. Harding, *Is Science Multicultural?: Postcolonialisms, Feminisms, and Epistemologies* (Indiana University Press, Bloomington, IN, 1998).
- [17] S. Harding, *Objectivity and Diversity: Another Logic of Scientific Research* (University of Chicago Press, Chicago, IL, 2015).
- [18] C. Smith, *The Science of Energy: A Cultural History of Energy Physics in Victorian Britain* (University of Chicago Press, Chicago, IL, 1998).
- [19] E. A. Wrigley, *Continuity, Chance, and Change: The Character of the Industrial Revolution in England* (Cambridge University Press, Cambridge, England, 1988).
- [20] J. A. Banks, The canon debate, knowledge construction, and multicultural education, *Educ. Res.* **22**, 4 (1993), <https://www.jstor.org/stable/1176946>.
- [21] J. Thompson, K. Mawyer, H. Johnson, D. Scipio, and A. Luehmann, Culturally and linguistically sustaining approaches to Ambitious Science Teaching pedagogies, in *Preparing Science Teachers Through Practice-Based Teacher*, edited by D. Stroupe, K. Hammerness, and S. McDonald (Harvard Education Press, Cambridge, MA, 2020), pp. 45–62.
- [22] P. Bell, Infrastructuring teacher learning about equitable science instruction, *J. Sci. Teach. Educ.* **30**, 681 (2019).
- [23] J. A. Banks, Approaches to multicultural curriculum reform, in *Multicultural Education: Issues, and Perspectives*, edited by J. A. Banks and C. A. M. Banks (Wiley, New York, 2003), pp. 242–264.
- [24] M. M. Atwater, Multicultural science education and curriculum materials, *Sci. Act.* **47**, 103 (2010).
- [25] B. N. Hinnant-Crawford, Increasing access: The application of multicultural education to STEM, *J. Multicult. Educ.* **10**, 250 (2016), <https://www.emerald.com/insight/content/doi/10.1108/JME-06-2016-0035/full/html>.
- [26] L. A. Reddick, W. Jacobson, A. Linse, and D. Yong, A framework for inclusive teaching in STEM disciplines, in *Teaching Inclusively: Resources for Course, Department and Institutional Change in Higher Education*, edited by M. L. Ouellett (New Forums Press, Stillwater, OK, 2005), pp. 435–450.
- [27] T. O. B. Odden and R. S. Russ, ‘Charges are everywhere’: A case of student sensemaking about electric current, in *Proceedings of PER Conf. 2017, Cincinnati, OH*, [10.1119/perc.2017.pr.065](https://doi.org/10.1119/perc.2017.pr.065).
- [28] T. O. B. Odden and R. S. Russ, Defining sensemaking: Bringing clarity to a fragmented theoretical construct, *Sci. Educ.* **103**, 187 (2018).
- [29] M. Eisenhart, Generalization from qualitative inquiry, in *Generalizing from Educational Research: Beyond Qualitative and Quantitative Polarization*, edited by K. Ercikan and W.-M. Roth (Routledge, New York, 2009), pp. 51–66.
- [30] F. Erickson, Qualitative methods in research on teaching, in *Handbook of Research on Teaching*, edited by M. C. Wittrock (Macmillan, New York, 1986), pp. 119–161.
- [31] R. K. Yin, *Case Study Research and Applications: Design and Methods*, 6th ed. (SAGE Publications, Inc., Los Angeles, 2018).
- [32] The Underrepresentation Curriculum Project, www.underrep.com (accessed 09/04/22).
- [33] R. E. Scherr, B. W. Harrer, H. G. Close, A. R. Daane, L. S. DeWater, A. D. Robertson, L. Seeley, and S. Vokos, Energy tracking diagrams, *Phys. Teach.* **54**, 96 (2016).
- [34] C. D. Allen and W. R. Penuel, Studying teachers’ sense-making to investigate teachers’ responses to professional development focused on new standards, *J. Teach. Educ.* **66**, 136 (2015).
- [35] C. E. Coburn, Shaping teacher sensemaking: School leaders and the enactment of reading policy, *Educ. Eval. Policy Anal.* **19**, 476 (2005).
- [36] E. Ketelaar, D. Beijard, H. P. A. Boshuizen, and P. J. den Brok, Teachers’ positioning towards an educational innovation in the light of ownership, sense-making and agency, *Teach. Teach. Educ.* **28**, 273 (2012).
- [37] K. E. Weick, *Sensemaking in Organizations* (SAGE Publications, Inc., Thousand Oaks, CA, 1995).
- [38] K. E. Weick, K. M. Sutcliffe, and D. Obstfeld, Organizing and the process of sensemaking, *Organ. Sci.* **16**, 409 (2005).
- [39] J. P. Smith III, A. A. diSessa and J. Roschelle, Misconceptions reconceived: A constructivist analysis of knowledge in transition, *J. Learn. Sci.* **3**, 115 (1993).
- [40] A. A. diSessa, Toward an epistemology of physics, *Cognit. Instr.* **10**, 105 (1993).
- [41] R. Driver and B. Bell, Students’ thinking and the learning of science: A constructivist view, *Sch. Sci. Rev.* **67**, 443 (1986).
- [42] D. K. Cohen, S. W. Raudenbush, and D. L. Ball, Resources, instruction, and research, *Educ. Eval. Policy Anal.* **25**, 119 (2003).
- [43] M. L. Franke, T. P. Carpenter, E. Fennema, E. Ansell, and J. Behrend, Understanding teachers’ self-sustaining, generative change in the context of professional development, *Teach. Teach. Educ.* **14**, 67 (1998).
- [44] J. Lave and E. Wenger, *Situated Learning: Legitimate Peripheral Participation* (Cambridge University Press, New York, NY, 1991).
- [45] D. Hammer, Student resources for learning introductory physics, *Am. J. Phys.* **68**, S52 (2000).
- [46] J. A. Maxwell, Causal explanation, qualitative research, and scientific inquiry in education, *Educ. Res.* **33**, 3 (2004).
- [47] J. A. Maxwell, Using qualitative methods for causal explanation, *Field Methods* **16**, 243 (2004).
- [48] M. Matsuda, Voices of America: Accent, antidiscrimination law, and a jurisprudence for the last reconstruction, *Yale Law J.* **100**, 1329 (1991), <https://www.jstor.org/stable/796694>.
- [49] P. Freire, *Pedagogy of the Oppressed* (Bloomsbury, New York, NY, 2000).
- [50] A. Lorde, *Sister Outsider: Essays and Speeches* (Ten Speed Press, New York, 2007).
- [51] C. Prescod-Weinstein, L. M. Walkowicz, S. Tuttle, B. Nord, and H. R. Neilson, Reframing astronomical research

- through an anticolonial lens—for TMT and beyond, [arXiv:2001.00674](https://arxiv.org/abs/2001.00674).
- [52] A. Mesa-Bains, *Ceremony of Spirit: Nature and Memory in Contemporary Latino Art* (The Mexican Museum, San Francisco, California, 1993).
 - [53] G. Ladson-Billings, Toward a theory of culturally relevant pedagogy, *Am. Educ. Res. J.* **32**, 465 (1995).
 - [54] O. Agirdag, M. S. Merry, and M. Van Houtte, Teachers' understanding of multicultural education and the correlates of multicultural content integration, *Educ. Urban Soc.* **48**, 556 (2016).
 - [55] S. Nieto, Multicultural education in the United States: Historical realities, ongoing challenges, and transformative possibilities, in *The Routledge International Companion to Multicultural Education*, edited by J. A. Banks (Routledge, New York, 2009), pp. 99–115.
 - [56] J. A. Banks, Approaches to multicultural curriculum reform, *Multicultural Education: Issues and Perspectives* (John Wiley & Sons, Hoboken, NJ, 1997), p. 229.
 - [57] J. A. Banks, *An Introduction to Multicultural Education* (Pearson/Allyn and Bacon, Boston, 2008).
 - [58] O. N. Ukpokodu, The challenges of teaching a social studies methods course from a transformative and social reconstructionist framework, *Soc. Stud.* **94**, 75 (2003).
 - [59] P. Bourdieu and J.-C. Passeron, *Reproduction in Education, Society, and Culture*, 2nd ed. (SAGE Publications, Inc., London, UK, 2000).
 - [60] P. Bourdieu, *Outline of a Theory of Practice* (Cambridge University Press, Cambridge, 2003).
 - [61] L. Z. Jaber and D. Hammer, Engaging in science: A feeling for the discipline, *J. Learn. Sci.* **25**, 156 (2016).
 - [62] E. Cramer, M. E. Little, and P. A. McHatton, Equity, equality, and standardization: Expanding the conversation, *Educ. Urban Soc.* **50**, 483 (2018).
 - [63] C. P. Battle, Climate change will displace millions. Here's how we prepare, TED (2019), https://www.ted.com/talks/colette_pichon_battle_climate_change_will_displace_millions_here_s_how_we_prepare.
 - [64] R. Delgado, J. Stefancic, and A. Harris, *Critical Race Theory*, 3rd ed. (NYU Press, New York, 2017).
 - [65] D. Solórzano and T. Yosso, Critical race methodology: Counter-storytelling as an analytical framework for educational research, *Qual. Inq.* **8**, 23 (2002).
 - [66] D. Stovall and S. A. Annamma, OPINION: Using Critical Race Theory to understand the backlash against it, Hechinger Report (2021).