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Transforming Science Learning Framework: Translating an Equity Commitment into Action through Co-Design

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ABSTRACT

In this study, we present a conceptual tool for guiding teachers' principled pedagogical actions toward equitable instruction, referred to as the *Transforming Science Learning* (TSL) framework. The TSL framework was developed to address the challenges of enacting an ideological commitment in local contexts–promoting equity and justice through culturally relevant pedagogy (CRP) in K-12 science classrooms. TSL consists of five design principles that articulate the goals (the '*why*" of practice), instead of prescribing pedagogical activities (the "*what*" of practice). The five principles are: a) make it matter, b) support sense-making, c) attend to race, language, and identities, d) build a welcoming community, and e) disrupt power hierarchies. We use a co-designed high school physics unit enacted by one teacher, Ms. Davis (pseudonym), as an illustrative case to contextualize our overall data analysis in three physics classrooms. We examine what teachers did, guided by each design principle, including when they planned lessons, interacted with students during instruction, and assessed student learning. We discuss the affordances of a well-designed conceptual tool in addressing the problem of enactment by productively mediating co-design toward transformative and consequential learning.

KEYWORDS
co-design; design principles; equity; research-practice partnership; problem of enactment; secondary sciences

Introduction

Despite the presence of powerful theoretical frameworks for equity and justice-centered teaching (see Calabrese Barton & Tan, 2019; Gay, 2018; Ladson-Billings, 1995 for example), teachers continue to struggle to enact such theoretical ideas in their own classrooms. To address this problem of enactment, researchers seek out ways to create collaborative design spaces where teachers and researchers work together to co-construct new, equitable forms of learning (Bang & Vossoughi, 2016; Fishman & Penuel, 2018; Gutiérrez & Jurow, 2016; Penuel et al., 2011). Essential to this co-design process are tools to help diverse members develop shared goals, navigating a wide range of priorities, concerns, and values. A well-designed tool mediates complex professional interactions in co-design, leading individuals to take principled and collective pedagogical actions toward shared goals (Severance et al., 2016).

In this study, we present the *Transforming Science Learning (TSL) Framework*, a conceptual tool for guiding principled and collective pedagogical decision-making to

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enact equity-centered science instruction. TSL is a form of principled pedagogical knowledge (Bereiter, 2014) that emerged from several years of co-design in an equity-oriented university-school partnership. TSL consists of five design principles that articulate teaching goals, or the "*why*" of practice. Using a co-designed high school physics unit as a subject of inquiry, we examine three teachers' translation of each design principle into classroom practices. We aim to understand the affordances of a conceptual tool in addressing the problem of enactment. The following questions guide our inquiry:

(1) How does each of the design principles translate the ideological commitment to promoting equity and justice in K-12 science classrooms into pedagogical goals?
(2) What are the key features of teachers' pedagogical actions informed by each of the five design principles in the TSL framework? What do teachers do when they plan lessons, interact with students during instruction, and assess student learning of the focal unit?
(3) What are the affordances of a tool in supporting teachers' enactment of equity-centered science instruction?

Transforming Science Learning (TSL) framework: a tool for guiding principled and collective pedagogical decision-making in equity-centered co-design

With the call for transforming science instruction at schools toward a more equitable and just future, teachers have expressed high levels of support for integrating Culturally Relevant Pedagogy (CRP) in science (Harris et al., 2018). The CRP pillars of *academic achievement, cultural competence*, and *sociopolitical consciousness* provide a robust theoretical framework for leveraging students' lived experiences and identities beyond school, validating cultural ways of knowing, and transforming students, the school, and broader society (Ladson-Billings, 1995). Despite the promise and popularity of CRP, however, enacting this ideological commitment has proven difficult. Teachers who embrace this ideology constantly wonder, "What does it look like in my classroom?," "Am I doing this right?" (Casey & McManimon, 2020). Ladson-Billings, who proposed CRP, is known for telling teachers that even if she could prescribe exact instructions, she would not. Teacher educators promoting CPR explain, "If we tell a teacher what to do, we foreclose possibilities for engaged learning with the *actual* students who inhabit our classrooms" (Casey & McManimon, 2020, p. 7). Teachers often struggle and feel frustrated with the lack of concrete advice, preferring checklists and strategies (Casey & McManimon, 2020). Consequently, researchers report a mis-alignment of CRP with observed teaching practices at schools, such as only celebrating holidays and food (Harris et al., 2018; Young, 2010).

In our view, the fundamental challenge resides in the complexity of supporting teachers to *enact* the abstract ideological commitment in local contexts, rather than lack of clarity in theoretical ideas (Tzou et al., 2021; Young, 2010). To create powerful learning contexts for students in K-12 science classrooms, in particular minoritized students, we must support teachers in designing and facilitating learning experiences in local contexts. The TSL framework, which was initially formulated by the first author and revised through the co-design processes, was intended to mediate the process of developing shared goals with a commitment to equity. We hoped that formulating shared goals between teachers and researchers through co-design would help teachers take principled and intentional pedagogical actions toward equitable instruction, while working with diverse students in their local contexts.

The TSL Framework consists of five principles: (a) make it matter, (b) support sense-making, (c) attend to race, language, and identities, (d) build a welcoming community, and (e) disrupt power hierarchies. Each principle draws teachers' attention to an aspect of the classroom activity *system* that shapes minoritized students' learning, and then motivates teachers to take deliberate pedagogical actions to create a better context for students' engagement. The proposed five principles are not mutually exclusive; rather, they are tightly related to each other. Additionally, the principles are not static, inflexible tenets but an evolving framework meant to be modified through partnership with teachers over time. The following unpacks each principle.

Make it matter

Historically, the science that minoritized students encounter at schools has been disconnected from their lives. These students are more likely to be tracked into low-level courses, which are off-putting due to their focus on rote memorization and completing worksheets rather than inquiry-based exploration (Parker, 2014). Latinx students have pushed back against curriculum that they find "unhelpful for their economic future and, simply, boring" (Villenas & Deyhle, 1999, p. 427). Not surprisingly, research shows that youths, especially those from economically and racially non-dominant communities, are more likely to engage when they feel that what they do in their classrooms matters, whether to them or to the people they care about (Birmingham et al., 2017; Ladson-Billings, 2017). This sense of mattering refers to establishing a personal connection and seeing a real impact of their work on students' lives and their communities. From our perspective, this construct of mattering is different from other motivational constructs, such as interest or relevance. Things that are interesting or personally relevant do not necessarily matter (Stuckey et al., 2013). For example, a video that shows a "magical event" (e.g., a singer shattering a wine glass without touching it) can spark interest and curiosity for most students in the moment, but students don't necessarily feel that understanding the science matters to them, especially for those who have difficult life situations (see, Tan & Calabrese Barton, 2008 for example). Instead, when teachers *make it matter*, students find phenomena meaningful because their investigations have a positive influence on the lives of people they care about. This sense of mattering is deeply personal and heavily dependent upon historical, social, geographical, and political contexts where their lives are situated.

Support sense-making

The second principle is directly related to the goal of science education in recent reform documents (NGSS Lead States, 2013; National Research Council, 2012). The discipline of science is fundamentally about deepening one's understanding of how the world works (National Research Council, 2007, 2012). Different from the generative work scientists do, historically, instruction has focused on delivering canonical scientific knowledge while positioning students as passive receivers with "wrong" ideas that need fixing. Supporting sense-making calls for re-framing the relationships among knowledge, learning, and learners (National Academies of Sciences, Engineering and Medicine, 2018). It involves positioning students as capable sense-makers who exert epistemic agency to deepen their understanding about the world while expanding their ways of thinking, talking, and doing (Bang et al., 2017; Herrenkohl & Mertl, 2010).

Supporting students' sense-making has been a major focus of science education research. There are several promising frameworks, tools, and strategies that can be leveraged to design student experiences toward this goal (e.g., Reiser, 2014; Windschitl et al., 2012). Some examples of the research-based strategies are framing a unit around a phenomenon; beginning an activity sequence by eliciting students' ideas; and developing a cohesive unit storyline where each lesson is driven by students' questions. At the stage of enactment, students should be guided to engage in scientific and engineering practices to expand their sense-making repertoires (ways of thinking, talking, and doing). Researchers highlight the important role of classroom discourses facilitated by teachers in expanding students' understanding about the world (e.g., Kelly, 2007; McDonald & Kelly, 2012; McNeill & Pimentel, 2010; Michaels et al., 2002). A key aspect of supporting sense-making in our framework is taking an expansive epistemic view on various repertoires as legitimate and valid, without norming the White, western, Eurocentric ways of thinking, talking and doing as the right version (Bang et al., 2012; Warren et al., 2020). This perspective is crucial to support minoritized students' learning, without contributing to assimilation or reproduction of power hierarchies.

Attend to race, language, and identities

Researchers have documented the struggles of students of color and multilingual students in navigating the spaces across home, community, and schools in a highly racialized and deeply unjust society that has been constructed through the history of colonization (Bang et al., 2012; Calabrese Barton et al., 2013; Villenas & Deyhle, 1999). Students from non-dominant communities constantly have social encounters that undermine their rightful presence as members of the scientific and classroom community (Calabrese Barton & Tan, 2019). For example, during one of our student interviews, a Latinx boy shared his experiences of being accused as a "stealer" when the adults at school were "racially profiling" him. He didn't feel like he belonged at school and although he maintained a love for science, he didn't share that with most teachers or peers. The principle of *attend to race, language, and identities* draws teachers' attention to students' racialized experiences encountered every day, both inside and outside the classroom. This principle also draws teachers' attention to structural inequities that create differential access to resources and opportunities across students along with racial, linguistic, cultural, and socioeconomic lines in historical and political contexts. Researchers note that this "thick" perspective on equity is foundational for teachers to make complex interpretations about students' academic performances and behaviors in classrooms (Kang & Zinger, 2019). This principle points to the importance of creating a space where students feel comfortable to be who they are; where students use their home languages and practices to *do* science and students think of themselves as valuable members of a classroom learning community. Since minoritized students' identities are multifaceted, it's important to not essentialize or stereotype, and bring in dimensions beyond ethnicity and race. For example, leveraging local youth culture or interests and hobbies such as music or sports (Irizarry, 2007). Additionally, students can leverage forms of expression not typical in science class including informal language, drawings, and sense of humor.

Build a welcoming community

This principle is closely linked to the third one, *attend to race, language, and identity* in that it aims to support the rightful presence of students who have been historically marginalized in science classrooms. Whereas the third principle facilitates teachers to design academic tasks that leverage students' everyday experiences, practices, languages, and identities, the principle of *build a welcoming community* draws teachers' attention to a *non-academic* aspect of teaching, that is the classroom culture or atmosphere built around cumulative interactions and relational work. A recent study about teachers' responsiveness that promotes equity shows how brief non-academic interactions between the teacher and minoritized students can be consequential in students' opportunity to learn (see Kang, 2022). For example, a teacher's friendly introduction of a recently immigrated Vietnamese student to peers helped students form new social relations, and facilitated the student's participation in a group task despite linguistic challenges. Through detailed analysis of 658 events from six lessons, Kang found that a responsive teacher continuously attended and addressed minoritized students' relational challenges–their difficulties of relating to people (i.e., peers and the teacher), the space, and discipline–in addition to supporting their disciplinary engagement. In other words, classroom culture goes beyond disciplinary content, and is co-constructed by both the teacher and students who bring their own life histories (Milner et al., 2018). Creating a space where minoritized students feel welcomed, valued, and socially and emotionally connected with people is foundational for students to engage in deep intellectual work (Kang, 2022).

In our partnership, teachers noted that this principle attended to a broader issue beyond the development of a storyline, curriculum, and assessment of a unit. The teachers also agreed that it was unlikely that students from non-dominant communities would engage in science meaningfully without building a welcoming culture grounded in teachers' intentional, cumulative, and ongoing relational work. Therefore, they needed to work on this from day one because equity could not be achieved simply by having a well-designed curriculum. This principle serves as a reminder for teachers to be intentional about the relational work that they do on a daily basis, including when they enact the co-designed curriculum and assessments.

Disrupt power hierarchies

Research shows how learning in schools has traditionally been racially coded and cultured in oppressive ways for historically marginalized groups (Bang & Medin, 2010; Mensah & Jackson, 2018). The power is systematically distributed in classrooms along racial or linguistic lines while norming particular ways of doing, talking or being as appropriate or better. Critical scholars point out the "Whiteness" of school science, as it privileges a Eurocentric knowledge frame over others (Mensah & Jackson, 2018) and constrains students, particularly those from racially, linguistically, and socioeconomically non-dominant communities (Bang & Medin, 2010). Accordingly, critical scholars point to disrupting or "de-settling" the settled expectations of what it means to "do science" or "be good at science" as a key for addressing inequity (Bang et al., 2012; Warren et al., 2020). The principle of disrupting power hierarchies aims to create expansive learning experiences where various ways of thinking, talking, and doing are leveraged, recognized, legitimized, and valued toward collective construction of knowledge in a classroom learning community.

Researchers note that disrupting power hierarchies involves teachers' sensitivities to "multiplicity" (Warren et al., 2020)–multiplicity of doing sciences in the professional science communities as well as multiplicity of students' diverse ways of thinking, talking, doing and being. This sensitivity facilitates teachers and researchers to ask critical questions of what counts as "science," what it means to be good at science, who is positioned and recognized as a "science person" and who is not, and why. It is necessary to problematize simplistic dichotomies such as right or wrong, good or bad in order to disrupt power hierarchies and create expansive learning experiences that are equitably consequential.

Transforming science learning framework in action

Introduction and use of the tool

This work occurred within a multi-year research-practice partnership among high school teachers, education researchers and scientists at a research-oriented university in the Pacific Southwest of the United States. The team co-designed and implemented four units of chemistry and physics curricula in 2019–2020. The TSL Framework tool was initially devised by the lead researcher based on literature review and analysis of a local pilot program. Participants were introduced to TSL during a Summer Institute on designing science curricula for students from marginalized backgrounds. The research team taught a condensed science unit that modeled the five design principles in action. Teachers then critiqued both their existing curricula and the modeled unit, discussed their interpretation of the principles, and finally wrote their names on "Design Commitment Posters" explaining why they wanted to attend to that particular principle in their focal units. Following this sense-making conversation about the TSL framework, the teachers worked together to draft a storyline for their unit including selecting a phenomena, crafting an overarching unit essential question, creating pre and post assessments, and designing a sequence of activities connected by the overarching essential question. Feedback was provided by the team in relation to the design principles (e.g., "questions like "Which students would this matter to and why?" and "How does this activity help students make sense of the world around them?" or praise like, "It was powerful how you provided opportunities for students to use their home languages in the final assessment!")

Teachers also received TSL-aligned support during enactment. During an on-site professional development (PD) meeting employing a version of lesson study, two of the three physics teachers, who worked at the school site, taught the first lesson of their co-designed unit. The third physics teacher, who worked at the other school, attended the PD before he taught the lesson. At the beginning of the day together, the lead researcher reminded everyone of the principle they discussed before observing each other's teaching. The group co-constructed a checklist and guiding questions to self-check implementation of the co-designed lesson according to the TSL framework. After teaching and observing the co-designed lesson, the teachers met with the research team to discuss student experience during the unit launch, analyze student work according to the five principles, and plan for the rest of the unit to support equitable science instruction. During a follow up PD and through exit interviews, teachers helped modify the framework for the following year. They discussed their interpretation of the tool and experiences designing and enacting.

Classroom and school setting

To document a wide range of intentional pedagogical actions guided by the principles, we analyzed data from the three physics teachers who co-designed and taught a unit on momentum and impulse. We used one teacher's enactment of the co-designed unit as an illustrative case to contextualize the meanings of the intentional actions for a particular group of students over a few months. Transcripts and examples came from Ms. Davis' (pseudonym) lower-track 11th grade physics class in Fall 2019. Ms. Davis was a Chinese-American female teacher in her twenties who grew up in the community and had taught for four years. The focal class was representative of the demographics of the school, where 78% of learners were Latinx, 10% were White, and 5% were Asian. Tracking was widespread in the school and primarily minoritized students were in the lower-track compared to Honors classes.

The school site was a Title 1 school with two thirds of students receiving free and reduced priced meals. Twenty one percent of students at the school were designated "English learners" while 49% of students were redesignated as "fluent English proficient." We focused on Ms. Davis since we had the most comprehensive data from her classroom plus interviews with her before and after the program. In addition, student performance in the co-designed unit revealed expansion of meaningful learning opportunities for Latinx and female students in high school physics classrooms (see the detailed performance analysis in Kang et al., 2022).

Data sources and analysis

Data sources include teacher and student interviews (160 minutes of audio), classroom observation (60 hours of video), and student and teacher artifacts for all three physics classrooms (see, Table 1).

We sought to make visible various forms of intentional actions guided by each TSL design principle. In alignment with our goal of transforming minoritized students' science learning, we began analysis from the perspective of understanding students' experiences. First, for each class session, we generated a detailed video log or "event map" (Green et al., 2012) that chunked the video by events such as "launch of the task." We utilized these ethnographic event maps to make visible classroom dynamics, and capture moment-to-moment dialogue and actions that expanded or constrained opportunities to learn in educational settings (Green et al., 2012). Next, to better understand the mediation of student experiences from multiple perspectives, we looked holistically at documents from the teacher planning process including preliminary unit plans, design principle commitment posters, and drafts of initial and final assessment plans. We also reviewed student work including assessments, and discussed across multiple research team meetings how the design principles were evidenced by students' writing and drawings.

After generating a rich characterization of student experience based on the unit implementation, we returned to the video log for each class and coded each sub-event according to the TSL Framework, creating a "systematic index" (Baker et al., 2008). Each member of the research team (science education faculty, postdoctoral researcher, graduate research assistant) watched the classroom videos and reviewed logs to perform closed, structural coding (Saldaña, 2009) according to the five TSL design principles. During weekly research

Table 1. Overview of audio, video, artifacts data for physics team.

Data type	Data source	Event	# Sessions	Hrs video/ audio	Artifacts
Planning	Professional Development (PD) video	PD Summer Institute	3	24	• Unit storyline • Sketch of initial and final assessment • Commitment posters
		PD Afterschool	1	2	• Modified activity
		PD Instructional rounds	1	8	• Co-planned lesson outline • Student exit tickets
		Total PD video	***5***	***34***	
Enactment	Classroom video	Teaching videos (teacher cam)	13	13	• Various teaching artifacts
		Student observation videos (focus group cam)	13	13	• Student work (initial and final assessments, letters to loved ones, initial and final car designs, physics models, drawings, lab notebook pages, and worksheets.)
		Total classroom videos	***26***	***26***	
Reflection	Interviews	Teacher interviews	6	3	• NA
		Student interviews	18	3	• NA
		Total interviews	***24***	***6***	

meetings over two months, the team reviewed codes for each event. When there was a disagreement, the team discussed until a consensus was reached. The team collectively identified three to four "key events" per class, where enactment of the design principles appeared most salient (Baker et al., 2008; Green et al., 2012). These key events generated new datasets, as we extracted corresponding sections of video and generated rich descriptions by adding photos of classroom interactions and student artifacts. For each key event we "transcribed a segment of life," transcribing dialogue and nonverbal cues, but also writing a detailed description of how the design principle came to life (Baker et al., 2008, p. 15). This process was repeated with videos from professional development activities. Next, we applied the same coding scheme to analyze pre and post interviews with the physics teachers. Finally, the two authors categorized all the key events according to the codes of 1) curriculum, 2) pedagogy, or 3) assessment to illuminate the connection between design principles, pedagogical actions, and student experience.

Teaching a high school physics unit about momentum: five design principles in the TSL framework and teachers' pedagogical actions

Findings came from all three participating physics teachers' classrooms. Table 2 presents a comprehensive list of teachers' *intentional* pedagogical actions and connection between curriculum and assessment, guided by each of the design principles. While we found the same TSL-aligned examples of enactment in each classroom, for the expanded results below we present examples from Ms. Davis' focal class. For each design principle, we unpack one example from Ms. Davis' class, based on the most salient illustrations.

Table 2. Teachers' intentional pedagogical actions informed by each of the five design principles (DPs).

Design Principles	Curriculum	Pedagogy	Assessment
Making it matter	• Humanize the learning of physics; bringing the experiences of people that students care at the center of learning physics & positioning students who can make the world a better place for the people whom they care (e.g., engineers who improve the safety of car in a collision) • Frame essential questions centering around something that students care (e.g., designing a dream car for the loved ones that can be safe in a collision and communicating the safety features in relation to physics ideas in multiple ways)	• Launch the task in a way that students make a personal connection with the task (e.g., giving a post collision worksheet that students can keep in their car and use when collision happens) • Continuously revisit and connect back to the problem or concern that students care about throughout the unit	• Use curriculum-embedded non-traditional forms of assessment tasks where students share their personal stories (e.g., Writing a letter to the loved one, drawing the car)
Supporting Sense-making	• Develop a unit storyline where students explain "how" and "why" of the phenomena or solve a problem • Formulate an overarching unit essential question that highlights key observations or patterns, and invite students to explain how and why • Organize activities in a way of following/responding to students' unfolding thinking • Plan participation structure that facilitates students' social and intellectual interactions (e.g., sharing their ideas, modifying their models)	• Formulate daily essential questions in a way of following students' thinking • At the onset of each lesson, connect the day's lesson to the big picture while connecting prior day's lesson to the day's lesson and giving the sense of the future (where we are heading for). Explain "why" behind the activity, not just telling them "what to do" • Prompt students to share their observations, predictions; validate students' ideas and languages; juxtapose different ideas and get students to notice the difference • Frame the goal of the activity as making sense of the world • Draw students' attention to key observations or patterns, then help them to notice "changes", and explain by pressing "why" rather than only making observations • Press students to use the data from the activities to support their claims • Provide opportunities for students to make sense of the phenomena individually, in small groups, and in whole class discussions	• Use initial and final assessments that help both the teacher and students to see the progress in student thinking • Enact multiple forms of curriculum-embedded assessments throughout the unit (e.g., exit ticket, worksheet, practice speech) and use the information to set up the following activities.

(*Continued*)

Table 2. (Continued).

Design Principles	Curriculum	Pedagogy	Assessment
Attend to race, language, and identities	• Set up a unit context with the attention to students' culture, different facets of their identities (racial, linguistic, age, gender identities) (e.g., be excited to get a license and become a driver) • Design tasks where students could use their home language • Design tasks where students share their stories about themselves and their lives outside the classroom (e.g., family, concerns, values, interest, etc)	• Creating spaces for students to share their stories with each other & form new social relations (building a new relationship with people (teacher & peers) in the classroom learning community through story-sharing • Prompt students to share more about themselves as individuals • Attend to and validate students' experiences, who they are beyond physics students	• Story-telling through letter writing & using home language to communicate with their loved one • Use non-traditional forms of assessment tasks where there is a recipient or audience, and asking the student to address that person in the language they use at home or feel most comfortable using
Building a welcoming community	• Design tasks that prepare students to engage with each other in Physics but are not necessarily science-related (e.g., "mindful minute" reflection, sharing classroom news) • Plan participation structure that facilitates students to share and build on each other's experiences and personal interests	• Create moments for individualized interactions with students before, during, and after the instruction (e.g., calling on every single student's name while greeting students coming in the door) • Create a space for students to get to know each other and the teacher (e.g., I like you to take a little bit of time, get to know each other, share your work . . . .find one more person that you haven't talked to yet."	• Use non-traditional forms of assessment tasks where students receive support from each other and authentic feedback (e.g., presenting their sales pitch as a team to judges from the school and university community)
Disrupting power hierarchies	• Broaden what it means to "be good at" science, create multiple ways to communicate science expertise • Design tasks so students figure things out by themselves, instead of the teacher telling them • Consider the ways students would ask questions to frame the essential question, instead of following the logic of sciences • Plan participation structure that facilitates all students to share and build on each other's ideas (e.g., same small group throughout, labs and small group discussions)	• Explicitly and publicly communicate that everyone's voice matters and should be heard, and everyone has valuable ideas (e.g., "We would like to hear each other's voices today, hearing each other's idea.") • Affirm students' presence by provide positive and encouraging words to students when sharing their ideas regardless of scientific accuracy ("nice to hear your voice") • Juxtapose students' ideas without any indication of right or wrong, noting the diversity of students' opinions and how peers are a source of insight and knowledge • Reformulate participation structure of conventional science activities (e.g., students define variables and lab procedure collectively, students' wonderings set up the day's question) • Refer to students as engineers, designers, scientists	• Create multiple ways of being good at science by using multiple forms of assessments, including non-traditional ones with different forms of expression (e.g., drawing, writing, presenting) • Include feedback and evaluation other than the teacher's comments (e.g., peer feedback, panel judges)

Make it matter

The teachers were committed to making their physics content truly matter to students, and purposefully employed several actions toward this aim as they designed the curriculum, facilitated classroom interactions, and designed and enacted assessment (see, Table 2). For example, they brought the experiences of people that students cared about at the center of learning physics; launched the task so students made a personal connection with the task; used curriculum-embedded non-traditional forms of assessment tasks where students shared their personal stories. Specifically, the teachers developed the unit storyline focusing not on the principles of momentum but instead on how students could make the world a better place for someone they cared about. Enacting this humanized design depended heavily on how the teachers framed the unit's focal problem and overarching question and kept the framing throughout. For the sake of space, we highlight how Ms. Davis launched the unit on the first day in a way that fostered deep personal connections using the humanized physics curriculum.

Launching to form a sense of mattering, where students make deep personal connections to the activities. On the first day of the unit, students started by envisioning their loved one and a car for them, rather than learning the definition of momentum or seeing the equation for Newton's second law on the board. To introduce the essential question that would drive the unit, Ms. Davis invited students to visualize someone they cared about:

> I want you to think about **someone in your life, who you care about**, someone who has cared about you, who was taking care of you when you were sick, when you were down on your luck, or just down in general . . . Do you have someone in mind? Now I want you to fast forward, 20 years from now. You guys have been all successful in your lives . . . Now you have extra money to share. And this person, who you care about and who cares about you, comes to mind. **I want you to think about, what kind of car would you design for this person?**

After this introduction, students created personalized car designs, forming new attachments with both peers and the physics content. But beyond personalization, the cars were designed as an act of gratitude and connection to someone "who you care about and who cares about you." When they shared their designs with other classmates, students showed how they included GPS in Spanish to help their parents navigate, back-up cameras to protect their siblings with learner's permits, and four wheel drive for their friend who enjoyed camping and off-roading. From the first day, students saw how physics related to everyday life, with a direct connection to the people and things that mattered to them. The launch was not used as a "hook" to generate interest before launching into science content. Instead, all the activities that followed this first day were organized within the central question of "How are modern cars designed to keep you and your loved ones safe in a collision?"

Throughout the unit, students shared their designs with peers and the teacher. They shared stories about people, places, and things they cherished. Ms. Davis, like the other teachers, reframed the activities that they had used before when teaching the topic of momentum and included new personalized activities such as writing a letter to their loved one describing their car design and features that protected them while driving. The letter was used as an alternative form of final assessment to gauge students' understanding of physics concepts. Ms. Davis also communicated to students that they were not learning about momentum for the sake of developing abstract physics knowledge but to understand

and impact the world around them. Although students engaged in standard physics activities such as collision carts and egg drop labs, they watched dash cam footage, received collision report forms for real car crashes, and envisioned the egg as a passenger to investigate how materials impact a collision. At the end of the unit, students showcased how their car followed physics principles to decrease impact in a collision, but connected these ideas to memories and stories when explaining to their loved ones how it worked and how it was designed especially for them. They also evaluated Toyota's proposed design change, so they saw a broader impact in how to better protect people in car accidents.

Support sensemaking

We identify multiple actions teachers took to help students make sense of the world around them (see, Table 2 for the other actions). These pedagogical actions drew students' attention to observable changes, supported students to notice important patterns in the focal phenomenon, and provided new experiences that expanded the ways in which students thought about the phenomenon using unobservable or theoretical ideas. Below, we illustrate one action regarding formulating essential questions in Ms. Davis' class.

Formulate daily essential questions using students' language and help students figure it out for themselves. One way all the teachers, including Ms. Davis, supported students' sense-making was by formulating daily essential questions using students' responses and wonderings elicited from prior activities. Building upon the initial assessment, Ms. Davis invited students to explore, *"How can we predict the outcome of a collision?"* Students watched dashcam footage of car crashes and engaged in chat stations to predict what would happen in scenarios such as a hockey player and figure skater crashing into each other. From this activity, students were left wondering, "*Why do some collisions cause more damage than others?*" They figured out some answers from simulations where they adjusted the initial velocity and mass of two colliding carts but asked, "*How does the material influence the damage in a collision?"* They tested out the compressibility of materials and damage during an egg drop lab, and also recorded and reviewed slow motion video footage to observe the moment of impact and consider *why* there was a difference between the egg hitting cotton balls versus paper. In their final set of activities, students conducted research in small groups and made connections between their labs and car designs, answering "*How do safety features reduce injury during a collision?"*

Ms. Davis made a deliberate effort to "let students figure out" their own answers to the series of questions, instead of giving answers quickly to support students' sense-making. Students predicted and tested their ideas and wonderings, and had conversations with peers and the teacher both individually and collectively. Ms. Davis continuously guided students to make observations and construct explanations. For example, students explored how the material would influence the damage in a collision through the egg drop activity. Students first predicted the outcome of various collisions between eggs ("passengers") and materials (flexible vs. less flexible), before gathering and analyzing data on the resulting collisions. Next, students made observations while filming the egg dropping onto different materials and discussed the patterns. The teacher directed students to the *changes* happening when the egg hit the material and helped students become more aware of how they were describing what was happening in order to translate it into their models. In the transcript below Ms. Davis helps students focus in on and describe what happens when the egg hits the sponge:

Ms. Davis: When you guys are going back and replaying the footage, what do you notice is happening to the sponge as the egg makes contact? [gestures egg hitting into hands]

Student: It's adjusting [moves hands down, motions downward]

Ms. Davis: Adjusting in what way?

Student: Elastically.

Ms. Davis: Uh, in which direction? What do you mean by "adjust"?

Student: In itself [motions downward]

Ms. Davis: Into itself? [copies student's downward motion] I see you're using your hands to push down.

Student: Yah.

Ms. Davis: So you mean downwards? Okay. Can we actually show that kind of adjustments in our model? [points to other student's paper]

Student: In them?

Ms. Davis: Yes, in the model.

Ms. Davis repeated the student's wording of "adjustment" and downward motion to communicate the change in the sponge when the egg hit. The teacher helped students focus on the essential question of how materials reacted differently and come to *their* own conclusions informed by *their* data about how differences in material made a difference. Students reached the conclusion that a flexible material was best for protecting the egg ("passenger") in a crash.

Attend to race, language, and identities

The teachers took the following actions to attend to students' identities: set up the unit with attention to students' cultures and facets of their identities; include home languages; share stories of home lives; validate students' experiences; and include an audience for the assessment (see, Table 2). Below, we illustrate how Ms. Davis purposefully designed and enacted assessment tasks that integrated students' experiences into scientific explanations, creating spaces for students to do identity work.

Create a space for identity work by designing tasks where students share stories and interests with others. When teaching this unit previously, the teachers, including Ms. Davis, relied on a more conventional assessment that prompted students to construct scientific explanations using a format of claim-evidence-reasoning ("CER assessment") to assess students' understanding of momentum, impulse, and inelastic and elastic collisions. Inspired by the principle of attending to race, language, and identities, the teachers included unconventional forms of assessment tasks, such as writing a letter ("Letter assessment") and giving a sales pitch about their designed cars. These tasks created spaces for students to share stories with peers and teachers while leveraging their assets, talents, or interests that were typically invisible in science classrooms.

For their final project, Ms. Davis' students created a car design and wrote a letter to their loved one detailing the safety features and why they designed it for that person. Students connected safety features to physics core ideas about energy transfer in a collision, but also wrote about their loved ones' preferences, needs, routines, and interests. In their letters, students described the crumple zone, explained the relationship between force and time in a collision, and how features like seatbelts and airbags keep a passenger from moving forward with their car. In addition, they addressed loved one's needs to see at night, drive long hours, or transport people, equipment, and groceries for trips, work, and errands. One student mentioned specific modifications that would allow his uncle to operate the car from his wheelchair, writing that "El carro tiene asientos para soportarlo y también el carro está modificado para que puedas manejar" ("The car has seats which support [the wheelchair] and the car is also modified so that you're able to drive it"). Students shared personal concerns, family struggles, and joyful moments, foregrounding race, youth culture, and other components of their identity through storytelling. Students referred to their ages and geographical location, family relationships and values, physical features like being short or large, interests and hobbies, their personalities and job requirements like working the nightshift. The independence associated with learning how to drive was clear, as was the importance of spending time with family, whether on road trips, visits around town, or fixing cars. Some students' concerns were tied to being a low-income first generation student with parents who immigrated from Mexico. There was heightened anxiety in the community following heated debates around the Trump administration's policies toward immigrants. Ms. Davis commented on family members' insecurity about and understandable challenges with learning a second language in these circumstances and encouraged students to pursue features such as GPS in Spanish as legitimate safety concerns and affordances in their car designs. Additionally, due to how the unit was launched, many students saw this envisioned "dream car" gift as a way of giving back to someone who had cared for them and deserved more comfort in their life. For example, one student wrote, "I believe you deserve something that will take care of you just as well as you have with me." The letters provided opportunities for students to reflect on their relationships, tell stories, and develop deeper connections to loved ones, within the context of learning about momentum and impulse (see the details of the letter assessment, including examples and student performance in Kang et al., 2022).

Build a welcoming community

We observed diverse actions that contributed to building a welcoming community, including: design tasks that prepare students to engage with each other but are not necessarily science-related, and create moments for individualized interactions with students before, during, and after instruction (see, Table 2). These actions facilitated relational work among the teacher and students, while surfacing and legitimizing learners' emotions, skills, and struggles. Below we present how Ms. Davis, on the first day of this unit, created a space for students to get to know each other.

Creating a space for students to build social relations while doing science. As usual, students had a new seating chart as they transitioned into a new unit. As illustrated above, the task of the first day was to draw a dream car for themselves and for their loved one and think of important design features as an engineer. After quietly drawing a dream car for themselves, Ms. Davis asked all students to share their car with two people (one with the same colored shirt, and the other with the same height). Students walked around the room, introduced themselves to each other, and talked about *their* dream car. Ms. Davis then gave the next task, to draw a dream car for their loved one and describe essential features for them, including the top three "must have" features. After quiet individual drawing, Ms. Davis asked students to stand up once again and share their dream car with their peers, saying "I'd like you to take a little bit of time, get to know each other, share your work . . . .find one more person that you haven't talked to yet." Students found someone they did not know well, introduced themselves, and excitedly shared essential features such as for their friend who had gotten into an accident and needed a backup camera, their sibling who loved to visit the beach and would appreciate a sunroof, or their mother who needed room for a cooler when taking their cousins on trips. Before transitioning to the next activity, Ms. Davis asked, "How many of you have learned something new about someone else in our classroom?" Several students, as well as Ms. Davis, raised their hands. With a big smile, Ms. Davis said, "I certainly did. I heard a lot of passion about cars out there. Some people have adventurous spirits but I didn't know about them. There are some students who have dogs or pets that they want to take on road trips. I didn't know about this. Thank you for sharing."

Sharing about their experiences in relation to the dream car was not the initial hook to pique their interest, but instead remained central throughout the unit. Throughout the co-designed unit, Ms. Davis created a space for students to get to know each other and build social relations as part of doing academic work. Students connected with the material through their loved one, but also connected with peers while sharing their designs. In addition, students stayed in the same small group of four students throughout the unit, working together to solve the physics problems but also learning about each other. When they conducted their own research on safety features and reported back to their small group, one student added details he knew from fixing cars with his dad and uncle and another student talked about modified safety features for babies like his younger cousin. Throughout the unit, Ms. Davis (and the other teachers) implemented activities that encouraged students to formulate relationships not only with the teacher but with their peers.

Disrupt power hierarchies

Pedagogical actions taken to disrupt power hierarchies include: create a participation structure that facilitates all students to add their voices, explicitly communicate that everyone's voice matters and should be heard, affirm students' presence by providing positive words to students (see, Table 2). Below, we illustrate the first pedagogical action: creating multiple ways of being good at science by using multiple forms of assessments.

Create multiple ways of being good at science. Historically, students in this community engaged in Claim-Evidence-Reasoning (CER) assessments from middle to high school. CERs were recommended by the school district, to support students in developing an NGSS-aligned way of thinking, talking, and doing science. During the exit interview, we learned many students struggled with CER assessments, finding them unmotivating, difficult, or a type of busywork. For example, one Mexican-American female student, Courtney (pseudonym) "was scared to move on and take the [physics] class" because she heard that "it involved a lot of math and difficult types of formulas." Courtney said, "coming from a student perspective I think CERs are . . . they're mainly just I think of it as another assignment . . . I'm not gonna, what's called, make a big deal of what I'm doing it."

With the goal of disrupting the settled norms, expectations, and practices of doing science at schools, in this co-designed unit, the researchers and Ms. Davis and the other teachers intentionally designed multiple forms of curriculum-embedded assessments (see the details in Kang et al., 2022). The unconventional assessments, such as drawing a dream car, writing a letter to loved ones, and giving a sales pitch, were meant to facilitate students to leverage their personal concerns, assets, home practices and languages. Whereas CER assessment was considered as the valued ways of doing science by the NGSS, Letter assessment facilitated students to use their personal concerns, relationships, interests, and home languages to do physics while explaining how the design features of the car would protect their loved ones from a collision. Unconventional forms of assessments were received very positively by both teachers and students. The teachers learned more about students and their families, which opened up the door to deeper relationships. Students, in particular those who had been marginalized in physics and chemistry classes, expressed their excitement. For example, Courtney said, "I think the letter one was really different, because I hadn't done one like that or an activity similar to that in any of my classes before. I think it was really good because it has you thinking about other people, instead of just yourself." While powerful in developing relationships and sustaining engagement, the Letter assessment also revealed deep understanding about the car safety issue in relation to momentum. The analysis of student learning, as measured by the quality of student explanation using 152 copies of student assessments, showed the statistically significant improvement of the quality of student explanations throughout the unit (see Kang et al., 2022).

Summary

We presented examples of the five principles of the TSL Framework *in use*, emphasizing the interaction between pedagogical actions informed by these principles and the resulting student experience. Our intention is not to extol the virtues of this one unit but rather to illustrate and unpack how the principles from the TSL Framework translate into classroom practices. We supplement the existing examples of what culturally relevant pedagogy (Ladson-Billings, 1995) look like in practice on both the design and instructional sides, with specific pedagogical actions that are broad enough to be applicable outside of secondary science. In the next section, we discuss the affordances of the TSL framework in addressing the problem of enactment through co-designing activities in an equity-oriented partnership, therefore contributing to transforming teaching for equity.

Affordances of the TSL framework in addressing the problem of enactment

A key challenge facing the science education community is to create *conditions* for teachers and researchers working together to break from normalized modes of disciplinary teaching and learning, reimagining and bringing about new forms of activity in schools. The TSL Framework, as one form of principled practical knowledge (Bereiter, 2014), provides guidance, rather than explanation or prediction. The proposed framework communicates key lessons from prior studies on how and under which conditions students from non-dominant communities engage in science meaningfully. The phrasing of the framework's dimensions also encourages the team to specify pedagogical goals ("why" of practice), rather than describing actions, activities or strategies ("what" of practice). By specifying *goals*, teachers are positioned to leverage rich contextual knowledge about their communities and students to tailor to their own classroom contexts. In this way, the principles empower teachers as active designers and engineers of student experiences, instead of passive consumers of expert-developed curricula which fall short of enacting equitable science instruction (Kang & Orduña Picon, 2021).

Our analyses suggest that a well-designed conceptual tool is useful for mediating collaborative design and addressing the problem of enactment. Such affordance depends heavily on the features of the tool. The TSL design principles conceptualized in this study have an intermediate level of abstraction in that they are not higher-level phrases that communicate ideological, theoretical orientation or commitment (e.g., "promoting equity and justice," "implementing culturally relevant pedagogy") nor concrete descriptions of teaching behaviors that provide instructions (e.g., "five best practices," "eliciting students" initial ideas'). It appears that this "in-between" level of abstraction opens up a space of collective meaning-making of pedagogical goals communicated with design principles during the co-designing activity. Take as example of the principle, *attend to race, language, and identities*. Teachers and researchers in this project had to unpack why they should attend to intersecting identities in order to create engaging and empowering science learning experiences for the students in local contexts. They also had to unpack what *attend to race, language, and identities* meant and how it might look in classrooms. The built-in uncertainty of the design principles facilitates the team engagement in collective meaning-makings of the principle, therefore guiding their collective and principled actions (see details about the meaning-making conversation in Kang & Orduña Picon, 2021). We speculate that the collective meaning-making, facilitated by the uncertainty of design principles, had a transformative impact on student experiences, instead of the principles themselves. This conjecture needs to be carefully examined in the future. Furthermore, the built-in uncertainty of principles allows teachers to connect their own problems of practice to a lofty goal or commitment in the community. Many science teachers struggle with enacting culturally relevant pedagogy while addressing content in the state standards, such as "momentum" or "Newton's Laws." The principles, such as *make it matter, support sense-making* and *attend to race, language, and identities*, provide practical guidelines of how to set up and facilitate learning experiences in a culturally congruent and sustainable way while addressing problems of practice grounded in the daily work of teaching.

The other characteristic that makes this tool useful in addressing the problem of enactment is *provisionality*. It is important to note that in the focal partnership project, design principles were a subject of ongoing critique, refinement and revision by the members in the partnership, rather than a complete set provided by an inventor. For example, the principle *disrupt power hierarchies* was originally framed as *disrupt <u>the</u> power hierarchy* when it was first introduced to teachers. During the co-designing process, this principle was interpreted as a call for creating student-centered instruction, while attending mainly to the epistemic power hierarchy between the teacher and students. Although this was one important aspect of power dynamics that shaped students' opportunities to learn in a classroom community, there were other forms of power dynamics that were not addressed. For example, attending to power dynamics that transpire in daily interactions along the lines of race, gender, and language as well as power dynamics operationalized through the schooling system. This awareness, inspired by critical scholars, led the team to revise the principle from “disrupting *the* power hierarchy” into “disrupting power hierarch*ies*.” We speculate that the process of creating, critiquing, and revising the design principles as a collective provides powerful opportunities to make progress toward transformative and consequential learning.

Conclusion and implications

Supporting teachers to enact an abstract ideological commitment in local contexts is incredibly challenging. In education, researchers have acknowledged the “enormous task that this type of paradigm shift will require of teachers, designers, and school systems” (Tzou et al., 2021, p. 863). This study provides one tool that effectively mediates complex professional interactions in co-design toward equity and justice centered instruction. The *Transforming Science Learning* Framework, with built-in uncertainty and provisionality, can help teachers and researchers move toward transformative and consequential learning at schools. In addition, this study provides a concrete image of student experiences in one co-designed physics unit. Numerous studies highlight the need for more concrete images of “what culturally responsive education looks like” to support teachers’ reimagination. Not only does this study provide a concrete image of student experiences in one co-designed secondary science unit, we explicate “the links” among: (a) pedagogical goals communicated with each principle, (b) teachers’ actions informed by the principles, and (c) students’ experiences mediated by pedagogy, curriculum, and assessment. To be clear, we do not argue or consider that the presented image of student experiences in the co-designed unit is *the* ideal or finalized one. Although the form of learning observed was radically different from the mode of learning physics normalized in schools, we view the image of learning reported here as a subject of critique, revision, and discussion for improvement toward transformative and consequential learning.

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References

Baker, W. D., Green, J. L., & Skukauskaite, A. (2008). Video-enabled ethnographic research: A microethnographic perspective. In S. Delamont, M. Foresey, & W. D. Baker (Eds.), *How to do educational ethnography* (pp. 76–114). Tufnell Press.

Bang, M., Brown, B., Calabrese Barton, A., Rosebery, A. S., & Warren, B. (2017). Toward more equitable learning in science. In C. V. Schwarz, C. Passmore, & B. J. Reiser (Eds.), *Helping students make sense of the world using next generation science and engineering practices* (pp. 33–58). NSTA Press.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education*, *94*(6), 1008–1026. https://doi.org/10.1002/sce.20392

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. *Cognition and Instruction*, *34*(3), 173–193. https://doi.org/10.1080/07370008.2016.1181879

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*(5–6), 302–318. https://doi.org/10.1159/000345322

Bereiter, C. (2014). Principled practical knowledge: Not a bridge but a ladder. *Journal of the Learning Sciences*, *23*(1), 4–17. https://doi.org/10.1080/10508406.2013.812533

Birmingham, D., Calabrese Barton, A., McDaniel, A., Jones, J., Turner, C., & Rogers, A. (2017). "But the science we do here matters": Youth-authored cases of consequential learning. *Science Education*, *101*(5), 818–844. https://doi.org/10.1002/sce.21293

Calabrese Barton, A., Kang, H., Tan, E., O'Neil, T., Guerra, J.B., & Brecklin, C. (2013). Crafting a future in science. *American Educational Research Journal*, *50*(1), 37–75.

Calabrese Barton, A., & Tan, E. (2019). Designing for rightful presence in STEM: The role of making present practices. *Journal of the Learning Sciences*, *28*(4–5), 616–658. https://doi.org/10.1080/10508406.2019.1591411

Casey, Z. A., & McManimon, S. K. (2020). *Building pedagogues: White practicing teachers and the struggle for antiracist work in schools*. Suny Press.

Fishman, B., & Penuel, W. (2018). Design-based implementation research. In F. Fischer, C. E. Hmelo-Silver, & S. R. Goldman (Eds.), *International handbook of the learning sciences* (pp. 393–400). Routledge.

Gay, G. (2018). *Culturally responsive teaching: Theory, research, and practice*. Teachers College Press.

Green, J. L., Skukauskaite, A., & Baker, W. D. (2012). Ethnography as epistemology. In J. Arthur, M. J. Waring, R. Coe, & L. V. Hedge (Eds.), *Research methodologies and methods in education* (pp. 309–321). Sage.

Gutiérrez, K. D., & Jurow, A. S. (2016). Social design experiments: Toward equity by design. *Journal of the Learning Sciences*, *25*(4), 565–598. https://doi.org/10.1080/10508406.2016.1204548

Harris, K., Sithole, A., Kibirige, J., & McCarthy, P. (2018). The Next Generation Science Standards and the quest towards culturally responsive pedagogy: Perceptions of K-12 educators. *American Academic Scientific Research Journal for Engineering, Technology, and Sciences*, *49*(1), 192–208.

Herrenkohl, L. R., & Mertl, V. (2010). *How students come to be, know, and do: A case for a broad view of learning*. Cambridge University Press.

Irizarry, J. G. (2007). Ethnic and urban intersections in the classroom: Latino students, hybrid identities, and culturally responsive pedagogy. *Multicultural Perspectives*, *9*(3), 21–28. https://doi.org/10.1080/15210960701443599

Kang, H. (2022). Teacher responsiveness that promotes equity in secondary science classrooms. *Cognition and Instruction*, *40*(2), 206–232. https://doi.org/10.1080/07370008.2021.1972423

Kang, H. & Orduña Picón, R. (2021, April). *Transforming science teaching for equity and justice by teachers and researchers working together* [Paper presentation]. AERA Virtual Conference.

Kang, H., Talafian, H., & Tschida, P. (2022). Expanding opportunities to learn in secondary science classroom using multiple forms of classroom assessments. *Journal of Research in Science Teaching*. Advance online publication. https://doi.org/10.1002/tea.21824

Kang, H. & Zinger, D. (2019). What do core practices offer in preparing novice teachers for equity? *Science Education*, *103*(4), 823–853. https://doi.org/10.1002/sce.21507

Kelly, G. J. (2007). Discourse in science classrooms. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 443–469). Lawrence Erlbaum.

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal*, *32*(3), 465–491. https://doi.org/10.3102/00028312032003465

Ladson-Billings, G. (2017). *The (r) evolution will not be standardized: Teacher education, Hip hop pedagogy, and culturally relevant pedagogy 2.0. Culturally sustaining pedagogies: Teaching and learning for justice in a changing world, 141-156*. Teachers College Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press.

McDonald, S. P., & Kelly, G. J. (2012). Beyond argumentation: Sense-making discourse in the science classroom. In M. S. Khine (Ed.), *Perspectives on scientific argumentation* (pp. 265–281). Springer.

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education*, *94*(2), 203–229. https://doi.org/10.1002/sce.20364

Mensah, F. M., & Jackson, I. (2018). Whiteness as property in science teacher education. *Teachers College Record*, *120*(1), 1–38. https://doi.org/10.1177/016146811812000108

Michaels, S., O'Connor, M. C., Hall, M. W., & Resnick, L. (2002). *Accountable talk: Classroom conversation that works*. University of Pittsburgh.

Milner, H. R., IV, Cunningham, H. B., Delale-O'Connor, L., & Kestenberg, E. G. (2018). *"These kids are out of control": Why we must reimagine "classroom management" for equity*. Corwin Press.

National Academies of Sciences, Engineering, and Medicine. (2018) . *How people learn II: Learners, contexts, and cultures*. National Academies Press.

National Research Council. (2007) . *Taking science to school: Learning and teaching science in grades K-8*. National Academies Press.

National Research Council. (2012) . *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

Parker, C. (2014). Multiple influences: Latinas, middle school science, and school. *Cultural Studies of Science Education*, *9*(2), 317–334. https://doi.org/10.1007/s11422-014-9573-4

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher*, *40*(7), 331–337. https://doi.org/10.3102/0013189X11421826

Reiser, B. J. (2014, April 3-7). *Designing coherent storylines aligned with NGSS for the K-12 classroom* [Paper presentation]. National Science Education Leadership Association Meeting.

Saldaña, J. (2009). *The coding manual for qualitative researchers*. Sage Publications.

Severance, S., Penuel, W. R., Sumner, T., & Leary, H. (2016). Organizing for teacher agency in curricular co-design. *Journal of the Learning Sciences*, *25*(4), 531–564. https://doi.org/10.1080/10508406.2016.1207541

Stuckey, M., Hofstein, A., Mamlok-Naaman, R., & Eilks, I. (2013). The meaning of 'relevance' in science education and its implications for the science curriculum. *Studies in Science Education*, *49*(1), 1–34. https://doi.org/10.1080/03057267.2013.802463

Tan, E., & Calabrese Barton, A. (2008). Unpacking science for all through the lens of identities-in-practice: The stories of Amelia and Ginny. *Cultural Studies of Science Education*, *3*(1), 43–71. https://doi.org/10.1007/s11422-007-9076-7

Tzou, C., Bang, M., & Bricker, L. (2021). Commentary: Designing science instructional materials that contribute to more just, equitable, and culturally thriving learning and teaching in science education. *Journal of Science Teacher Education*, *32*(7), 858–864. https://doi.org/10.1080/1046560X.2021.1964786

Villenas, S., & Deyhle, D. (1999). Critical race theory and ethnographies challenging the stereotypes: Latino families, schooling, resilience and resistance. *Curriculum Inquiry*, *29*(4), 413–445. https://doi.org/10.1111/0362-6784.00140

Warren, B., Vossough, S., Rosebery, A. S., Bang, M., & Taylor, E. V. (2020). Multiple ways of knowing: Re-imagining disciplinary learning. In N. S. Nasir, C. D. Lee, R. Pea, & M. M. de Royston (Eds.), *Handbook of the cultural foundations of learning* (pp. 277–294). Routledge.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education*, *96*(5), 878–903. https://doi.org/10.1002/sce.21027

Young, E. (2010). Challenges to conceptualizing and actualizing culturally relevant pedagogy: How viable is the theory in classroom practice? *Journal of Teacher Education*, *61*(3), 248–260. https://doi.org/10.1177/0022487109359775