frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 23 February 2023
DOI 10.3389/feduc.2023.1099480

OPEN ACCESS

EDITED BY
Xiang Hu,
Renmin University of China, China

REVIEWED BY
Jessica Gladstone,
New York University,
United States
Jianyun She,
The University of Hong Kong,
Hong Kong SAR, China

*CORRESPONDENCE
Tra Huynh
✉ trahuynh.per@gmail.com

SPECIALTY SECTION
This article was submitted to STEM Education, a section of the journal Frontiers in Education

RECEIVED 15 November 2022
ACCEPTED 31 January 2023
PUBLISHED 23 February 2023

CITATION
Huynh T, Bauman LC, Robertson AD and Scherr RE (2023) Physics teachers' conceptions of equity: Access and achievement. *Front. Educ.* 8:1099480. doi: 10.3389/feduc.2023.1099480

Physics teachers' conceptions of equity: Access and achievement

Tra Huynh[1]*, Lauren C. Bauman[2], Amy D. Robertson[3] and Rachel E. Scherr[1]

[1]Department of Physics and Astronomy, Western Washington University, Bellingham, WA, United States, [2]Department of Physics, University of Washington, Seattle, WA, United States, [3]Department of Physics, Seattle Pacific University, Seattle, WA, United States

Physics teachers' definitions of equity inform how they identify inequity and take action to transform it. In this paper, we adapted Gutiérrez's equity framework from mathematics education research to physics education research. The framework defines equity in terms of four dimensions: *access*, *achievement*, *identity*, and *power*. We used this equity framework to characterize the equity conceptions shared by 23 teachers who participated in an equity-focused professional development. We found that the access and achievement dimensions of equity are popular with teachers compared to the identity and power dimensions, and that teachers share a common understanding of conceptions of access and achievement in ways that is consistent with educational literature and discourses.

KEYWORDS

equity, access, achievement, high school teachers, physics

Introduction

Advancing equity has been a central goal in STEM (Science, Technology, Engineering, and Mathematics) education, including physics. For example, the National Science Foundation's strategic plan for 2022–2026 includes "advancing equity" as a primary goal, specifically stating a commitment to "grow STEM talent and opportunities for all Americans more equitably" (National Research Foundation, 2022, p. 29). This attention to equity in education shows up in the focus of teacher preparation programs that increasingly centers equity learning (Wiedeman, 2002; Darling-Hammond et al., 2005; Athanases and Martin, 2006; Garii and Rule, 2009; Cochran-Smith et al., 2016; Penner et al., 2019; Bukko and Liu, 2021; Morales-Doyle et al., 2021) and in growing demands for in-service teachers to adopt and enact diversity, equity, and inclusion (DEI) strategies in their practice (National Research Council, 2012).

In general, definitions of equity are often grounded in the concepts of fairness: equity refers to properties or attributes fairly distributed across different individuals or groups. However, scholars, policy makers, and educators can vary in their account of different attributes, ranging from learning access, resources, participation, outputs, outcomes, power, etc. (Lynch, 2000; Castelli et al., 2012) or take different measures to assess fairness (Rodriguez et al., 2012). Equity is also often defined with respect to inclusion and diversity. For example, the National Science Foundation (2022) names one of its core values as diversity and inclusion instead of equity. In this way, equity means that there is a diversity of people who earn high disciplinary achievements (for example, there would be more Scientists of Color), and equity means that all people presenting in a context can feel included (National Research Council, 2012; National Science Foundation, 2022). As a result, educational stakeholders have operationalized equity with various combinations of equity models, resulting in a complex landscape of equity orientations

and language in which they may disagree about what equity means and how to transform STEM education to be more equitable.

In physics, equity conversations, research agendas, and practices rarely explicitly or consistently move beyond the access and achievement foci in part because—similar to other sciences—physics, as a field, has been historically dominated by narratives that physics is culture free and politically neutral while consistently privileging the ideologies and epistemologies that reproduce hierarchies in society (Harding, 1994; Traweek, 2009; Bang and Medin, 2010; Grosfoguel, 2013). However, some scholars have begun to push against this narrow focus of equity. For example, Gutiérrez (2008, 2012) argues that most equity definitions and practices tend to focus on presenting the achievement gap rather than supporting educators to close it. This approach also risks perpetuating a deficit mindset in which marginalized populations are framed as lacking or behind, and where equity efforts are conceptualized in assimilative terms, "helping" marginalized students become more like the dominant group. Gutiérrez emphasizes that the ultimate goal of equity should be the redistribution of power—"power in the classroom, power in future schooling, power in one's everyday life, and power in a global society" (Gutiérrez, 2009, p. 5). Given that goal, Gutiérrez proposes a framework that defines equity along four dimensions: access, achievement, identity, and power (Figure 1).

Our work seeks to advance equity, and in particular, advance equity that extends beyond access and achievement, by supporting high school teachers through professional development programs to integrate equity concepts into physics curriculum. Studies such as Rodriguez et al. (2012) have demonstrated how different framings of equity can result in different interpretations, influencing the research questions and the results that are found. Similarly, because teachers' beliefs and conceptions of equity impact their views of their roles in education and shape their practice (Buehl and Beck, 2015; Cochran-Smith et al., 2016; Russo-Tait, 2022), it is important to explicitly articulating one's equity definition while doing equity work. Regardless of its significance, teachers' various understanding of equity is still unclear in literature (See Bartell and Meyer, 2008; Jackson and Jong, 2017 for a few examples). This paper contributes to the existing literature around teachers' conception of equity while begins to map out a space of equity in physics education with a goal to inform teacher praxis—critical reflection that will transform practice (Freire, 1972).

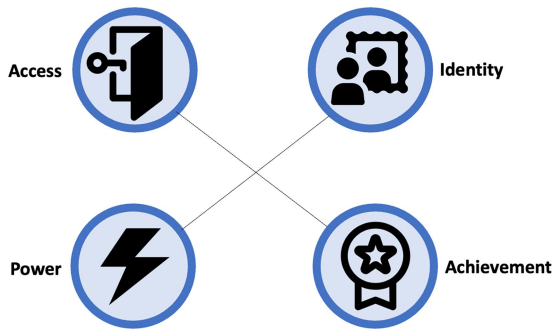

FIGURE 1
Four dimensions of equity (re-created from Gutiérrez, 2012).

In particular, we study high school physics teachers' conceptions of equity as they relate to their teaching, vocalized as teachers participated in a professional development (PD) that focused on integrating equity with physics. To characterize teachers' conceptions of equity, we adapt Gutiérrez's equity framework (2012) to analyze equity along 4 dimensions: access, achievement, identity, and power. The framework allows us to look for the patterns in teachers' existing ways of approaching equity, giving insights to aspects of equity that are most common and most challenging to the teachers.

Our goal is to understand how these high school physics teachers conceptualize equity as it relates to their professional practice. Specifically, in this paper, we aim to address two research questions:

> *RQ1*: How frequently do high school physics teachers conceptualize equity in terms of access, achievement, identity, and/or power?
>
> *RQ2*: In what ways do teachers' common conceptions of equity reflect literature and educational discourse?

Using coding and thematic analysis methods, we find that the access and achievement dimensions of equity are popular with the teachers compared to the identity and power dimensions, and that the teachers share similar conceptions of access and achievement among each other. In this paper, we are interested in understanding which aspects of equity are most salient to the teachers and the extent to which these aspects reflect scholarship and educational discourse. The identity and power dimensions are less popular, and are addressed in another paper.

Theoretical background

In physics education research, one of the notions of equity that is commonly used includes fairness of opportunity to learn for all students (Esmonde, 2009). Given that "opportunity to learn" is a vaguely defined term, scholars in mathematics and science education research have measured opportunities to learn using the quality and quantity of students' participation in the class (Archibeque et al., 2018; Shah and Lewis, 2019; Jeon et al., 2020; Holmes et al., 2022). In this case, equity means that all students share turns and time to speak and have authority over ideas and learning tools in class, such as experimental equipment, writing boards, etc. This definition aligns with Rodriguez's model of equity of fairness, which treats equity as the learning experience benefitting all students equally. Other work has operationalized equity by measuring students' performance, inferring that equity has been achieved when the gap between high-performance and low-performance students reduces (Lorenzo et al., 2006; Brewe et al., 2010; Traxler and Brewe, 2015; Van Dusen and Nissen, 2020). While physics educators and researchers have invested their effort in equity work in a diversity of ways, much of the effort is still access and achievement focused. While we celebrate this variety of equity work and efforts, we also seek equity frameworks that allow us to expand our equity conceptions beyond access and achievement that is dominant in physics education. We contend that Gutiérrez's equity framework serves as an example of such a framework and present a case for adopting this framework to the context of physics.

Gutiérrez's equity framework

In this paper, we adopt Gutiérrez's (2012, 2009, 2008) equity framework, developed in mathematics education, as an analytic lens for our study on high school physics teachers' conceptions of equity. As part of an effort to rethink equity-based mathematics education, Gutiérrez proposes a framework that defines equity along four dimensions: access, achievement, identity, and power (Figure 1).

Access, in Gutiérrez's framework, refers to the resources available to students to participate in knowledge building activities. These resources include but are not limited to quality teachers, infrastructure for inside and outside of classroom learning, rigorous curriculum, and classroom environments that invite student participation. Because students are affected by "opportunit[ies] to learn," attending to access ensures that students have, at least, the materials and environment needed for learning. *Achievement* is measured in terms of tangible student outcomes, which include but are not limited to students' classroom participation, course taking patterns, test scores, and trajectory through the education pipeline, etc. Because there are serious economic and social consequences for not obtaining a degree or participating in higher education—e.g., leading to lower socioeconomic status—Gutiérrez emphasizes that it is important for educators to ensure all students achieve academic excellence, beyond providing them access.

Equity in the *identity* dimension means supporting students to grow and become better "in their own eyes, not just in the eyes of others" (Gutiérrez, 2012, p. 19) through their academic experiences. Marginalized learners often must leave parts of their identity outside of schooling contexts in order to fit in Quichocho et al. (2020). Attending to identity includes attending to how students' past and present selves interact with society, i.e., how students are racialized, gendered, and classed, etc.; their ancestors' contributions; and the ways in which their perspectives and practices are (in)validated. Additionally, equity in the identity dimension means that students are able to draw upon their cultural and linguistic resources for learning. The *power* dimension takes up issues of social transformation at many levels: voice in the classroom (who gets to talk, who decides the curriculum), opportunities for students to use learned knowledge as a tool to analyze and critique societal issues, alternative notions of knowledge, and rethinking the field of knowledge (such as mathematics) as a more humanistic enterprise.

Access and achievement comprise the dominant axis, where access is a precursor to achievement. This axis prepares students to participate economically in society yet reifies a status quo and fails to address the past injustice. This dominant axis is what educators often look at to see how well students are learning, which Gutiérrez calls "playing the game." Identity and power make up the critical axis, where identity is a precursor to power. This axis ensures that students' resources and experiences are acknowledged in ways that help build critical citizens so that they may "change the game."

Gutiérrez emphasizes that equity must be framed along both the dominant and critical axes. It is not enough to learn how to play the game; students must also be able to change the game. Significantly, in order to change the game, students must play the game well enough. While recognizing the tension between the dominant and critical axes of equity, Gutiérrez proposed that teaching for equity placed itself in the interaction with those tensions, in ways that "recognizes opposing forces and values and maintains those tensions rather than trying to shut them down" (Gutiérrez, 2008, p. 24). Gutiérrez's equity framework aligns with other models that have been proposed across different educational contexts, including Banks' (1993) framework of multicultural education and Philip and Azevedo's (2017) equity approaches in everyday science learning. Across these approaches, there is a consensus that although all equity work is important, all definitions are not equal. Some equity approaches may focus on leveling the playing field for marginalized students while still perpetuating the power structures and reproducing the same knowledge that upholds the power hierarchy.

In physics, equity conversations, research agendas, and practices rarely explicitly or consistently move beyond the access and achievement foci. For example, the National Science Foundation focuses their equity efforts mostly on increasing accessibility and diverse representation of scientists from different social and geographic groups in their 2022–2026 strategic plan (National Science Foundation, 2022). Therefore, we take up Gutiérrez's framework because it can serve as a mapping tool for us to effectively understand equity ideas and approaches while providing space for expanding equity conceptions beyond access and achievement toward identity and power.

Methods

Context

The data for this analysis comes from a teacher professional development (PD) workshop that took place in August 2020. The goal of the PD was to support high school physics teachers to bring a sociopolitical analysis to equity in their energy lessons. The workshop was the first PD facilitated as part of a larger project—"Professional Development for Teaching and Learning about Energy and Equity in High School Physics"—which aims to create a model that supports secondary science teachers in integrating science concepts and equity education. To the workshop designers and facilitators, a model for energy and equity is responsive to a key epistemological issue: 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 (1) addressing specific social needs and (2) empowering people or groups of people. One of the primary goals of the PD was to support teachers in building an understanding of energy as a historically and politically situated science concept and empowering them to develop instructional materials that teach energy to their students in this way.

The workshop was 1 week long and was held by remote video conference. Each day consisted of 3 h of synchronous sessions, consisting of presentations from facilitators, whole group discussions, and smaller breakout discussions and activities. There was a different featured guest facilitator each day of the workshop, in addition to two regular facilitators and one "expert teacher" with substantial experience integrating equity into physics teaching. Between the synchronous sessions, teachers worked through asynchronous activities designed by the facilitators. The PD covered various content as following:

1. Day 1 consisted of introductions and logistics, as well as discussions on equity and antiracism.

2. Day 2 covered a model for energy (Gray et al., 2019; Scherr et al., 2012a,b) and energy tracking diagrams, a representation that emphasizes conservation and transfer of energy among objects and systems (Scherr et al., 2016).
3. Day 3 focused on climate change and "energy stories"—an equity-oriented application of energy tracking diagrams.
4. Day 4 supported teachers exploring positionality and their teaching philosophy.
5. Day 5 focused on next steps, "big picture" reflection, and discussion on equity and physics more broadly.

Twenty three high school physics teachers (22 from the U.S., 1 from Canada) took part in the PD. All applied to participate and were eager to incorporate equity into their classrooms. The self-reported demographic information of the teacher participants was: 15 females, 6 males, and 2 nonbinary people. 18 teachers identified as white/Caucasian, 2 as Black/African American, 1 as Asian, 3 as Latinx/Hispanic, and 1 as Multiracial. 10 teachers taught in Western states (including 1 teacher from British Columbia, Canada), 7 teachers taught in the Northeastern region of the U.S., 3 taught in the Midwest, and 3 taught in Southern states. 14 of the teachers described their student population as majority BIPOC students, while the other 9 teachers described their student population as majority white.

The data presented in this paper came from the first day of the workshop after the group of teachers had co-constructed community agreements and introduced themselves. The co-lead facilitator opened the discussion on equity with the goal to develop shared equity vocabulary and set the stage for transformation during the week of the PD. He posed the general question: "What is equity to you as an education professional? What is equity to you? What is equity in the classroom to you?." Each teacher was called on in alphabetical order by first name and given approximately 2–3 min to respond to the question. The nature of the conversation (e.g., one sharing after another rather than spontaneous back and forth conversation) supported only certain kind of expression from the teachers: stand-alone statements, possibly influenced by those who had spoken earlier but not revised after reflection. For this reason and others, we do not make claims that teachers have individual, fixed ideas. Additionally, our teachers self-selected into an equity-focused professional development experience; it would not be appropriate to use their statements to make claims about all physics teachers. Rather, we study this group of teachers' equity ideas as situated in the particular context of our PD. Although we do not make claims that generalize to the population of all physics teachers, we do claim that our result should inform teacher professional development. Our study shows that application of Gutiérrez's mathematics equity framework to physics expands equity discourse that is currently dominated by access and achievement. Furthermore, our sense that teacher discourse reflects dominant themes around equity in the literature suggests that this literature can shape teacher discourse in professional contexts. The video data was transcribed using an artificial intelligence transcribing service and both the video and the transcripts were used for data analysis.

Deductive and inductive coding

To address research question 1 ("*How frequently do high school physics teachers conceptualize equity in terms of access, achievement, identity, and/or power?*"), we took a combined approach of deductive and inductive coding (Bingham and Witkowsky, 2021). Deductive and inductive coding is well suited for our analysis because our study seeks to understand how a sample of 23 teachers' conceptions of equity map onto Gutiérrez's equity framework. In particular, coding allows us to make claims about the relative frequency of the four dimensions of equity.

We used the four dimensions of Gutiérrez's equity framework as the basis for our coding scheme (Table 1). Although there are differences between mathematics education and physics education, such similar inequities exist across STEM disciplines (Whitcomb and Singh, 2021) that we expected that the four dimensions would also be relevant for the ways in which physics teachers discussed equity. Therefore, we first constructed our codes deductively using the four dimensions of Gutiérrez's equity framework, only minimally adapting their description to fit into the physics context. For example, when developing the code for the power dimension, we looked for instances of teachers discussing how students can use physics to address societal issues (see Table 1, code "power").

We also took an inductive approach to refining the codebook, i.e., we used the information that emerged from the data to clarify the themes and develop sub-codes, as we iterated on the coding. This allowed us to adapt Gutiérrez's framework to our context of physics instruction and to the particularities of our data set. For example, in the (original) deductive application of Gutiérrez's equity framework, we took the code of "achievement" as applying when teachers discuss tangible outcomes of achievement (e.g., standardized test scores, course taking patterns, etc.). When the first author, TH, applied deductive coding during a practice round, however, she noticed that the teachers often emphasized students' success and potential, without explicitly naming tangible measurements for achievement. For example, some teachers expressed the desire for "students to reach their full potential." Therefore, we broadened this dimension to include any instance in which teachers use general notions of success or imply the importance of their students' success (see Table 1, code "achievement").

Authors TH and LCB refined the codebook together and then coded the whole data set independently. Teachers' answers to the question of what of equity meant varied; some teachers gave a direct definition, some teachers indirectly defined equity by giving examples of equity-oriented actions. Therefore, it made sense to us to code their whole answer at once, trying to characterize for the essence of their equity ideas, rather than code line-by-line. We also engaged in simultaneous coding, which means each excerpt of data can receive a combination of codes; from no code, to one code, to all codes. For example, a teacher can give a multiple-sentence statement about equity, in which equity is identified along more than one dimension. Simultaneous coding is an appropriate method for our coding of teachers' conceptions of equity because teachers' equity statements are multifaceted and complex.

The reliability between the two coders was calculated using percent agreement, taking the normalized difference of all possible codes—23 teacher responses x 4 possible codes (access, achievement, identity, power)—minus the number of coding disagreements:

$$\frac{\left(n_{possible\ codes}\right)\left(n_{coded\ responses}\right)-n_{coded\ disagreements}}{\left(n_{possible\ codes}\right)\left(n_{coded\ responses}\right)}$$

TABLE 1 Equity dimension codebook.

Code	Descriptors	Sample (pseudo) quote
Access	Ensuring students have resources they need for learning. This can include material resources (e.g., access to physics classes, rigorous curriculum, learning materials: lab equipment and textbooks) and access to a conducive learning environment (e.g., where students *feel* a sense of belonging to participate in the classroom.)	"Every student deserves to have the experiences, the tools, the help. We need to make sure they have the resources to get whatever they need."
Achievement	Specific, actualized achievement in physics (e.g., high test scores, taking advanced physics classes, mastery of materials, success in future educational and career pursuits) and general notions of success and the importance of students' success.	"Some of my students are afraid to take physics. Equity for me is showing all students that they can be successful and helping them reach their potential."
Identity	Attending to students' assets and lived experiences by building on students' ideas and increasing representation in classroom content. Recognizing and addressing the complex interactions between their students' identities, school, physics, and society which causes disparity, bias, stereotypes, etc.	"I want to discuss and challenge stereotypes and bias in physics that make students feel they do not belong in physics class."
Power	Social transformation, including disrupting power dynamics in the classroom, analyzing societal issues using physics knowledge, and critiquing the objective notions of physics knowledge.	"I want to collaborate with my students to address energy injustices so that we can find ways to change them."

The two coders had an agreement of 96.7% before discussion and reached 100% of agreement after discussion. In discussion, the two coders checked the codings in constant comparison and decided to adjust a total of 4 codings (4.3% of the total codings).

Inductive thematic analysis

To address research question 2 (*"In what ways do teachers' common conceptions of equity reflect literature and educational discourse?"*), we characterized ways that teachers conceptualized each dimension of equity. In other words, after coding the teachers' definitions into the four dimensions of equity to address research question 1, we conducted an inductive thematic analysis to search for patterns in teachers' conceptions of equity within each dimension of equity. Thematic analysis offers a method for analyzing, identifying, and interpreting emergent meaning from qualitative data, which is an appropriate tool for our exploratory qualitative research. We followed a 6-step iterative process to conduct our thematic analysis (Braun and Clarke, 2006). The first author, TH, generated initial codes that identify different ways the teachers in our sample conceptualized equity within each dimension. For example, in instances in which we coded teachers talking about the access dimension, teachers' statements often clustered around two ways to offer access: providing individual support or providing a sense of belonging. The two authors, TH and LCB, then coded each teachers' statement into the emergent themes and revised the themes iteratively. The emergent themes were reviewed among all authors for face-validity. This iterative process resulted in a final set of themes that were distinctive and collectively covered teachers' ways of discussing each dimension of equity throughout the whole data set.

Positionality

Tra Huynh is an able-bodied, physics Ph.D.-holding, Asian migrant, cisgender 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, sexism, classism, and colorism were central to her lived experiences, but she was not conscious of global White supremacy and racism, due to her living in a racially homogenous context such as Vietnam and her privilege of identifying with the majority ethnicity. Her lived experience began centralizing around racism at the time she moved to the U.S and pursued graduate school. Entering physics education research around physicist identities, critical race theory, and antiracist-work by Scholars of Color has helped her to define and make sense of her experiences. Her learning journey is filled with struggles to abolish her assimilated mindset, unlearn what is being normalized, and connect what she learned with her experiences as a Vietnamese, both in the contexts of the U.S. and of her home country. Her point of view is different from Asian Americans and Americans of Asian heritage, yet the feeling of being excluded is shared when it comes to social justice issues in the U.S. context.

Lauren C 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 ever discussed. She has been heavily shaped by her positive experiences in educational spaces and her authentic, 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 had genuine interest in learning as much as possible about a little bit of everything. Although she primarily studied physics, it was during this time that 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 what is a deeply unjust world. She recognizes her position as primarily a learner in this space, and approaches this role with genuine curiosity, honesty, and a commitment to reflection and self-awareness. She sees this work as part of her continued commitment to learn, amplify the voices and lived experiences of others, and support equity-oriented work in all parts of life.

Amy D. Robertson is a chronically ill and disabled, physics Ph.D.-holding, thin, wealthy, white, cisgender woman. Robertson's access to

and achievement within physics learning and professional spaces have been deeply shaped by both her privilege and her minoritized status. As a white, wealthy woman who grew up in a small upper-middle-class suburb, Robertson had access to AP courses in physics and was seen in many ways as belonging there, supported (and successful) in achieving high scores on tests and in courses. At the same time, as a disabled woman, Robertson was consistently in a position of needing to advocate for access and to substantiate her belongingness with identity performances that resembled those of white, non-disabled men. Her analytic lens in this paper is shaped by these experiences: Robertson's position of power within white-dominant culture and the hegemony of whiteness conspired to make power structures invisible to her for most of her life, and her marginalization as a disabled woman has shaped her capacity to see oppressive dynamics at work in physics teaching and learning spaces.

Rachel E. Scherr is 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 supporting a culturally diverse team to construct knowledge in full view of their race, ethnicity, nationality, gender, religious commitments, social class, ability status, and other features of social identity that may be important to them. 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 non-dominant cultures.

Findings

Access, achievement, and identity dimensions are salient to the teachers

Access, achievement, and identity are more frequently shown up in teachers' ideas of equity

The frequency of each equity dimension within teacher responses to the question of what equity means to them is shown in Figure 2. An equity dimension's frequency is the number of individuals whose definition of equity were coded as including that dimension, rather than how often that dimension is represented within each teacher's definition.

As shown in Figure 2, all four dimensions of equity are present when teachers define equity in our context. However, the frequencies of each dimension are strikingly different. The access dimension is the most common, brought up by 18 teachers, and the achievement dimension comes next, with 15 teachers including it. The high frequency of the access and achievement dimensions shows that the dominant axis (or "playing the game" axis) is popular among the total of 23 teachers. On the other hand, identity and power dimensions are less popular among all the teachers. Eleven teachers mention the identity dimension of equity, whereas only five teachers mention the power dimension, making the critical axis (or "changing the game" axis) uncommon compared to the dominant axis.

Similarity of conceptions along dominant axis

Using an inductive theme analysis, we show that the teachers share similar conceptions of access and achievement among each other.

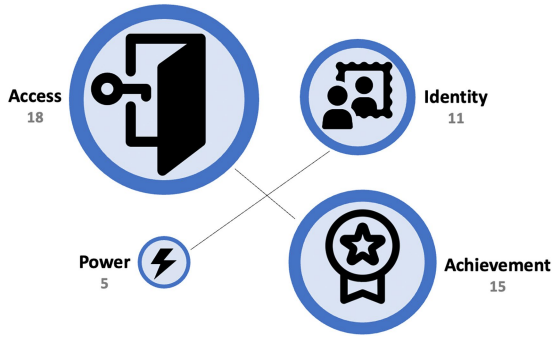

FIGURE 2
Frequency of four equity dimensions in the teachers' conceptions of equity (N=23). The size and the thickness of each circle are proportional to the number of teachers who mentioned each dimension (numbers are next to the circles). Dominant axis: Access – Achievement, Critical axis: Identity – Power.

Access dimension

Eighteen teachers' equity ideas were coded as including the access dimension of equity, and their conceptualizations clustered around two themes. Theme 1 foregrounds *how* teachers think they should provide students access to learning—being responsive to students' needs. Theme 2 is about *what* type of access teachers commonly think of as most important—access to belonging in the classroom (See Table 2). That all 18 teachers' ideas could be characterized with two themes suggests that there is significant consensus in their conceptions of the access dimension of equity.

Theme 1: Providing students access to resources based on their needs

Many teachers mentioned that equity means that they need to be responsive to the unique needs of their students and provide the individualized support necessary for their students to learn. For example, Lori said, "each [student] has to have access to whatever they need, which might not be the same as the person that's sitting next to them." Similarly, Sonia stated: "I should be a teacher to everyone, and that does not look the same for each student." In these statements, both Lori and Sonia highlighted the difference in what each student needs for their learning and stated that it is important to recognize that students' needs are different in order to provide equitable access for students to learn.

Joaquin (Table 2), another teacher participant, explicitly addressed inequities of access for his student community. Joaquin noted the inequity in distribution of learning resources across different communities: his students face the lack of access to learning materials *and* engineering ideas, although their school is located very close to aerospace industry infrastructure. Joaquin's idea of access highlights how theme 1 is not limited to access to material resources, but also includes how (limited) access to ideas affects his students' opportunities to learn. Joaquin saw one important aspect of equity in his practice was to ensure his students are provided with learning access that is systemically limited to them: "providing them that access to materials, but also to new ideas that they never thought of or had experiences to" (Table 2).

Lori, Sonia, and Joaquin's statement are representative of the essence and nuances among the rest of teachers who state this theme. They are all attentive their students' unique access needs in

10.3389/feduc.2023.1099480

TABLE 2 Emergent themes of teachers' conceptions of equity in access dimension.

Access dimension (*N*=18)		
Emergent themes	Teachers' exemplary quotes	Teachers who state this theme
Theme 1: Providing students access to resources based on their needs *Teachers need to be responsive to the unique needs of their students and provide individualized support because access to learning materials and scientific ideas are unequally distributed.*	Lori—"I believe every person–, I think someone had said this too, deserves dignity and has value. And so that means that each person has to have access to whatever *they* need, which might not be the same as the person that's sitting next to them"	(*N* = 12) Brian, Erica, Eva, Chris, Joaquin, Lori, Rebecca, Sam, Sonia, Steve, Tim, Vivian
	Sonia—"I should be a teacher to everyone, and that does not look the same for each student because the students with means are usually taught to ask for help; students without means are usually, like, taught–, like are not taught to ask for help. So, I got to make sure that every kid is reached."	
	Joaquin—"[…] I work in the same low-income community that I grew up in, and there was always this issue of access to ideas. […] So it was providing them that access, you know, to materials, but also to new ideas that they never thought of or had experiences to."	
Theme 2: Providing access to belonging in a classroom *Teachers need to create an inclusive classroom so that every student feels comfortable contributing their ideas and participating freely because active participation enhances learning but is only possible if students feel a sense of safety and belonging.*	Eva—"So, for me talking about equity without talking about inclusion is almost impossible. Um, you know, kids cannot learn unless they feel like they belong in class. […] Um, and so creating a sense of everybody does belong and everybody is bringing something."	(*N* = 8) Eva, Elena, Kelsey, Maggie, Megan, Rebecca, Riley, Tim
	Tim—"So for me and my school, equity takes the form of–, I need to create the conditions and atmosphere in my classroom to–, so that students feel safe enough to be their authentic selves, so that I can support them in the ways that they need."	

their conceptions of equity. While some teachers explicitly addressed the systemic inequities in access that underlie their conceptions of equity (such as in Joaquin's statement), others simply affirmed that based on the importance of personalization (such as in Lori's statement).

This theme represents conceptions of access that align with other popular definitions of equity, including that there is no one-size-fits-all in education, and with common approaches in education, such as differentiated instruction (Roberts and Inman, 2021). Differentiated instruction is a model in which teachers customize their curriculum and instruction to address students' diverse needs, interests, and abilities, ensuring that students experience meaningful learning by allowing students to learn at appropriately challenging levels (Roberts and Inman, 2021). Differentiating instruction is especially prevalent among K-12 teachers and is specifically supported by many schools. Many K-12 teachers are also familiar with project-based learning (Bender, 2012), which is one avenue for differentiated instruction that is strongly recommended for 21st-century classrooms. Models such as differentiated instruction participate in equity transformation by responding to the needs of different learners in order to improve their learning outcomes in school. This approach, as stated by the teacher, however, is different from *culturally responsive teaching* (Gay, 2000), which aims to reconnect the cultures between students' homes and school. Culturally responsive teaching requires teachers to expand beyond merely attending to students' personal differences and into understanding students' cultural knowledge and prior experiences as assets to learning and using various frames of reference to make learning more relevant to students (Gay, 2000).

Theme 2: Providing access to belonging in a classroom

In addition to acknowledging students' different access needs for learning, many teachers emphasized the relationship between sense of belonging and student learning. More specifically, teachers connected the need for an inclusive classroom with the importance of students feeling comfortable contributing their ideas and participating freely, as active participation would enhance their learning. For example, Eva stated: "[students] cannot learn unless they feel like they belong in class," and equity for her was to "[create] a sense of everybody does belong and everybody is bringing something."

Tim, another teacher in the PD, also named the importance of belonging: "I need to create the conditions and atmosphere in my classroom so that my students feel safe enough to be their authentic selves so that I can support them in the ways that they need." In Tim's statement, the importance of a safe space for students was that it allowed him to provide them what they needed to learn. Both Eva and Tim emphasized the importance of teachers creating an environment that welcomes students' participation, which is an example of a theme that we describe as *Providing access to belonging in a classroom.*

This theme strongly aligns with the dominant discussion of equity in education, which frames equity in terms of inclusion. Equity as inclusion seeks to ensure students' access to high-quality opportunities to learn, in which "high-quality" typically refers to instruction that supports student participation in learning activities and facilitates students being valued by the learning community (Windschitl et al., 2020). Considerable research has shown how inclusion and sense of belonging impacts opportunities to learn and learning outcomes, including knowledge excellence, interest, and future pursuits for STEM learners across levels (Carlone and Johnson, 2007; Cwik and

Singh, 2022; Mulvey et al., 2022; Smith et al., 2022). Equity as inclusion has become popular in school contexts, embodied in schools' DEI (Diversity-Equity-Inclusion) statements, as well as the languages of contemporary reform efforts, such as mathematics and science for *all* students (National Council of Teachers of Mathematics (NCTM), 2000; Next Generation Science Standard Lead States, 2013). However, Calabrese Barton and Tan (2020) articulate how equity efforts focused on inclusion do little to disrupt systemic inequities in classroom practice, which is consistent with how Gutiérrez (2009, 2012) discusses the role of the inclusive learning environment within the access dimension.

Achievement dimension

Fifteen teachers' equity ideas were coded as including the achievement dimension of equity, clustered around two themes (themes 3 and 4). Theme 3 centers around the *belief* that all students can achieve in physics, and theme 4 focuses on the *goal* of closing achievement gaps. Table 3 presents the themes, as well as exemplary quotes and the teachers who used these themes. Similar to the findings within the access dimension, these two themes expand the 15 teachers' equity conceptions in the achievement dimension and show the essence of the teacher statements in regard to the achievement dimension.

Theme 3: Believing in students' ability to achieve in physics

Many teachers expressed that believing in all students' ability to achieve in physics is essential to advance equity. For example, Steve said: "equity in the classroom [..] is closely connected with setting up every student to be successful" (Table 3). In his complete statement, Steve explained that it is important to support students in seeing themselves as capable of achieving highly in physics, because just like students will not choose to pursue physics if they do not feel like they belong in physics, students will not pursue physics if they do not feel that they can succeed in their physics class.

Megan, another teacher, observed that many students did not choose to take physics because they do not see themselves as "smart enough." Megan defined equity as: "equity in my classroom is showing all kids that they can be successful, that they have a valid contribution, no matter what their background is, no matter if they see themselves as a smart kid or not a smart kid" (Table 3).

Brian, another teacher whose achievement conception fits under this theme, stated: "whatever background you [the students] have, how confident you are in the subject matter, I'm going to work with you [..] and trying to make it a challenging and fun course for each one of them [the students]." While both Steve and Megan emphasized the importance of showing students that they can achieve highly in

TABLE 3 Emergent themes of teachers' conceptions of equity in achievement dimension.

Achievement dimension (N=15)		
Emergent themes	Teachers' exemplary quotes	Teachers who state this theme
Theme 3: Believing in students' ability to achieve in physics *Teachers should have high expectations for all their students and should support them to reach their highest potential because students feeling successful in the classroom is important.*	Brian—"Whatever background you have, however confident you are in the subject matter, I'm going to work with you; I'm going to push you however far I think you can go. And…so… I feel like it has to be personal to each kid's situation, and taking from there and trying to make it a challenging and fun course for each one of them, so it's different based upon their backgrounds; absolutely."	(N = 10) Brian, Erica, Eva, Elena, Lori, Megan, Riley, Sam, Steve, Vivian
	Megan—"They [my students] feel like they are not physics kids; they are not smart enough. […] And so to me, equity in my classroom is showing all kids that they can be successful, that they have a valid contribution, um, no matter what their background is, no matter if they see themselves as a smart kid or not a smart kid."	
	Steve—"I think equity in the classroom, or in my classroom, is closely connected with setting up every student to be successful. I think that some things [are] very universal, like dignity and belonging and feeling like they have a voice, you know, I think everyone, all students need that to be successful."	
Theme 4: Closing the achievement gap *Teachers need to close the achievement gap because having diverse students achieve highly and continue in the physics pipeline is an important part of equity in physics.*	Josh—"When I think about equity, I think about the field of physics, um, and how physicists are responsible for sort of answering a lot of the world's big questions. But the pool of people that have worked on those questions, historically, is really small, and so, as a physics teacher, I try to get more people in that conversation. And I derive my–, sort of idea of equity as–, of getting more kids involved in conversations, so that more–, maybe more of them, a bigger diversity, ends up working on those big questions in the future."	(N = 6) Chris, Josh, Joaquin, Lisa, Tim, Vivian
	Vivian—"[..] We would see more students taking upper division science classes, more students feeling like they could compete in those classes, more students becoming scientists, and not just the white male students."	

physics, Brian emphasized the importance of setting high expectations for every student, regardless of their backgrounds, and his responsibility to support them in reaching their potential. With their focus on helping students succeed in physics, Brian, Megan, and Steve are some examples of the theme we define as *Believing in students' ability to achieve in physics*.

This theme presents conceptions of achievement that are similar to the "growth mindset" framework that has become prevalent among K-12 educators and school leaders (Yettick et al., 2016). Mindset refers to one's belief about abilities and intelligence (Dweck, 2006). Educators with growth mindsets believe that all learners can cultivate significant growth and achievement through hard work and dedicated effort (Ricci, 2021). Educators with growth mindset therefore seek to provide appropriate support for all students, including challenging students to see themselves as potential and successful learners. Research on teachers' mindset have reported that teachers with a growth mindset can significantly impact student learning outcomes (Canning et al., 2019; Wacker and Olson, 2019; Ricci, 2021). Therefore, teachers' fostering of growth mindset is significant to closing achievement gaps (Dweck, 2015).

Theme 4: Closing the achievement gap

Some teachers asserted that equity efforts should aim to close the achievement gap, specifically in recruiting and retaining underrepresented students in physics. Both Josh and Vivian named the disparity in who pursues physics, and they both saw themselves working to bring a more diverse population of students to physics. For example, Josh stated: "as a physics teacher, I've tried to get more people in that [physics] conversation, […] so that maybe more of them, a bigger diversity of [them] ends up working on those big [physics] questions in the future" (Table 3). Vivian stated that more students should be able to become scientists and not just the white, male students: "we would see more students taking upper division science classes, more students feeling like they could compete in those classes, more students becoming scientists and not just the white, male students."

Among the 15 teachers whose characterizations of equity fell along the achievement dimension, 10 teachers state theme 3, six teachers state theme 4, and one teacher mentions both themes of achievement in their equity definition (Table 3). The teachers' conception of achievement presented in this theme is strongly consistent with the equity discussion around closing the achievement gap that takes places in almost every equity conversation in education. Not only is the achievement gap the most common way in which educators and stakeholders present the problem of inequity, closing the achievement gap is also usually taken as a measure of success of educational reform and teachers' quality. The National Science Foundation, for example, identifies "missing talents" (National Science Foundation, 2022, p. 29) from certain social groups as the concerns of their inequities and sets empowering these missing talents' participation as one of their goals.

Discussion and conclusion

Although teachers' views of equity are central to actualizing equity-centered education (Cochran-Smith et al., 2016), little has been discussed in literature. We found that all four dimensions of equity from Gutiérrez's framework for equity in mathematics education show up in physics teachers' definition of equity, although with varying frequency. In particular, the access and achievement dimensions show up with a similar high frequency across the teachers (18 teachers and 15 teachers, respectively), suggesting the possibility of a strong link between them, similar to what Gutiérrez would predict (see Tables 2, 3). For example, we found many teachers brought up the access and achievement dimensions concurrently, for example, in the statement, "provide students whatever they need [access] so that they can reach their full potential [achievement]." This result is consistent with previous studies of teachers' understanding of equity (Bartell and Meyer, 2008). Considering subsequent teachers' responses may be influenced by others' previous sharing, the popularity of access and achievement reifies how salient these dimensions are to teachers. That is, even though equity ideas in critical axis (e.g., power dimension) were brought up, teachers' discourse consistently move away from critical axis and re-centers the dominant axis. As the data was collected in the thick of COVID-19 pandemic where teaching in the US were remote and online, students' access to online learning and quality education was a major concern of educational policies and discourse. This concern may have also influenced the teachers' equity ideas in our context.

We also found that, although expressed in various ways, our teachers have a shared understanding of equity along the dimensions of access and achievement. Our study found two themes within our sample of teachers' conceptions of access and another two themes of conceptions of achievement. These patterns show that there are shared definitions of equity in terms of access and achievement. This result makes sense because stakeholders and administrators have consistently centered equity conversations around concerns of access distribution and closing the achievement gaps, in line with prominent themes in the literature. Furthermore, our findings allow us to speculate that physics teachers have been well supported by institutions and school leaders to take up and enact equity along the access and achievement dimensions, which is evident by the coherence in the way our teachers discuss equity and prevalent equity approaches in education.

In reflection to Gutiérrez's (2012) argument that equity transformation demands more than solely supporting students in "playing the game.," our findings also show that access and achievement, though important dimensions of equity work, offer little space for critical reflections that are *specific* to physics, including its values and culture. Rather, an access and achievement framing of equity would lead teachers to discuss equity more *generally*—i.e., in reference to their classroom, students, and success, etc. These dominant narratives of equity center individual teachers' actions and responsibilities to address equity rather than address systemic structures that pervade educational inequities. This is consistent with our findings.

Our findings—that power and identity are uncommon, and that teachers share definitions of access and achievement that are common in the literature—suggest that educational literature and discourse around equity shape teachers' thinking of equity. That is, what is most common in the literature is most common in the teacher talk, and substantively similar. This suggests the power of scholarship to shape educational practice, such that what scholars emphasize seems to matter. Given that many teachers have already been engaging in equity practices in access and achievement, equity-focused PD programs for

teachers should spend less time on getting teachers on board with doing equity work, specifically in access and achievement. Instead, teacher educators should spend more time supporting teachers take on issues of identity and power, challenging how science may transform to embrace and enhance diverse ways of knowing and being.

Additionally, our findings present a snapshot of teachers' conception of equity at a certain place and time. It can be beneficial to study the shift of teachers' equity conceptions over time of practice or through participation of equity-focused learning environments, especially in exploration of aspects of learning that can help teachers transform their equity approach. By exploring teachers' various conceptions of equity, our study contributes to the existing literature around teachers' equity practice. Our findings support us to predict the types of equity work that is most likely to be brought into teachers' practice based on how they think about equity, yet future research can contribute by following teachers to their classroom and investigating the possible (dis)connections between their conceptions and actualization of equity due to personal and structural barriers.

Data availability statement

The datasets presented in this article are not readily available because raw data is identifiable human subject data and therefore not shareable under IRB decision. Requests to access the datasets should be directed to trahuynh.per@gmail.com.

Ethics statement

The studies involving human participants were reviewed and approved by University of Washington Institutional Review Board. The participants provided their written informed consent to participate in this study.

Author contributions

TH conducted the analysis and wrote the manuscript. LB supported analyzing the data and writing the manuscript. AR collected the data and helped the framing of the analysis. RS collected the data and helped the framing of the analysis. All authors contributed to the article and approved the submitted version.

Funding

This material is based upon work supported by National Science Foundation (Grant No. 1936601).

Acknowledgments

We are greatly indebted to the teacher participants and the Energy and Equity PD program organizers and facilitators.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Archibeque, B., Kustusch, M.B., Genz, F., Franklin, S., and Sayre, E.C. (2018). Qualitative measures of equity in small groups [arXiv preprint]. arXiv:1803.01459.

Athanases, S. Z., and Martin, K. J. (2006). Learning to advocate for educational equity in a teacher credential program. *Teach. Teach. Educ.* 22, 627–646. doi: 10.1016/j.tate.2006.03.008

Bang, M., and Medin, D. (2010). Cultural processes in science education: supporting the navigation of multiple epistemologies. *Sci. Educ.* 94, 1008–1026. doi: 10.1002/sce.20392

Bartell, T. G., and Meyer, M. R. (2008). Connecting research to teaching: addressing the equity principle in the mathematics classroom. *Math. Teach.* 101, 604–608. doi: 10.5951/MT.101.8.0604

Bender, W. N. (2012). *Project-Based Learning: Differentiating Instruction for the 21st Century*. Thousand Oaks, CA: Corwin Press.

Bingham, A. J., and Witkowsky, P. (2021). *Deductive and Inductive Approaches to Qualitative Data Analysis. Analyzing And Interpreting Qualitative Data: After the Interview*. eds. C. Vanover, P. Mihas and J. Saldaña (Los Angeles, CA: Sage Publications).

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101. doi: 10.1191/1478088706qp063oa

Brewe, E., Sawtelle, V., Kramer, L. H., O'Brien, G. E., Rodriguez, I., and Pamelá, P. (2010). Toward equity through participation in modeling instruction in introductory university physics. *Phys. Rev. Special Topics Phys. Educ. Res.* 6:010106. doi: 10.1103/PhysRevSTPER.6.010106

Buehl, M. M., and Beck, J. S. (2015). "The relationship between teachers' beliefs and teachers' practices" in *International Handbook of Research on Teachers' Beliefs* (London: Routledge)

Bukko, D., and Liu, K. (2021). "Developing Preservice teachers' equity consciousness and equity literacy" in *Frontiers in Education* (Lausanne: Frontiers Media SA)

Calabrese Barton, A., and Tan, E. (2020). Beyond equity as inclusion: a framework of "rightful presence" for guiding justice-oriented studies in teaching and learning. *Educ. Res.* 49, 433–440. doi: 10.3102/0013189X20927363

Canning, E. A., Muenks, K., Green, D. J., and Murphy, M. C. (2019). STEM faculty who believe ability is fixed have larger racial achievement gaps and inspire less student motivation in their classes. *Sci. Adv.* 5:eaau4734. doi: 10.1126/sciadv.aau4734

Carlone, H. B., and Johnson, A. (2007). Understanding the science experiences of successful women of color: science identity as an analytic lens. *J. Res. Sci. Teach. Off. J. Natl. Assoc. Res. Sci. Teach.* 44, 1187–1218. doi: 10.1002/tea.20237

Castelli, L., Ragazzi, S., and Crescentini, A. (2012). Equity in education: a general overview. *Procedia Soc. Behav. Sci.* 69, 2243–2250. doi: 10.1016/j.sbspro.2012.12.194

Cochran-Smith, M., Ell, F., Grudnoff, L., Haigh, M., Hill, M., and Ludlow, L. (2016). Initial teacher education: what does it take to put equity at the center? *Teach. Teach. Educ.* 57, 67–78. doi: 10.1016/j.tate.2016.03.006

Cwik, S., and Singh, C. (2022). Not feeling recognized as a physics person by instructors and teaching assistants is correlated with female students' lower grades. *Phys. Rev. Phys. Educ. Res.* 18:010138. doi: 10.1103/PhysRevPhysEducRes.18.010138

Darling-Hammond, L., Hammerness, K., Grossman, P., Rust, F., and Shulman, L. (2005). "The design of teacher education programs," in *Preparing Teachers for a Changing World: What Teachers Should Learn and be Able to Do*. eds. L. Darling-Hammond and J. D. Bransford (San Francisco, CA: Jossey-Bass, A Wiley Imprint), 390–441.

Dweck, C. S. (2006). *Mindset: The New Psychology of Success*. New York, NY: Random House.

Dweck, C. (2015). Carol Dweck revisits the growth mindset. *Educ. Week* 35, 20–24.

Esmonde, I. (2009). Mathematics learning in groups: analyzing equity in two cooperative activity structures. *J. Learn. Sci.* 18, 247–284. doi: 10.1080/10508400902797958

Freire, P. (1972). *Pedagogy of the Oppressed*. New York: Penguin Books.

Garii, B., and Rule, A. C. (2009). Integrating social justice with mathematics and science: an analysis of student teacher lessons. *Teach. Teach. Educ.* 25, 490–499. doi: 10.1016/j.tate.2008.11.003

Gay, G. (2000). *Culturally Responsive Teaching: Theory, Research, and Practice. 3rd Edn*. New York, NY: Teachers College Press.

Gray, K. E., Wittmann, M. C., Vokos, S., and Scherr, R. E. (2019). Drawings of energy: evidence of the next generation science standards model of energy in diagrams. *Phys. Rev. Phys Educ. Res.* 15:010129. doi: 10.1103/PhysRevPhysEducRes.15.010129

Grosfoguel, R. (2013). The structure of knowledge in westernised universities: epistemic racism/sexism and the four genocides/epistemicides. *Hum. Archit. J. Sociol. Self-Knowl.* 1, 73–90.

Gutiérrez, R. (2008). Research commentary: a gap-gazing fetish in mathematics education? Problematizing research on the achievement gap. *J. Res. Math. Educ.* 39, 357–364. doi: 10.5951/jresematheduc.39.4.0357

Gutiérrez, R. (2009). Framing equity: helping students "play the game" and "change the game". *Teach. Excell. Equity Math.* 1, 4–8.

Gutiérrez, R. (2012). "Context matters: how should we conceptualize equity in mathematics education?" in *Equity in Discourse For Mathematics Education* (Dordrecht: Springer), 17–33.

Harding, S. G. (1994). Is science multicultural?: Challenges, resources, opportunities, uncertainties. *Configurations* 2, 301–330. doi: 10.1353/con.1994.0019

Holmes, N. G., Heath, G., Hubenig, K., Jeon, S., Kalender, Z. Y., Stump, E., et al. (2022). Evaluating the role of student preference in physics lab group equity. *Phys. Rev. Phys Educ. Res.* 18:010106. doi: 10.1103/PhysRevPhysEducRes.18.010106

Jackson, C., and Jong, C. (2017). Reading and Reflecting: elementary preservice teachers' conceptions about teaching mathematics for equity. *J. Math. Teach. Educ.* 19, 66–21.

Jeon, S.M., Kalender, Z.Y., Sayre, E.C., and Holmes, N.G. (2020). "How do gender and inchargeness interact to affect equity in lab group interactions?." in *2020 Physics Education Research Conference Proceedings*.

Lorenzo, M., Crouch, C. H., and Mazur, E. (2006). Reducing the gender gap in the physics classroom. *Am. J. Phys.* 74, 118–122. doi: 10.1119/1.2162549

Lynch, S. J. (2000). *Equity and Science Education Reform*. London: Routledge.

Morales-Doyle, D., Varelas, M., Segura, D., and Bernal-Munera, M. (2021). Access, dissent, ethics, and politics: pre-service teachers negotiating conceptions of the work of teaching science for equity. *Cogn. Instr.* 39, 35–64. doi: 10.1080/07370008.2020.1828421

Mulvey, K. L., Mathews, C. J., Knox, J., Joy, A., and Cerda-Smith, J. (2022). The role of inclusion, discrimination, and belonging for adolescent science, technology, engineering and math engagement in and out of school. *J. Res. Sci. Teach.* 59, 1447–1464. doi: 10.1002/tea.21762

National Council of Teachers of Mathematics (NCTM) (2000). *Principles and Standards.* Reston, VA: NCTM.

National Research Council (2012). *A Framework For K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: National Academies Press.

National Sciene Foundation (2022). Leading the world in discovery and innovation, STEM talent development and the delivery of benefits from research—NSF Strategic plan for Fiscal Years 2022–2026. National Science Foundation. Available at: https://www.nsf.gov/news/special_reports/strategic_plan/ (Accessed February 9, 2023).

Next Generation Science Standards Lead States (2013). Next Generation Science Standards: For States, by States. Appendix d: All Standards, all students: Making the Next Generation Science Standards Accessible to all Students. Washington DC: The National Academies Press.

Penner, E. K., Rochmes, J., Liu, J., Solanki, S. M., and Loeb, S. (2019). Differing views of equity: how prospective educators perceive their role in closing achievement gaps. RSF: the Russell Sage Foundation. *J. Soc. Sci.* 5, 103–127. doi: 10.7758/rsf.2019.5.3.06

Philip, T. M., and Azevedo, F. S. (2017). Everyday science learning and equity: Mapping the contested terrain. *Sci. Educ.* 101, 526–532.

Quichocho, X., Schipull, E., and Close, E. (2020). "Understanding physics identity development through the identity performances of Black, Indigenous, and women of color and LGBTQ+ women in physics." in *Paper presented at Physics Education Research Conference 2020, Virtual Conference*.

Ricci, M.C. (2021). *Mindsets in the Classroom: Building a Culture of Success and Student Achievement in Schools*. London: Routledge.

Roberts, J. L., and Inman, T. F. (2021). *Strategies for Differentiating Instruction: Best Practices for the Classroom*. London: Routledge.

Rodriguez, I., Brewe, E., Sawtelle, V., and Kramer, L. H. (2012). Impact of equity models and statistical measures on interpretations of educational reform. *PRPER* 8:020103.

Russo-Tait, T. (2022). Science faculty conceptions of equity and their association to teaching practices. *Sci. Educ.* doi: 10.1002/sce.21781

Scherr, R. E., Close, H. G., Close, E. W., and Vokos, S. (2012a). Representing energy. II. Energy tracking representations. *Phys. Rev. Special Topics Phys. Educ. Res.* 8:020115. doi: 10.1186/s12868-016-0283-6

Scherr, R. E., Close, H. G., McKagan, S. B., and Vokos, S. (2012b). Representing energy. I. Representing a substance ontology for energy. *Phys. Rev. Special Topics Phys. Educ. Res.* 8:020114. doi: 10.1103/PhysRevSTPER.8.020114

Scherr, R. E., Harrer, B. W., Close, H. G., Daane, A. R., DeWater, L. S., Robertson, A. D., et al. (2016). Energy tracking diagrams. *Phys. Teach.* 54, 96–102. doi: 10.1119/1.4940173

Shah, N., and Lewis, C. M. (2019). Amplifying and attenuating inequity in collaborative learning: toward an analytical framework. *Cogn. Instr.* 37, 423–452. doi: 10.1080/07370008.2019.1631825

Smith, T. J., Hong, Z. R., Hsu, W. Y., and Lu, Y. Y. (2022). The relationship of sense of school belonging to physics attitude among high school students in advanced physics courses. *Sci. Educ.* 106, 830–851. doi: 10.1002/sce.21725

Traweek, S. (2009). *Beamtimes and Lifetimes.* Cambridge, MA: Harvard University Press.

Traxler, A., and Brewe, E. (2015). Equity investigation of attitudinal shifts in introductory physics. *Phys. Rev. Special Topics Phys. Educ. Res.* 11:020132. doi: 10.1103/PhysRevSTPER.11.020132

Van Dusen, B., and Nissen, J. (2020). Associations between learning assistants, passing introductory physics, and equity: a quantitative critical race theory investigation. *Phys. Rev. Phys. Educ. Res.* 16:010117. doi: 10.1103/PhysRevPhysEducRes.16.010117

Wacker, C., and Olson, L. (2019). *Teacher Mindsets: How Educators' Perspectives Shape Student Success*, Washington, DC: Gorgetown University.

Whitcomb, K. M., and Singh, C. (2021). Underrepresented minority students receive lower grades and have higher rates of attrition across STEM disciplines: a sign of inequity? *Int. J. Sci. Educ.* 43, 1054–1089. doi: 10.1080/09500693.2021.1900623

Wiedeman, C. R. (2002). Teacher preparation, social justice, equity: a review of the literature. *Equity Excell. Educ.* 35, 200–211. doi: 10.1080/713845323

Windschitl, M., Thompson, J., and Braaten, M. (2020). *Ambitious Science Teaching*. Cambridge, MA: Harvard Education Press.

Yettick, H., Lloyd, S., Harwin, A., Riemer, A., and Swanson, C.B., 2016. *Mindset in the Classroom: A National Study of K-12 Teachers*. Editorial Projects in Education.