

How instructors can view knowledge to implement culturally relevant pedagogy

Clausell Mathis

Michigan State University, East Lansing, Michigan 48824, USA

Abigail R. Daane 

South Seattle College, Seattle, Washington 98106, USA

Brandon Rodriguez

NASA Jet Propulsion Laboratory, Pasadena, California 91109, USA

Jessica Hernandez and Tra Huynh ^{*}

University of Washington Bothell, Bothell, Washington 98011, USA



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Culturally relevant pedagogy (CRP) described in Ladson-Billings' framework has three conceptions: *conceptions of self and others*, *conceptions of knowledge*, and *conceptions of social relations*. Instructors can support students with positive learning experiences when they are cognizant of all three conceptions. In 13 interviews of physics instructors about CRP, we found many instructors shared only two productive conceptions: conceptions of self and others and conceptions of social relations. However, we found two instructors who effectively described all three conceptions. Their conceptions of knowledge focused on physics knowledge as constructed, reconstructed, and in some aspects containing subjectivity. They both articulated a critical approach to examining the historical and contextual factors that influence physics learning today. Our findings indicate that instructors' beliefs about the nature of science can be entangled with their own enactment of CRP and we show how a sophisticated epistemology can be one route to more culturally relevant instruction.

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I. INTRODUCTION

A. The myth that physics is acultural

Physics and science as a whole are often presented as culturally “neutral,” meaning that no cultural factors are integrated into the field [1]. The notion of subjectivity in physics is “taboo” to many as subjectivity is seen as a weakness in scientific design and knowledge formulation [2]. This perception pushes many to avoid discussing subjectivity rather than acknowledge the nuances that should be considered. Additionally, scientists are often trained to believe that they can achieve objective results and eliminate all internalized biases through careful design in their analysis, claims, and interpretation [3]. Bitbol, Kerszberg, and Petitot describe objectivity in two ways: ordinary and critical [4]. Ordinary objectivity refers to something separate and exists outside of human thought, whereas

critical objectivity refers to “what can be made valid for any one of us, independently of our situation” [4] (p. 1). Physics as a field is often touted as ordinarily objective [5], and thus, principles in physics are typically presented as facts, established theories, static, orderly, and rational [6]. Other scholars corroborate this idea by identifying physics as authoritarian, abstract fact oriented, and theoretical, with minimal room for creativity and curiosity [7]. The belief in objectivity in science has permeated all scientific disciplines and cultures, leading to much resistance to creating different approaches and perspectives on knowledge construction [2].

In many physics classrooms, students are taught to mirror these ideas and assume that what is in textbooks has been discovered without bias, free from subjectivity [8]. This, along with a traditional lecture format of content delivery, without reference to the culture of the field or space for exploration, can make students feel disempowered and isolated, especially students from nondominant identities (e.g., students of color, female, and nonbinary students, etc.) [9].

In these academic spaces, students are rarely asked to think about the nature of scientific knowledge and how it is formulated [10]. As Calabrese-Barton suggests, “...It might be important to think about science not only as a way of

^{*}Present address: Western Washington University.

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understanding the world but also as a political activity. By political activity, we mean that the doing of science is framed around power, status, and influence in its history, practice, and implications." [11]. Without examining the practices of science, students are left to adopt a systemic approach that is prescribed and rigid [6]. This inflexibility can stifle students' creativity and willingness to express alternative perspectives.

In contrast, cognitive and social constructivists believe that knowledge is internally and/or collaboratively constructed, controlled, and rationalized by the learner [12–15]. In 1934, prominent sociocultural theorist Vygotsky [13–15] wrote that humans are grounded in their cultural environment, which impacts how they think, learn, observe, and interpret. Constructivist teaching practices encourage instructors to view physics and other science disciplines with a critical lens toward knowledge construction [16,17]. These practices also examine how sociopolitical influences affect the development and acceptance of scientific ideas among other scholars [6,18]. Thus, the notion of objectivity goes against constructivist and sociocultural theories of learning [3].

And yet, knowledge construction in science teaching has challenged many instructors [16,19]. Many instructors and students have been normalized to accept factual canonical physics knowledge without being encouraged to think critically about or contribute to the canon [6]. Although the current national standards have made significant steps toward increased fluidity in the canon [18], in practice, the rigidity of the benchmarks and standards mandated at the state and district level add to the static view of knowledge. In addition to the aforementioned challenge for students that comes from the strong tie to objectivity, it can also be difficult for teacher educators to empower instructors to change their pedagogy.

All that aside, this work highlights the practices and views of instructors who work to address these challenges. We provide exemplars of critical discourse that articulate ideas to guide teacher development in this space. First, we examine physics instructors' views toward objectivity in physics and then share descriptions of how cultural relevance is actualized in their classrooms. This paper contributes to the research on equitable or transformative instruction in physics by operationalizing CRP (which has been largely used in science education) within a physics context. The dynamics of the connection of instructor conceptions, beliefs, and epistemologies to the implementation of pedagogy is a relatively recent area of physics education research [20]. We claim that the rigidity of "physics culture" and its lack of acknowledgment of subjectivity has impacted instructors' agency to empower students to become scientists by critically analyzing what is "factual" using their cultural knowledge.

B. Importance of culture in learning

Recent research in physics education urges us to consider the culture and daily experience as a tool

for constructing more equitable and empowering classroom experiences [21–23]. Scholars have described how culture affects students' learning processes and social adjustment [13,24,25]. It is important to understand that there are different approaches to learning, communication patterns, and participation norms within each different cultural demographic [26–28]. Indeed, differences exist in how students of different cultural groups interact, communicate, and learn [29]. Thus, to be truly equitable, science must recognize and incorporate the cultural means by which science is practiced. For example, some cultural groups are accustomed to collective learning, whereas others are more individual and competitive [30]. Some cultures have a rich history of oral traditions, in which power and meaning are derived from stories passed down through the generations [31], while other cultures embrace more empirical approaches to knowledge construction with more expository ways of relating knowledge [32,33]. A child within the classroom may be expected to employ discourse patterns that are often antagonistic and incongruent with those at home, making the negotiation of social norms and practices and learning science concepts particularly difficult for many students traditionally underserved and underrepresented in schooling [34]. For instance, science classrooms structured around visions of reform use concept negotiation and the logical evaluation of evidence as scientific practices. These particular practices are often privileged in required student work. This distinction between the discursive norms of students' cultures and those of science can make the development of "appropriate" scientific talk particularly difficult for some groups of students [35].

Instructors should encourage students to construct scientific knowledge while maintaining cultural integrity.

"Fundamental to these claims is that science is a cultural construct and that science educators ought to be open to how youth construct science in our presence in classrooms and other informal learning sites...Youth need opportunities to apply scientific ideas to their lives, to understand how doing science is intimately connected to larger social, cultural, and political issues, and to value the ways in which their own personal and community stories contribute to how, why, and when science is done." [11] (p. 136)

Students bring "cultural capital" into the classroom that can differ from the cultural capital that is already found and normalized in the commonly used and more highly valued traditional beliefs and views about school, learning, and society. Cultural capital is a term that refers to the social norms, practices, language, and behaviors that are encompassed in students' culture. Different types of cultural capital can include aspirational capital, linguistic capital, familial capital, social capital, and resistant capital [36]. The dichotomy between students who are advantaged in mainstream cultural capital and those who are not could

explain the achievement gap of those from diverse backgrounds [37]. To support instructors' use of students' cultural capital and bridge connections between cultural backgrounds, scholars have developed culture-based pedagogies to maintain and legitimize students' cultural identity while supporting their academic performance.

In the case of science, instructors who develop a critical awareness of how science is subjective can then make space for students in their classroom to do so as well. Instructors can foster students to believe they have something unique to bring to the discipline instead of just retaining information said to them.

II. THEORETICAL FRAMEWORK

A. Culturally relevant pedagogy

Culturally relevant pedagogy (CRP) emerged from work attempting to bridge learning gaps by emphasizing the role of culture and students' cultural resources in learning science [28,38]. CRP is an instructional approach developed by Ladson-Billings [28] to improve educational experiences for African-American students. Using a grounded theory approach, Ladson-Billings developed the theory for CRP, which consists of three major domains: *academic excellence*, *cultural competence*, and *sociopolitical consciousness*. These domains are used to develop instruction focused on improving students' performance, accepting their cultural identity, and addressing, critiquing, and challenging issues that pertain to their culture both inside and outside the classroom. In these pedagogical approaches, effective instruction is when an instructor orchestrates opportunities for students to make sense of the world by engaging in meaningful scientific practices—epistemic practices emphasizing sensemaking through knowledge construction and critique [39].

Within the CRP framework, Ladson-Billings described how successful teachers who implement their pedagogy across the three domains have key conceptions aligned with self and others, knowledge, and social relations. Conceptions of self and others center on how instructors view themselves and others (usually students) in the classroom. This conception applies to multiple demographic factors such as race, class, gender, and sexuality that can positively or negatively influence individuals' perceptions. CRP believes teachers' views toward themselves and students can influence their pedagogy.

Conceptions of social relations focus on how instructors view building relationships with students inside and outside the classroom. Approaches to developing relationships can be productive or superficial, and instructors' views on relationships can impact how strong they can become. When cultivating social relations in their classrooms, culturally relevant pedagogues connect with all students and encourage them to learn communally and hold each other accountable.

Conceptions of knowledge focus on how instructors view knowledge: Is knowledge something obtained and/or created? CRP instructors encourage students' ideas to lead the development of knowledge in the classroom and develop pathways for students to contribute to the canon. Regarding conceptions around knowledge about the curricula and canon, culturally relevant pedagogues view knowledge as constructed, shared, and recycled. They promote the idea that knowledge is not static and must be viewed critically.

B. Importance of knowledge construction in STEM

A goal of multicultural education in science, technology, engineering, and mathematics (STEM) is to support students' learning about how knowledge is constructed. Knowledge construction is defined by Banks [16] as a conception that

“encompasses the procedures by which social, behavioral, and natural scientists create knowledge in their disciplines. A multicultural focus on knowledge construction includes a discussion of the ways in which the implicit cultural assumptions, frames of reference, perspectives, and biases within a discipline influence the construction of knowledge... Teachers help students to understand how knowledge is created and how it is influenced by factors of race, ethnicity, gender, and social class.” (p. 5)

Through Banks' definition of knowledge construction, teachers should encourage students to investigate and determine how “assumptions, frames of reference, perspectives, and biases” in science impact the construction of scientific understanding. We claim that students' sources of ideas are based on a culmination of experiences, both in and out of the classroom, which impacts how they view ideas (assumptions) and develop new ideas or construct knowledge.

Multicultural education in STEM encourages students to develop and articulate their own claims, ideologies, and assumptions. Giving students various opportunities in class to create claims can support their understanding of how personal assumptions and experiences can influence their knowledge construction. Students can also be encouraged to compare and contrast different claims and interpretations made by others. Ultimately STEM instructors can support students to become critical thinkers through this process of critiquing knowledge construction. Seeing scientific knowledge as influenced by cultural practices and assumptions can support students in believing that their knowledge, skills, and attitudes can contribute to science [16].

Unfortunately, many academic institutions focus mainly on mainstream and school knowledge while neglecting transformative approaches such as those described above. Emphasizing transformative approaches challenges

mainstream academic knowledge by critically examining the historical contexts in which the knowledge was constructed. The traditional positioning of knowledge in STEM is problematic because it posits STEM knowledge as without culture and at odds with the theory behind CRP. Instructors who seek to apply CRP must recognize the value of transformative knowledge and how culture affects what knowledge counts in STEM.

III. RESEARCH QUESTION

Our study wanted to understand instructors' views around cultural relevance, specifically toward knowledge construction. The research questions are (1) *What are physics instructors' views toward objectivity in physics?* and (2) *How do these views connect to the use of culturally relevant pedagogy?*

IV. METHODS

A. Data collection

For our study, participants were recruited through emails obtained from a Listserv from the American Association of Physics Teachers, the Society for the Advancement of Native American and Chicano Studies, and other national groups serving physicists and physics educators. A group of 145 physics instructors volunteered to participate in a larger study on beliefs in physics regarding objectivity, cultural relevance, settler colonialism, and equity. We selected 13 participants through three selection criteria based on maximum diversity in gender, race, and years of teaching experience. Teachers at the time of the interview had a range of 1–25 years of experience working in a K-12 setting. Regarding gender, teachers identified as male, female, and nonbinary. For race and ethnicity, at least one teacher identified with each of the following categories: Asian, Indian, Korean, Puerto Rican, and White. Once participants were finalized for our study, data were collected through semistructured interviews conducted on an online web interface (Zoom) and recorded.

For the purposes of our study, we analyzed instructor responses to two questions:

1. Do you agree with the following statement? Physics is an objective science free from subjectivity and bias.
2. What does culturally relevant instruction mean to you?

B. Data analysis

Instructor interviews were transcribed and analyzed using thematic coding [40]. The two first authors co-examined interviews to identify moments where instructors' views aligned with conceptions of CRP with an emphasis on conceptions of knowledge. In our units of analysis, we looked for instructor statements that included ideas about how "knowledge is constructed, revised, and

recycled" and whether or not instructors mentioned ideas reflecting "a critical approach to what is considered knowledge" [28]. Statements that focused on how students created knowledge and contributed to physics from a canonical reference were also documented. The first and second authors discussed any discrepancies in our interpretations explicitly.

In our first question about objectivity, we identified instructors who acknowledged that physics is not completely objective and also mentioned aspects of subjectivity in physics (e.g., bias, interpretation, errors in analysis, etc.). In addition, we examined instructors' descriptions of how sociopolitical influences impact the development and analysis of scientific ideas.

For the second question regarding culturally relevant instruction, we looked for instructors' responses that explained how teachers believed culturally relevant instruction should be done in their classrooms. We looked for mention of academic excellence, cultural competence, and critical consciousness.

We understand that the term "culture" is a very fluid term that can be interpreted differently among individuals. For the purposes of our study, we will define culture as the norms, values, and behaviors of a group. We examined responses that closely aligned with our definition of culture.

C. Member checking

We used member checking by reaching out to interviewees to provide clarity and validation of our analysis [41]. In particular, we explicitly asked for feedback on the interpretation of "modern" physics and confirmed that its use was regarding current and recent research in physics. Additionally, we asked for feedback on the interpretation of the entire paper from one interviewee to validate our representation of their ideas and to provide their perception of our research process and analysis.

V. FINDINGS

A. RQ1: Overview of the instructors' views toward objectivity in physics

Our analysis of the 13 interviews reveals myriad ideas about objectivity in physics. In response to the question, "Do you agree with the following statement, physics is an objective science free from subjectivity and bias?", six instructors identify physics as having some aspects of subjectivity. These instructors describe the limitations of our physics knowledge and/or subjectivity in our interpretations. For example, two interviewees' responded as follows:

I mean, it's more objective in so far as the idea of mathematics... but not so much as in interpretation.—Bruce

Our observations can be subjective. So even if we have cold, hard data, even the data we decide to take is subjective. So, I would say that it's mostly objective, but we interpret the data that brings in bias. We take data, and that brings in bias as well.—Adam

The first response uses the “idea of mathematics” as an example of objectivity in physics. The second half of the response: “not so much as in interpretation,” alludes to a lack of objectivity in interpretation. Four instructors described this dichotomy of how math and physics are co-related in the sense that many view the mathematization of physics as objective, whereas the process of understanding and interpreting data and mathematics is subjective. The rest of the instructors did not describe any subjective aspects of physics.

B. RQ2: Overview of the instructors’ views toward cultural relevance

Instructors shared varying views of how CRP can be enacted in their classrooms, but most of these instructors’ conceptions drew upon two of the three conceptions: social relations and self and others. What little of the third aspect of CRP: Conceptions of knowledge we found, we will share in Sec. V C. as examples. First, we will describe what we saw more commonly among the instructors.

Through our analysis, we found that many instructors interpreted CRP as making connections to students and getting to know them as unique learners, but not about knowledge construction as it pertains to the state of science as a whole. We found little mention of the third aspect of CRP: conceptions of knowledge. Only 2 of the 13 instructors described any ideas about the nature of science and how science is shaped by culture, epistemic agency, and empathy. That is to say, most interviewed teachers communicated a philosophy that science was wholly objective, and we as scientists are the lens through which it is observed. Thus, scientists are subjective interpreters, uncovering the “truth” as much as possible via scientific inquiry. This line of thought positions science as teleological: scientists may take different routes but eventually come to the same conclusion. This framing never considers *who* is doing science, how they came to their position as scientists, and whether or not their perspectives are shaped by experience and interest. This view is not an anomaly; within the larger umbrella of multicultural education research, knowledge construction is emphasized but rarely addressed [42].

In the 13 responses to the second question, “What does culturally relevant instruction mean to you?” eight instructors describe cultural relevance in their teaching from the social relations conception in the CRP framework [28]. Teachers share that CRP is about establishing strong relationships with students.

I do have some Latino and Black students, and I understand that they’re carrying with them different connections, especially I would say our Latino students kind of have, uh, you know, culture within the school that’s different than the white students... and so I think ... you know, connecting with them effectively takes some different strategies in terms of, you know, making sure that you’re thinking about how they see their futures.—Lennox

This interviewee highlights the diversity of their students first, then acknowledges that racial diversity also brings a diversity of culture. This instructor describes creating connections with students and recognizing that different students bring different cultural dynamics into their classrooms. Working toward understanding how students “see their futures” can be a productive step toward developing strong relationships. What is not said here explicitly is that these different cultural dynamics also impact how students view certain ideas, claims, and approaches toward knowledge construction.

Several instructors share ideas that align with conceptions of self and others, expressing that they want to learn about their students’ cultures. One instructor stated

I think [it] means a couple [of] things. One is for the content, and one is for what that means for the students. [As] for the content, I think that means introducing students to content from different cultures. So not just being like, here are all the old white dudes that made things, and they’re the only people that can make things, but being like, hey, look at some scientists that exist now, and what do they do? And look, these people look like you, isn’t that cool? And so having the content like that, but also knowing what that means for the students and how the way they engage with the content might be different based on their culture.—Adam

This instructor describes introducing representation for students that highlights people of different cultures doing physics, including people whose identities align with their students’ identities. This viewpoint demonstrates a social relations conception where the instructor deepens the students’ connection between their culture and the physics content. They also acknowledge that a student’s engagement with the content engagement can require a responsive effort on the instructor’s part based on cultural background. Another teacher builds on the latter idea, stating

I think part of it is thinking about the way that we learn and the way that we process information and engage in dialogue, and acknowledging the different individuals with different backgrounds have different approaches to learning. And so I think part of that—, kind of circling

around to understand that we all learn differently, but also respecting all of those differences and knowing that we're all human and we have those same commonalities.—Selena

The quote above also aligns with conceptions of self and others because the instructor focuses on understanding the different approaches students use to learn and drawing upon productive ideas that may be nontraditional to mainstream dialogue. The goal here seems to be to honor where the students are and respect their own expertise to support their learning.

Another instructor discusses how using CRP emphasizes the representation of different students.

Culturally relevant instruction means that I see the student, I hear the student, the student can be represented by the course or by the research that we are doing. Um, I want them to feel included, and to have equal contributions.—Lennox

Overall, instructors shared varying views of how CRP can be enacted in their classrooms. Still, most of these instructors' conceptions drew upon two of the three conceptions: Social relations and self and others.

In the interviews, however, we did find two exemplary instructors who illustrate how conceptions of knowledge can be effectively applied to instruction. We are not using the term "exemplary" from an ordinal perspective but instead highlighting how these two instructors' statements aligned with the conceptions of knowledge framework. We hope these ideas are not an exception but representative of what all teachers can use to organize their practice. We posit that other instructors also may have had these ideas but did not share them explicitly in the interview. In the sections below, we share some of these two instructors' sophisticated ideas to highlight the productive application of this conception and the nature of science.

C. Two exemplars: Instructors Bruce and Thomas

In this section, we posit that connecting conceptions of knowledge and the nature of science can support instructors in understanding CRP in science. We describe two instructors, whose pseudonyms are Thomas and Bruce, who shared ideas that align with conceptions of knowledge and also used the nature of science to describe CRP.

1. Bruce

In this section, we highlight Bruce's use of conceptions of knowledge through his rejection of objectivity and his critique of the past and current aspects of whiteness in physics. For context, Bruce is a male-identifying high school physics teacher with 6 years of experience. He teaches at a high school that is 99% Latinx. Bruce also works at a national research laboratory.

Bruce's view of CRP from a conceptions of knowledge standpoint first acknowledges subjectivity in physics. He then uses elements of whiteness and structural bias as examples of how subjectivity has shaped the past and current field and community. Bruce recognizes that physics is based on hypotheticals and predictions and gives examples of topics currently being researched. He states

I would say physics, more than any other sciences...[is] more hypothetical than objective. My kids spend a good chunk of the end of the year looking at dark matter and dark energy and quantum, just kind of intro and just topics in modern physics. ... and as such, I would say there's nothing objective about that.

In this quote, Bruce uses physics topics (e.g., dark matter, dark energy, and quantum mechanics) to describe knowledge as constructed—"more hypothetical" instead of objective. This is understandable given that subjectivity is an essential aspect of fields such as quantum, where measured properties can depend on the context and state of the system. Bruce recognizes that parts of physics are being constructed in "modern" times. Bruce also supports physics as not being a completed subject but a field where students can discover and add to it.

Bruce builds on this idea that the construction of physics is ongoing and therefore influenced by those who construct it when he answers a question about his physics identity.

[Physics learning] represents that there's no real finality kind of like what you're talking about with the modern component side that this is all a construct, right? That allows us to interpret as best as possible... we have to keep wondering, we have to keep questioning, and collecting data.

Bruce's view of subjectivity in physics centers on interpretations of physics phenomena and what is yet unknown and undeveloped. Bruce further discusses how physics can be objective from a mathematical perspective but not an interpretive lens. Bruce indicates that knowledge is nonfinite, but is always being constructed, aligning well with CRP's conceptions of knowledge.

Bruce also spends time discussing physics's current and past culture and that we need to include a more diverse perspective within the discipline. Bruce describes a desire to show his students that other people like him can do this in physics.

I mean, the traditional physics curriculum isn't just white-washed; it's white. Like it's just white. It's white from day one until the end. If we don't infuse a curriculum that includes a nonimperialist, [non] white culture into it, then I just can't imagine kids ever seeing themselves as physicists... And I feel like that's been a success, that is to say, yes, historically, all this

curriculum that I'm required to cover is so, so white-washed. And I could try to force in some like,..., you know, tangential people of color along the way who did some, some work in this..., but they don't care about the past. Right. So, I find that too many teachers are trying to do this. Like if we slap a photo of female scientists there in between the 600 male ones that all the girls are going to be like, Oh, wow, that's me. No, that doesn't work. That's not effective. ... instead of looking forward, who is doing it now, not some black and white picture of Marie Curie. Right. But like looking forward when you see real scientists doing this right now that look like you today, ..., that I think is much more motivating. So yeah. Is the curriculum white-washed? It couldn't be more whitewashed for any high school science.

Above, Bruce talks about how the curriculum is “white washed,” designed by white people, and this contributes to students of color not seeing themselves as having a future in physics. He dismisses the action that finding past “tangential people of color” as examples can be influential on students of color and instead suggests we can look forward to “seeing real scientists doing this right now” to change the culture. Bruce’s critique of the past and current whiteness of physics and his rejection of objectivity align with the identification of objectivity as a white supremacist characteristic [43]. The recent emergence of whiteness discourse in education has prompted several educators to reevaluate their pedagogies and question how whiteness influences teacher practices and educational policies [44]. Bruce highlights an example of how this reevaluation can look in practice:

“There’s no changing the fact that the physics curriculum that is required by the state and the country is white physics. It is a European, It is Isaac Newton, and it’s Niels Bohr, and it’s white guy after white guy after white guy. Right. And, again, anything you slip in is additional, right? Um, so I think it has to be forward-facing that says, now that we’re talking about modern physics, let’s talk about the people that are doing modern physics, and all of a sudden that doesn’t have to be white anymore. ... trying to show a historical physics that’s not white and saying like, Oh, at this same time, so-and-so was doing this. I don’t know that that’s value-added, personally. I think it’s, I think it’s actually more, more important to say like, and this is why science was done by a bunch of white guys. Like these guys bought a castle and built a telescope in it. Right. Like, must be nice. Must be nice. Right. Where did that money come from? You know, I’m, I’m more inclined to like to throw the shade on the whiteness as opposed to trying to sweep over and say like, oh, and also this scientist of color made a contribution. I dunno, the oppressors were doing most of the work off, off the backs of the oppressed.”

In this quote, Bruce talks about how in the modern physics world, there are scientists of color in contrast to history when people of color did not have access or privilege to participate in physics spaces. He again mentions that instead of trying to find the few people of color in the past to highlight, we have to acknowledge instead and interrogate the fact that people of color have not had the power, access, and money to control the physics field and community. Bruce suggests that students need to know why the field is whitewashed. He pushes us (and students) to think about physics teaching from a forward-thinking approach, where knowledge is not fixed, and students have something to contribute to the discipline now and in the future.

Also, in the interview, Bruce connects his views of CRP above to the idea that there are different ways of assessing and thinking about physics phenomena that come from outside the current culture. He suggests that instructors should appreciate and use the many alternative thinking methods as productive ideas.

2. Thomas

Thomas provides another example of how using conceptions of knowledge in the classroom can support students. He views part of CRP as critiquing the source of physics ideas and examining issues of whiteness ingrained in physics. Thomas is a male-identifying high school teacher with 12 years of experience. He teaches primarily Introductory and AP Physics. Thomas describes the demographics of his school as predominantly white, upper-middle-class, with a high population of International and students from low socioeconomic backgrounds.

Thomas posits that instructors should encourage students to develop a critical questioning mindset using Conceptions of Knowledge. He explains that context plays a role in how we interpret and learn ideas. When asked if physics was objective, Thomas disagreed, stating

I think any science requires questioning aspects, and the questions that we bring to the table are informed by our context and our identities. Right? So both our social context that we’re in, what matters to our society at the time, and the identities that we bring to the table. What matters to us? What do we see?

Thomas explicitly connects our approach to inquiry in science to our setting and science identity. He mentions that our experiences and societal environment can shape how we see the world and “what matters to us.” Thomas uses these contextual and identity influences as examples of how physics can be subjective. When asked about his view on cultural relevance, Thomas stated

“We spent a lot of time looking at Gloria Ladson-Billing’s work and moved more towards,...[Geneva]

Gay's work. So, I sit more—kind of—in that realm of culturally responsive teaching, needing to meet the students where they're at. So, what sorts of questions do our students have? How do we leverage those questions and interests into students asking questions, so they understand the physical world and get the ability to adjust models over time? To build a stronger and stronger model over time. In doing that, the purpose of understanding the physical world has to be to give students the power to effect change in the world around them. And it would be wonderful if the change that they choose to effect is to make the world more democratic, make the world more accessible to more people, think about power as not a zero-sum game but as an opportunity for each other's abilities. So I think, I think culturally responsive work both needs to situate the science interest in the culture of the student, but also allow students to see their way beyond what the current paradigm is."

Thomas uses CRP as a guide to support students in critically analyzing and shaping physics based on their own interests and questions. He describes this pedagogy's purpose as empowering them to build stronger models over time and work toward addressing sociopolitical concerns. In addition, Thomas wants to use CRP as a way for students to use science to overcome and break down implicit restricted boundaries placed on them. Thomas goes on to describe what he means by "current paradigm."

"We live in a structure that is very white-dominated, Christian-dominated, straight-dominated, right? Like all, all of those dominant identities need science to be used in very specific ways. Right? One of the things that we know about getting more women into physics and people of color into physics is that when you spend the whole time talking about physics, from the point of view of rockets and space, it tends to leave a lot of cultural identities, not interested in learning more about physics because they don't see how it's relevant to their context. Whereas if you could start using the physics to help students understand their current world,...then they start to take on power roles within both the study of physics and moving questions away from like, how do we make this missile shoot things into, like, how can we use the context of physics to provide more food to the world or to, you know, give more access to broadband or those, you know, those sorts of things that can give—that physics actually can help us answer, physics and math, because as I said in both worlds because we're not constraining the questions, just the questions of, you know, straight white Christian men."

In this quote, Thomas described the current paradigm of physics as problematic for nondominant cultures and suggests alternative teaching methods to counter that

paradigm. He again suggests starting with student questions. Thomas would like us to expand our critical approach to physics to include examining sociopolitical concerns of inequities. In this way, he is making room for students' interests to shape the field and critically examining the current canon and traditional approach toward teaching physics—essential elements of using the Conceptions of Knowledge part of CRP.

VI. DISCUSSION AND IMPLICATIONS

Our data analysis showed that most instructors viewed physics as primarily objective except for Bruce and Thomas, those instructors who did hold subjective views of physics mostly shared views that associated subjectivity with how ideas are interpreted, holding the mathematical aspect of physics as objective.

Instructors in the interviews generally appeared eager and willing to recognize the different cultural approaches to learning. Yet, the interviewees' articulation of the integration of CRP into educational settings seemed more challenging. Several instructors described CRP from social relations and self and others conceptions, focusing on improving teacher-student relationships and presenting representative aspects of physics curricula and imagery for students from underrepresented cultures in physics.

Only two instructors, Thomas and Bruce, also described CRP from a conception of knowledge perspective and demonstrated a robust sense of subjectivity in physics. Thomas and Bruce's statements suggest that instructors who want to become more culturally relevant pedagogues can work to acknowledge that many aspects of physics are subjective. This can create the opportunity to critique the educational landscape in two significant ways that Bruce and Thomas described: (1) Instructors more readily recognize and call out issues such as whiteness and structural bias that shaped the past and still dominate the current ways we study and interpret physics. (2) These two instructors' views of CRP supported them in using that knowledge to empower students to do the same. The instructors and their students can critique the sources of physics ideas and examine why we have a canon in which whiteness is so fully ingrained. From there, Thomas and Bruce provide avenues for students to simultaneously acknowledge where physics came from and look to the future as an opportunity to transform this knowledge into a more inclusive and diverse canon. Their use of Conceptions of Knowledge allows students to identify aspects of physics that are subjective—in both the problematic features of the past and the productive features that provide opportunities to pursue their passions and interests in the future.

Our study has implications for physics instructors who want to become CRP pedagogues. These findings are also important for teacher educators, researchers, and administrators who want to understand the affordances and

challenges for instructors attempting to use CRP in their classrooms.

It is not enough to simply accept the way it has been done and continue perpetuating a culture in physics that is neither diverse nor inclusive. Our educational programs need to provide more training and support for instructors to develop expertise across all three of the conceptions of CRP, with special emphasis on the conceptions of knowledge. We see these exemplary instructors as illustrating how a productive use of conceptions of knowledge can appear. We hope to see these ideas more commonplace soon. Using all three conceptions of CRP can engage both instructors' and students' sensemaking and understanding of the physics phenomena. Instructors can use conceptions of knowledge to help students understand the historical context in which physics phenomena were developed and understand how these historical contexts play a role in the underrepresentation of certain demographics. Instructors can use their learning to create more equitable opportunities and experiences for marginalized groups.

Instructors can begin this practice by simply asking probing questions about the "who" and "how" during the introduction to scientists in the field. For example, both Thomas and Bruce did not necessarily dive into knowledge creation in other cultures, nor did they convey a deep historical understanding of how other groups in the world were exploring similar concepts in physics. They did, however, draw light upon the fact that many of these scientists—from Newton to Brahe—had unimaginable wealth and infrastructure at their fingertips, and this elicits at least some reflection as to how power and privilege become canon in scientific discovery. Instructors can also make use of resources freely available such as The Underrepresentation Curriculum [45], to support students (and themselves) in discussing subjectivity and demographics in the physics field.

While ideally, professional development will be more commonplace about subjectivity in the history of science, we hope to see an increase in the number of physics instructors who embrace the notion of subjectivity in physics along with all three conceptions in culturally relevant instruction.

Our findings have implications for researchers who focus on understanding the relationship between teacher identity and practice. Particularly, this study has implications for researchers who want to understand teachers' conceptions around knowledge and how it impacts their practice and student learning. Teachers' conceptions around knowledge impact teacher practice in how they push students to be critical in their learning process. Ideally, physics instructors should view physics knowledge as nonobjective, with an understanding that knowledge can be revised and changed over time. Instructors' view of physics knowledge has an influence on curriculum development and student reasoning around physics ideas. Given that the nature of physics is viewed to be objective by most instructors, there are

challenges in shifting their conceptions from physics being objective toward nonobjective and practitioner dependent.

VII. CONCLUSION

Findings from the study show teachers' views of objectivity and cultural relevance in physics can vary widely, even within this group of interviewees who signed up with an interest in CRP. Some teachers believed that physics has aspects of subjectivity, primarily in interpreting data and ideas. Other teachers viewed physics as more objective because of the mathematical emphasis. When describing cultural relevance in their instruction, some shared ideas aligned with CRP conceptions of self and others, along with social relations. Only two teachers' (Bruce and Thomas) interview responses on cultural relevance aligned with conceptions of knowledge.

We acknowledge that many physics teachers, as well as physicists and the broader society, are not accustomed to viewing knowledge in a nonobjective manner, and engaging in a discussion on this topic can be difficult. Practices and conversations, such as those highlighted in this work, provide a roadmap for teachers and teacher trainers who wish to implement a more culturally relevant perspective on physics and the nature of science. Moreover, this work does not view any individual instructor's beliefs pertaining to objectivity as fixed or as necessarily a barrier to a particular implementation of pedagogy, but instead, seeks to connect those to the broader culture in which we are all embedded. We call on physics instructors to increase efforts to think and teach more critically about what factors and systems play a role in how we view knowledge and its impact on our teaching and students.

In future interviews, we hope to see instructors more readily describe the influence of subjectivity on the construction of knowledge, instructors' increased efforts to critique the physics canon, and more instructors sharing descriptions of students as epistemic agents who can control their science learning and role in the field. This shift in emphasis can interrogate the conventional practice of following or being inundated by the culture and instead empower instructors and students to feel like they are a part of a malleable physics community. Together, we can shape the culture, the focus, the research, and the way learning happens. We can move away from being "*white-washed*" (Bruce) and "*allow students to see their way beyond what the current paradigm is*" and "*give students the power to effect change in the world around them.*" (Thomas).

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