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Abstract

Physics, like other scientific disciplines, attempts to remain objective and free from political and social implications. Thus, there is a huge dissociation of core concepts, such as energy, from sociopolitical landscapes. This disconnection from geographies and sociopolitical landscapes heavily influences physics curriculum, pedagogies and education. Given the indirect and direct impacts physics has on societal and political inequalities—e.g., climate change, energy injustices and technological inequities— it is important to shift this narrative so that learners can start addressing real world problems through physics. Physics should no longer be taught as an abstract and philosophical field that is far removed from real world examples, especially in secondary school settings. To start shifting this narrative of objectivity that excludes sociopolitical landscapes in physics education, we offered a year-long virtual professional learning community (PLC) to physics teachers from across the country. In this PLC we explored a major question in connection to the concept of energy; How do we explore sociopolitical landscapes in physics education? In this paper, we draw from classroom, teachers, and PLC experiences and observations to begin to answer to our major question. The purpose of this paper is to start addressing the critical need to include sociopolitical landscapes in physics education. We contend that by reflecting on this major question, physics teachers can start understanding how equity can be integrated into science classrooms. In support of this conclusion, we offer two case studies of energy lesson plans developed by PLC teacher participants, which can aid physics teachers in addressing sociopolitical landscapes in science education. We hope that these case studies foster dialogue as to why physics education should be more strongly connected to sustainability and environmental education.

Introduction

Energy is all around us. It is a universal concept that is embedded in all scientific disciplines—from environmental science to physics. There are various forms of energy found in our geographies—from automobiles to electric lights to wind power. However, like most scientific subjects, physics tries to remain apolitical and acultural in the name of objectivity (Traweek, 2009 & Harding, 2015). While physicists strive to not see how physics as a field is interconnected to geographies, physics is in fact connected to sociopolitical landscapes. These connections show the interrelationship of physics and environmental education, a connection that should be strengthened to combat climate change.

In order to understand why energy in physics education is cultural and political, we must first understand what physics is as a field. Physics is a combination of astronomy and mechanics that is derived from mathematical and philosophical approaches (Heisenberg, et al., 1971). The initial study of physics is credited to Aristotle (DiSessa, 1982 & Leijenhorst, et al., 2021). The main purpose of physics is to understand how the universe behaves through observations of matter and energy. Like other scientific disciplines, physics as a field has evolved due to climate change, energy supplies, and technological advancements (Wieman, et al., 2015). However, physics is still taught with the same objectives that founded this discipline: the major core concepts, topics, and problem solving philosophies are derived from the historical era when physics was being invented, developed, and formulated (Wieman, et al., 2015).

In physics classes, energy is taught in the context of work, heat, efficiency, and power (Figure 1). This is because the concept of energy was shaped primarily in the British Industrial Revolution, when Britain was establishing coal-powered factories with which to process goods from its global trading empire, brought to England on steamships (Smith, 1998). The concept of

energy was developed for the purpose of improving those factories and steamships (Smith, 1998). As a result, the energy concept as it is usually taught today carries the values of capitalist self-interest and colonialism that were prevalent in Britain in the 1800s. Far from being an abstract, pure description of nature, the concept of energy is laden with its historical origins. It embeds values of the time and place that it was developed and thus it is not apolitical or acultural (Harding, 1998). However, as it continues to be taught in physics, the concept of energy is far removed and not connected to sociopolitical landscapes (Figure 1).

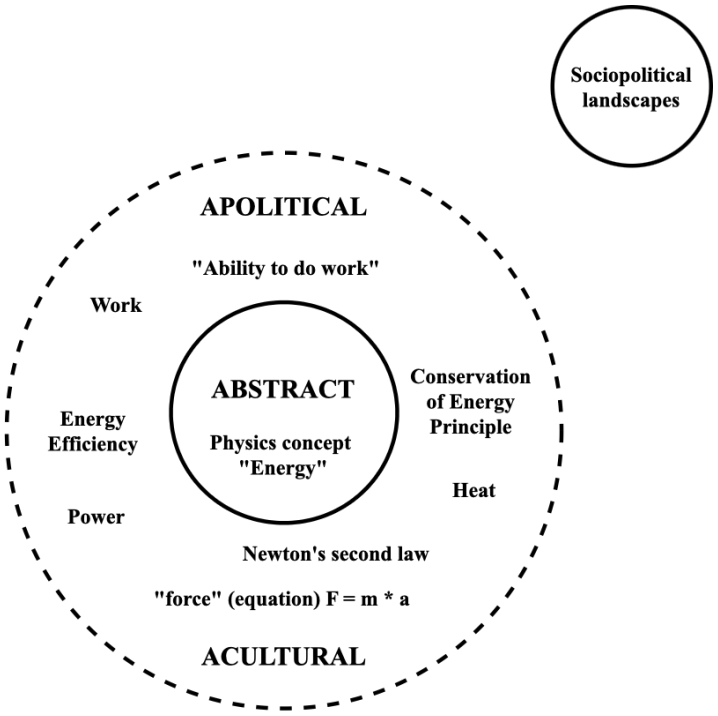

Figure 1: Concept of energy as taught in traditional physics classrooms

Since the British Industrial Revolution, our energy industry has drastically changed as we have new advancements that are heavily reliant on extractive fossil fuels. We are aware that these extractive fossil fuels are accelerating climate change at a more rapid rate than our society can adapt to. More importantly, we are also aware that climate change disproportionately impacts

Black and Indigenous communities (Thomas et al., 2019, Whyte 2020, & Shi, 2021). For Indigenous communities, climate change threatens the continuance of cultural systems that have been based on the reciprocal relationship between humans and nature (Ford et al., 2020). For example, in some traditions women's relationship to water and men's relationship to hunting and fishing are the special roles in their cultural systems (Sarma et al., 2020). Because of climate change, when Indigenous peoples are displaced and relocated to other lands, they are separated from that traditional knowledge (Brave Heart, et al., 2012). For the African American community, climate change impacts livelihoods, especially those who rely on natural resources for sustenance. For example, Paolisso et al., 2018 states that the effects of climate change on the Eastern Shore of Maryland, a region that is currently inhabited by descendants of slaves freed after the Civil War, show how climate change is drastically impacting the African American community. In this region, African Americans work in agricultural and commercial fisheries and live on low-lying lands, which are more vulnerable to climate change impacts such as flooding, storms, and erosion. However, physics education rarely connects the concept of energy to climate change—even as it continues to drastically impact human communities, and Black and Indigenous communities most of all.

Unlike environmental education, which explicitly links the concept of energy to human uses (Forinash, et al., 2021), physics teaching typically does not make connections to modern social problems. As a result, physics education weakens the connection between physics and climate change—among other environmental problems (Lehman, 1973). Interestingly, results from a recent physics education initiative concluded that when physics courses applied environmental problems to physics concepts, theories and practices, 30% more students liked physics (Busch 2010 & Meyers, et al., 2021). This study demonstrates that students are more

inclined to like physics and enjoy problem solving when sociopolitical landscapes are integrated. Therefore, it is important to explore sociopolitical landscapes in physics education, not only because physics concepts and the discipline itself in fact have a sociopolitical history, but also to support physics students to engage meaningfully with physics learning by connecting to environmental concerns.

To the extent that the physics discipline and its core concepts continue to claim cultural and political neutrality, all aspects of physics practices are disconnected from the sociopolitical landscapes, including physics teaching. In our PLC for secondary physics teachers, a survey with teachers at the beginning of the PLC revealed the teachers' self-evaluated knowledge about three sociopolitical landscapes in physics education. These include: how concepts of energy are shaped by the historical period in which they were constructed, present day inequities in the energy field, and historic inequities in the energy field. As shown in table 1, most teachers expressed that they came to the PLC lacking knowledge of the sociopolitical origins of energy physics as well as the role it plays in existing social inequities. The PLC is designed to support physics teachers to explore and integrate sociopolitical landscapes into their physics lessons through a multidimensional space, while also acknowledging the structural challenges and barriers that physics teachers encounter when disrupting this disconnection.

Table 1: Pre-assessment by Center for Evaluation & Research for STEM Equity (CERSE) of teachers' knowledge regarding energy and sociopolitical landscapes

	Extremely knowledgeable	**Somewhat knowledgeable**	**Somewhat not knowledgeable**	**Not at all knowledgeable**	**Total**
How concepts of energy are shaped by the historical period in which they were constructed.	1	4	11	6	22

Present day inequities in the energy field.	0	6	12	4	22
Historic inequities in the energy field.	0	2	13	7	22

Thus, the overarching goal of the PLC was to increase teachers' knowledge of these three sociopolitical landscapes. Specific activities included supporting teachers to facilitate classroom conversations that address equity issues; guiding teachers to learn about Indigenous issues and rights in their geographic region; expanding teachers' conceptions of equity by introducing them to relevant theoretical literature; and providing opportunities for teachers to share drafts of lessons that they developed. These strategies were implemented so that they could not only celebrate each others' efforts, but also benefit from the feedback of fellow teachers and PLC facilitators. Findings from other research studies indicate that this PLC experience supports teachers to enact place-based education, integrate social justice with science content, and acknowledge Indigenous issues in science teaching (Hernandez et al, 2022)

The measure of teacher learning we use is the teachers' ability to apply their knowledge to create lessons that address the three sociopolitical landscapes in high school physics teaching. Even as we articulate this "measure," we want to emphasize that there is no external standard by which the teachers' work is evaluated. Since PLC teachers are developing new physics lessons that are rare in physics education, given how physics continues to remove itself from any sociopolitical implications, there are no existing evaluation frameworks we can apply. In this context, the appropriate method for learning about teacher learning is a case study approach, in which we create detailed accounts of individual teachers' development as a means of better understanding their work.

How do we explore sociopolitical landscapes in physics education?

Current approaches to equity in physics education have tended to emphasize sociocultural approaches: these include how learning is shaped by learners' social interactions, often prompting teachers to increase students' sense of belonging by creating an inclusive and welcoming learning environment (Veresov 2020). A risk of this sociocultural approach is that it may maintain the disciplinary status quo, without transforming the conceptual system that maintains these inequities (Curenton et al., 2020). A sociocultural approach will not produce true equity, which requires all actors to redistribute power within all societal hierarchies. Gutierrez (2013) shows that educators who dedicate work to social justice, antiracism, and transformation education have moved beyond the sociocultural approach, instead advancing a sociopolitical approach to better advance equity. Although a sociopolitical approach has been taken up in science education research (Adiredja et al., 2017 & Tolbert et al., 2017), little work has been done in applying sociopolitical approaches to the teaching and learning of physics content. Through the sociopolitical approach, teachers and educators can support students to rethink physics knowledge and provide students with opportunities to use their knowledge to critique critical issues in their community— e.g. how energy benefits and harms certain communities disproportionately. This approach empowers students towards ethical decision making and community change.

This paper provides case studies of curriculum developed by high school physics teachers. These case studies demonstrate how sociopolitical landscapes may be explored in physics education. These case studies were selected based on teacher participants' perceptions of their coherence and usefulness in a wide range of physics classrooms. One of the primary considerations was that implementing these lesson plans does not require additional funding,

which is often nonexistent in public education. The team of PLC facilitators supported teachers to integrate sociopolitical landscapes in their energy units. Each of the following case studies represents the teacher's perspective, focusing on their own individual growth and learning. Student assessment information is reported by the teachers, not analyzed directly by the authors.

Case Study #1: Indigenous Communities and the Concept of Energy

Author 5 (she/they) teaches in an affluent suburban public school in the Northeast that is predominantly white. Their students completed a unit on energy that attempts to acknowledge the Indigenous populations that are impacted by energy production as well as the health consequences that these populations contend with due to their proximity to waste products (Singh et al., 2018 & Li & Achal 2020). This includes both communities in other continents and in the United States where resources are mined and communities that have been displaced in the United States in order for private companies to mine resources from sovereign Indigenous territories (Gnaedig 2018 & Rock & Ingram 2020).

Students considered the economic impact of Indigenous land loss (Gassiy & Potravny 2019) as they studied the massive infrastructure of the electrical system and roadways that allows for our ability to produce forms of what we often consider to be innocuous green energy. Certain sources of energy also inspire students to consider the differences in how the land is currently treated from its traditional stewardship under Indigenous care. For example, many communities have dams that shore up floodwaters that used to enrich the soils of farmlands in the area. Indigenous people in these areas were migratory (Maldonado et al., 2013), allowing the land to go through this seasonal cycle and tilling the land that became fecund each year in this method with a crop rotation of corn, beans, and squash which also allowed for the soil to regenerate.

Organic farms in the area are starting to learn about and utilize crop rotation, but for many years the norm had been to use fertilizers which left residual chemicals in the watersheds of communities that are detectable in wells of some residents to this day.

Through the course of this unit students learn how land that is known to be contaminated is developed into low income housing, perpetuating a cycle in which displaced Indigenous people continue to be harmed by our system of energy production (Townsend et al., 2020). Students examined how exposure to waste products of our energy production system impacts the health of low-income communities who often bear the brunt of this pollution. This unit helped open the students' eyes as global citizens and supported them to think about how the products they use every day are impacting lives they have never considered.

As author 5 recounted, “The few students of color in my classroom were validated in how we consider all of the consequences of our energy use, not just the highlighted benefits touted by the oil companies that are often developing many of these means.”

This demonstrates that students were able to understand that as a global society we must work in partnership with communities to ensure that the least harm possible is done in our production and use of energy and that the most people possible benefit from energy use (e.g. people of color) (Baker 2019). In this case study, the lesson is grounded on the physics concepts of energy, particularly energy production. While the acultural and apolitical teaching would limit the lesson to students learning about different types of energy production, their physics mechanisms and their benefits, the students in this case study were invited to investigate the impact of energy production on the environment and different communities. Specifically, taking the hydroelectric dams as an example of energy production, the students connected energy production to both environmental and economic impacts. These impacts were contextualized to

the experiences and harm Indigneous and underrepresented communities face as a result of these energy resources. The sociopolitical landscape connection to the concept of energy allowed students to be verbally engaged in the critical analysis of the economic sector and assess the environmental injustices energy has produced, especially towards communities that are often not provided the political leverage to make decisions in this realm. The lesson moved away from the traditional acultural and apolitical way the concept of energy is taught in physics by merging the concept with sociopolitical landscapes (figure 2).

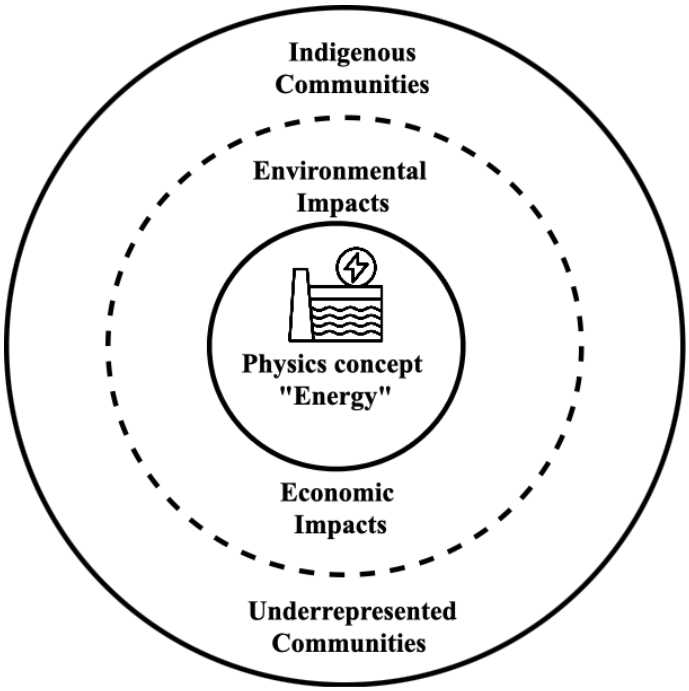

Figure 2: Economic & Environmental Sociopolitical Impacts of Energy

Case Study #2: Exploring Sociopolitical Landscapes in the Electricity Unit

Author 6 (she/her) teaches in a high school located in a rural agricultural area in the Sacramento Valley of northern California. Her electricity unit in 9th/10th grade Physical Science class was anchored by looking at how electricity is generated in their area. The students began

the unit by filling in a map of the county and found where the power plants and substations and power lines were. Then they spent several weeks learning about the physics of electricity and magnetism as it relates to motors, turbines, and power generation. They researched different methods of generating electrical power and compared the advantages and disadvantages of each, including environmental impacts and human impacts.

As their culminating project, the students were asked to write a letter to a local, state, or national elected representative of their choice advocating for the energy resources that we should invest in for the future. One of the main goals was for the students to see the ways in which a greater understanding of science concepts can empower students to work for change in their communities. To raise the students' awareness of local decision-making processes and complexity of the many impacts of power generation, they also watched a documentary called "Guarding Ancestral Ground with the Wiyot" (from the series Tending Nature on KCET). The Wiyot tribe from Humboldt County have fought for restored access to their land, including their traditional ceremonial grounds on Tululwat Island (Adams 2020). When an energy developer proposed a large wind project on a spiritual and gathering area, the Wiyot opposed the project's greater ecological disruption and rallied the community to defeat it. The documentary shows people speaking at a county supervisor's meeting, and was used as a transition to ask the students how much they knew about who represents them at the city, county, and state level and how they can have an impact on the decision-making process (Malloy 2021).

Like (Author 5)'s case study, this lesson also centers on the physics concept of energy, specifically energy generation, although with a more specific connection to the local area where the classroom takes place. The lesson included a socio-critical analysis of energy resources, where students not only researched different energy resources in the area but also analyzed their

impacts on the local environments and communities. The students were then supported to take action to advocate for local energy resources, based on the critical analysis they conducted.

In this case study, taking wind energy as an example of energy resources, students learned about the sociopolitical aspects of energy generation from the viewpoint of the Wiyot people. Their stories supported students to discuss power disparities in energy production, specifically which communities were impacted by energy decisions without being invited to contribute to those energy decisions. The connection to the sociopolitical landscape in this energy unit not only allows students to connect past and current events with their lives but also supports students to become critical thinkers and advocate for their local communities.

The concept of energy is connected to both local and global communities that are impacted by energy resources (figure 3). As in (Author 5)'s case study, the students connected dams to environmental and health impacts, especially on communities that already experience health disparities. This kind of connection is especially meaningful given that this unit was implemented during the COVID-19 pandemic, bringing the sociopolitical landscape into even closer relationship with current events that impact students' communities.

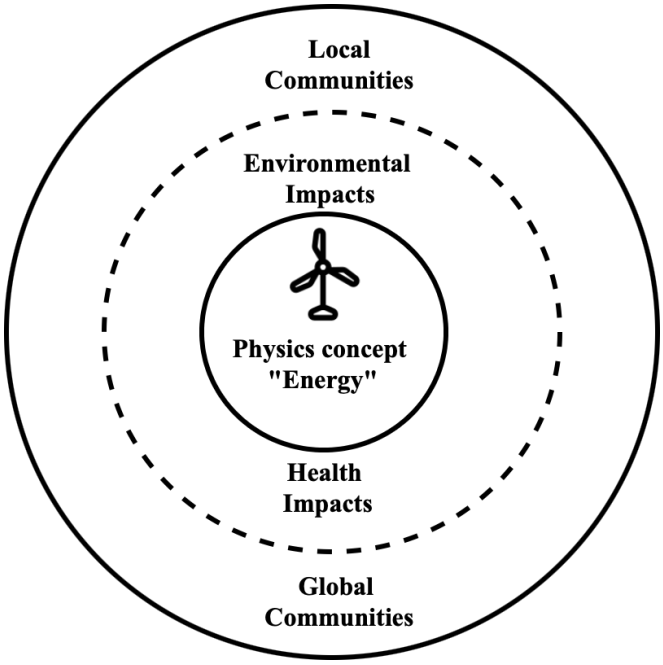

Figure 3: Health & Environmental Sociopolitical Impacts of Energy

Renovated Physics Courses

These two renovated physics courses demonstrate how the concept of energy in physics can move from being an abstract concept to a concept that connects to sociopolitical landscapes. Both case studies demonstrate physics teachers identifying the rationale and value of taking physics teaching in a new direction, beginning to reshape physics as a discipline to address 21st century injustices (e.g., climate change, energy distributions, Indigenous rights).

Unfortunately, both teachers experienced resistance from their teacher colleagues and administration. There was no added budget required to introduce these new pedagogical techniques into their classrooms, therefore, teachers did not receive any pushback from the administration regarding additional funding. Instead, the resistance referred to the social justice content that is integrated into the lessons. One teacher said, “There's definitely pushback [from] the school when I raised these issues. There is pushback, because everybody has their own image

of what equity and physics is." This pushback is very common for physics and other science teachers, demonstrating systematic forces that protect the status quo (Martins et al., 2021). Many in scientific spaces do not understand or value teaching towards equity, believing that teachers should "stick to the science pedagogy" (Rivera, 2022). In many cases, this pushback contradicts schools and other institutions' mission statements towards equity and diversity. The PLC supported teachers to counter the resistance, and to encourage their students to do the same.

In both case studies, the teachers did not introduce their own definition of "equity," but rather allowed their students to define it through the connections they made. In (Author 5)'s teaching, the approach to equity was to examine economic and environmental inequities. In (Author 6)'s class, students interpreted equity in terms of health and environmental inequities. In both cases, the definition of equity bridged the gap between the physical sciences and environmental sciences.

While the case studies focus on the teachers' applications of sociopolitical landscapes, our research project reports on the participant teachers' enhancement and enrichment in learning how to apply sociopolitical landscapes into their physics curriculum. Once their lesson units were created and implemented, we surveyed teacher participants again to understand how their knowledge had shifted or changed once they also learned from their students' discussion around sociopolitical landscapes and the implications energy has on environmental, health, and economic impacts on Indigenous and communities of color. The teachers' responses to the post-survey at the end of the PLC were shown in table 2. The teachers reported that they were much more knowledgeable of the sociopolitical landscapes of energy in physics than they were at the beginning of the PLC.

Table 2: Post assessment by Center for Evaluation & Research for STEM Equity (CERSE) of teachers' knowledge regarding energy and sociopolitical landscapes

	Extremely knowledgeable	Somewhat knowledgeable	Somewhat not knowledgeable	Not at all knowledgeable	Total
How concepts of energy are shaped by the historical period in which they were constructed.	4	17	1	0	22
Present day inequities in the energy field.	10	11	1	0	22
Historic inequities in the energy field.	7	15	0	0	22

Additionally, by working closely and supporting teachers to explore and integrate sociopolitical landscapes, PLC facilitators and researchers have been able to observe teachers' shift in their conceptualization of teaching science, including confidence and actions towards transforming science teaching. There were a total of 21 activities that the participants' teachers created and shared among the teachers since 2020. These lessons promote social justice by entering student scientific inquiries around social political landscapes. These lessons expand across the scope of science topics, including various topics in physics. This demonstrates the prevalence of PLC teachers' integration of sociopolitical landscapes into physics education.

The cases presented in this study not only show the teachers' growth in connecting science and sociopolitical landscapes for themselves, but also imply how impactful that reconnection is for teachers to make changes towards a more equity-oriented, socially-just science teaching. Teachers not only attend to access and achievement, but also bring in students' daily life experiences and concerns, empowering students to rethink what science or physics is. The presented approach of attending to the sociopolitical landscape therefore is an exemplary response to the call for a critical shift to advance equity in science education (Gutierrez, 2013).

Future work

So far, teachers have conducted this work in a small teacher-centered community (the PLC), supported by facilitators. Teachers currently share their work with one another via an online community resource called the Energy and Equity Portal (www.energyandequity.org), which is tailored to sharing instructional materials. As teachers grow in expertise and develop mature instructional activities, they are beginning to share them publicly, through a system that places their lessons in context for sharing worldwide. Soon, the Energy & Equity Portal will be the hub of an online community for teachers around the world to share and discuss ideas, instructional materials, and research results for integrated energy and equity instruction. The Portal will disseminate the materials created by the teachers, support teachers in benefiting from each others' work beyond their direct participation in the PLC, and ensure that their innovations reach a worldwide audience of teachers. The Energy and Equity Portal includes a library of instructional materials that address the sociopolitical landscapes described above; an action research exchange to support teachers in studying and reporting on the effectiveness of the instructional materials they implement in their classes; and a community forum to support teachers in collaborative discussions on energy and equity topics of their choosing. Teachers who create new instructional materials can contribute them to the instructional library; teachers who are looking for ideas can adopt or adapt materials from the library; and participants can comment on materials in the library to offer feedback or ask questions, which will be a form of collaboration for current participants and a source of information for future users. The action research exchange will provide structure for creating action research reports, prompting participants to document their work for the benefit of future participants. The Energy and Equity Portal will support, enrich, and sustain the community of teacher-leaders that have developed

their expertise in the PLC, and provide the platform to expand the community of teachers addressing sociopolitical landscapes in physics education.

In addition, the two case studies call for attention to the use of students' cultural resources as a tool for instructions. Aspects of multicultural pedagogies such as culturally responsive and culturally relevant pedagogy were used in both case studies. What was unique about the teachers' statements in our study was that their strategies were rooted in identifying student cultural resources and norms. Both teachers talked about recognizing students out of classroom lives and drawing upon that information to help guide their instruction. An examination of the effectiveness of these culture-based approaches would be beneficial for researchers and teacher educators who seek to understand ways to operationalize these pedagogies.

Conclusion

From the year-long professional learning community (PLC) that was offered to physics teachers, we were able to demonstrate that physics is indeed cultural and political. Sociopolitical landscapes should not be excluded from physics pedagogies, curriculum and lesson plans. During the PLC experiences, the participating teachers reported growth in their knowledge about the connection between physics concepts and sociopolitical landscapes, including the socio-historical context where physics ideas such as energy were created and the role such ideas play in perpetuating social inequities (see Table 1 and Table 2). More importantly, case studies provide first hand testimonies from teacher participants, demonstrating practices for other physics teachers to implement in their classrooms. Author 5 provided a way in which teachers can incorporate local Indigenous histories to help students analyze the sociopolitical landscapes embedded within the concept of energy. Author 6 connected electricity to students' local

communities that allowed them to critique the advantages and disadvantages of different energy resources. Both case studies demonstrate the importance of not completely separating physics from sustainability and environmental education, as both play a major role in each other. Physics must not be taught as abstract philosophies and theories: there are sociopolitical landscapes that also play a major role in the field. To engage in equity based instruction, teachers will need to navigate resistance to their efforts. Teachers must also navigate pedagogical challenges, in understanding how to effectively leverage students' cultural resources and using them as a foundation for their teaching. Within that, teachers will need to embrace themselves within the culture of their students, so they can effectively identify resources they can leverage. Lastly, teachers will have to engage in an identity shift to a more critical mindset where they encourage students to push the boundaries of knowledge and social norms, and use the classroom to address socio-political concerns. The PLC in our study disrupts traditional instruction in science classrooms in order to visualize science instruction that values learners' full humanity.

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