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Collaborative Professional Learning Communities for Culture-Based Physics Curriculum Development: Integrating Local Knowledge with NGSS

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1. Abstract

Many physics teachers who attempt to adopt a culturally relevant approach to their teaching express challenges. This research explores the dynamics of a professional learning community (PLC) of physics teachers seeking to make their instruction more culturally relevant. Our investigation focuses on how physics teachers develop a lesson around energy, focusing on selecting and integrating cultural resources that help students understand energy ideas. By analyzing the discussion of a single PLC meeting of these physics teachers, we identified key themes in their approach to describe how they attempted to create a culturally relevant physics lesson around energy. The identified themes include *incorporating political/social justice, creating content that connects with students' lives, emphasizing student voices,* and *integrating content and scientific practices*. The findings of this study are essential for physics teachers trying to include culturally relevant strategies in their teaching.

2. Introduction

Historically, our educational system has primarily benefited students from higher socioeconomic backgrounds while disadvantaging those from marginalized communities [1]. This lack of inclusivity has been a significant factor in the disconnect many students from diverse backgrounds feel towards traditional pedagogical approaches, such as didactic instruction [2,3]. Traditionally, physics has been taught didactically, where teachers present content in a lecture format, expecting students to absorb as much information as possible [4]. However, research indicates that this method has resulted in minimal positive outcomes in students' understanding and engagement with physics [5]. Because of this, there has been a shift towards more interactive and student-centered pedagogies, where students are more active in the learning process [6.7]. These methods have shown more promising student engagement and learning outcomes [8].

Despite these advances in pedagogical approaches, challenges remain in effectively reaching and engaging more diverse student populations. A critical aspect often overlooked in these efforts is the integration of students' cultural resources in their classroom teaching. The influence of culture on an individual's engagement with new ideas is substantial, as it shapes both their exposure to and preparation for new information [9]. Additionally, culture is pivotal in determining the relatability of information presented to students [10,11]. For instance, a student's willingness to engage or disengage with new material in physics can be significantly influenced by the method of presentation, the visual aids used, and their cultural perceptions of the subject matter [12]. The educational system often inadvertently overlooks the cultural diversity of students, a tendency that can perpetuate systemic biases, including racism [13]. A lack of cultural inclusivity and representation can lead to disconnection for students from diverse backgrounds, significantly increasing the likelihood of their disengagement in the classroom [14].

Adopting a culturally relevant approach to physics instruction offers the advantage of greater inclusivity and representation of diverse cultures [15,16]. Teachers can foster a deeper engagement through a culturally relevant teaching approach by aligning physics teaching with students' diverse backgrounds, languages, and presentation styles [15]. This tailored approach facilitates a more meaningful connection with the subject matter and enhances students' productive struggles while solving problems, enriching their learning experience [17].

Implementing a culturally relevant approach to physics education has its challenges. A primary obstacle is a need for more cultural synergy between most teachers and students. This occurs especially in contexts where teachers predominantly come from backgrounds significantly different from their students [18]. Another significant challenge is the scarcity of clear, practical examples and guidelines on "effectively implementing" culturally relevant pedagogy in physics education literature [16]. This gap often leads teachers to rely on assumptions about best practices in culturally relevant pedagogy, resulting in inconsistencies and conflict among scholars and teachers interested in adopting culturally relevant pedagogical methods.

Teachers seeking to implement culturally relevant pedagogy in physics also face challenges from constraints imposed by school districts and supervisory bodies [12,15]. These constraints often include specific benchmarks and curricular requirements that dictate the core concepts students must grasp. Consequently, teachers may feel hesitant to embrace pedagogical reforms and risks, as they often require patience with student learning, development of creative tasks and assessments, and enhanced engagement with students [19].

3. Research Question

This study examines the role a professional learning community (PLC) has on physics teachers regarding how they design and implement culturally relevant lessons. Notably, we examine one physics teacher's process in making his energy-focused lesson more culture-based. The central research question guiding this study is:

> *How can a professional learning community of secondary physics teachers transform an existing curriculum on energy into a more culturally relevant one?*

The participants in our study comprise secondary physics teachers who are actively involved in a PLC. These teachers come from diverse regions across the United States, bringing various regional perspectives and experiences to the PLC.

4. Theoretical Framework

Culturally relevant pedagogy (CRP) is a framework developed by Ladson-Billings [10] that leverages students' cultural resources to enhance academic performance. CRP is built upon three domains: *academic excellence, cultural competence,* and *sociopolitical consciousness*. Attempts have been made to incorporate CRP into classrooms [3,10], but more effort must be made in STEM fields, specifically physics. Author 1 has developed strategies where students utilize their cultural resources to engage with physics concepts and collaborated with secondary physics teachers to understand their challenges in enacting CRP [15]. His findings indicate that teachers are interested in implementing CRP but are

constrained by district requirements. Author 1 [12] also explored how teachers view the incorporation of CRP into their practice, focusing on a critical examination of knowledge construction. The study's findings reveal an uneven distribution in teachers' views on the nature of physics knowledge, which affects how they integrate CRP into their teaching.

Students' cultural resources are the diverse knowledge, skills, language, experiences, beliefs, values, attitudes, traditions, and artifacts that students can incorporate into the classroom [20]. Understanding and utilizing students' cultural resources can be challenging for many teachers [21]. Students bring numerous resources to the school that teachers often need help to incorporate into their teaching. Furthermore, since physics is frequently considered culturally neutral, some argue that culture-based approaches are unnecessary [12]. These perspectives present challenges for teachers who wish to incorporate culture-based approaches into physics instruction [22].

One challenge with using culture-based approaches in physics is that teachers must be more familiar with integrating them into physics curricula [12]. The current physics curriculum is perceived as static, leaving little room for the creative integration of students' cultural resources or for encouraging critical approaches to learning [22]. This rigidity causes resistance among teachers interested in reformative instructional strategies, such as CRP [12]. The question remains for teachers interested in culture-based approaches: How can teachers identify "useful" cultural resources for students, and how can they effectively incorporate them into their teaching curricula?

5. Research Design

Our study examines a Professional Learning Community (PLC) of eight secondary physics teachers (n=8) to understand how physics teachers leverage students' cultural resources to engage with physics ideas. The PLC met for 90 minutes each month. During each meeting, one teacher shared a culture-based lesson that included a local issue or cultural aspect at each meeting. Other teachers then discussed ways to improve the lesson. After the teacher presented the lesson, the other teachers discussed ways to improve the lesson. These meetings aimed to help teachers improve how they incorporated local socio-political issues into their lessons, alongside rigor and a focus on scientific practices.

The PLC meetings were audio recorded and transcribed through Zoom. These were then open-coded using Vosaic software and analyzed for common themes around teacher improvements and lesson revisions. We used pseudonyms to conceal the names of the participants for confidentiality purposes. Although eight teachers are in the PLC, only four contributed to the discussion around the lesson in this study. Participants include Jackson and Jada, physics teachers from the same school district in the Southwest United States; Amanda, a physics teacher in the Western United States, and Mary, a physics teacher from the Southeastern United States.

6. Findings

Our paper focuses on the instructional unit developed by Jackson around energy. The instructional unit was centered around a list of driving questions, some of which were:

1. What is energy, and why is it a fundamental concept in physics?
2. How can the conservation of energy be used to predict an object's motion?
3. How do potential and kinetic energy differ, and what factors determine their magnitudes?

4. What is work in physics, and how is it related to the transfer of energy?
5. What is your carbon footprint?
6. How can we analyze the efficiency of energy conversion processes in machines and systems?
7. How can we apply our understanding of energy and efficiency to make informed decisions about energy use and sustainability?
8. How can we apply our understanding of energy and efficiency to make informed decisions about energy use and sustainability?

This physics unit on energy acknowledged the importance of students' backgrounds and experiences and connected them to real-world contexts. The PLC discussed Jackson's "Research Races" lesson, which explored the effects of climate change through heat waves and ice storms in students' homes in Fort Worth, TX. A research race is an activity where students collaborate in a time-bound challenge to delve into a specific topic using online resources. The compressed timeframe prioritizes the development of foundational knowledge rather than exhaustive research. One valuable outcome of this activity was the discussion students engaged in afterward. Students shared their findings, contrasting them with their initial preconceptions, allowing participants to present their discoveries and solidify their newly acquired understanding through critical reflection and peer engagement.

Jackson's lesson plan fosters scientific literacy while considering students' local events by incorporating contextually relevant research. The goal is for students to connect energy concepts to their own lives and engage in discussions about how global issues affect their local environment. This is intended to empower them to make informed decisions about energy use and contribute to a more sustainable future.

Through thematic analysis [23], we identified four themes in how teachers gave suggestions to Jackson's lesson that leveraged students' cultural resources in their lessons. The major themes and definitions were:

- *Political/Social Justice* - Deliberately incorporating societal challenges, inequalities, and injustices within the educational content.
- *Relevance to Students' Lives* - Giving students meaningful choices and control over learning.
- *Student Voice* - Actively involving students in decisions, policies, and practices affecting their learning and schooling experience.
- *Merging Content and Scientific Practices* - Integrating the teaching of scientific knowledge (the content) with the methods and processes scientists use to conduct research and solve problems (the practices).

The following sections discuss how the PLC members analyzed Jackson's lesson and incorporated the abovementioned four major themes.

6.1 Political/Social Justice

Jackson's energy lesson integrated aspects of the sociopolitical climate by connecting local climate change events to his energy unit. This led to a discussion where teachers in the PLC shared ideas about other political and social justice factors that could be included in the energy lesson. First, Jackson shared his lesson:

> **Jackson:** *We [did] a quick research race, and this one was on the heat wave or the ice storm here in [our local city], and I had them figure out 'what have we learned?'* [about the heat wave] *There was a heat wave. It's pretty terrible. People passed away. There was an ice storm. People lost power."*

This made space for other teachers in the PLC to reflect and share ways in which energy ties to current events and social justice-related topics. For example, another teacher, Jada, reflected on how she could integrate the Dakota Access pipeline topic into her lesson plan to emphasize the importance of equitable energy access.

> **Jada:** *I'm still going to try to integrate the Dakota access pipeline because it's still happening* [about the building of the pipeline]. *But there's equity* [issues] *and where the energy comes from and who is affected… But that was showing a lot about how energy access should be equitable.*

Jada described the integration of the Dakota Pipeline to reference energy access. Another teacher, Amanda, proposed the example of forest fires and how the discussion of energy can be integrated into these recent events.

> **Amanda:** *Another example of energy storage in a current issue is with forest fires. So trees actually store a lot of energy just in the trees, so with these large fires we're having, all that is expelled into heat and light and just into the atmosphere.*

Amanda discussed how energy is released from these forest fires and related it to a possible future lesson tied to climate change.

6.2 Relevance to students' lives

Jackson integrated aspects of students' lives into his lesson plan by beginning the lesson with a question formulation technique (QFT) in which students can indicate prior knowledge and desired knowledge. A QFT, as Jackson explains, "*build[s] curiosity about the lesson, and see[s] what the students know and what they want to know."* The QFT technique allowed students to connect energy concepts with memories of their favorite childhood toys, allowing them to connect their background to the lesson better. As part of the activity, students also researched the carbon footprint behind their favorite snacks. The students also considered how climate change has changed relevant aspects of their lives.

> **Jackson:** *And then we talk about, again, the effects of global climate change on anything they want to think about. Has it affected music? Has it affected video games? So what is it, you know? In which ways are we thinking about climate change?*

Jackson used students' personal interests to help them engage in the idea of climate change.

6.3 Student Voice

Later in the lesson, Jackson integrated what he calls "whiteboard coaching," where students guided each other through questions and affirmations. Every student got a chance to be the "player" and the "coach," positioning all students as knowers while also allowing them to express areas of confusion.

> **Jackson:** *I do what's called whiteboard coaching, which is very much a collaborative thing where all of the students are around a single table. Well, there's a team of four at a table with a dry-erase board. One person is what I call the whiteboard player, who is actually doing the work on the board, talking it out, thinking it out. The other people are coaches who work in their notebooks but as they work in their notebooks, they're definitely helping, either by asking questions because they don't know or helping the person push along because they don't know. So the goal of the coaches is to either give affirmations or questions.*

Collaborative techniques ensured each student had a voice and role in each lesson. Jackson also had an advisory board within each class, in which the elected students gave feedback about the class.

> **Jackson:** *I have a, what I call, an advisory board. So the students elect one to two students from their class and then we all meet once every six weeks. I get them pizza and then we talk about class. What they like and what they don't and what's working, what's not working.*

Jackson integrated the advisory board within his lesson to represent the class holistically. The students chosen for the advisory board can draw attention to areas requiring amelioration.

6.4 Merging content/scientific practices:

In the energy unit, Jackson used an activity to connect content to the practice of modeling better. The students used items called "jumpeez"--toys that Jackson describes as "squishing down and jumping up [...] about a meter high" to examine and model the energy conservation principle. Students were tasked with figuring out how to make the toy jump the highest and creating a model to demonstrate the phenomenon. Students had to make predictions, claims, and arguments based on evidence. Jackson used another activity that involved students calculating the work and power of students going upstairs and then analyzing the caloric value burned.

> **Jackson:** *I call it snacks and stairs. It's a classic lab for physics teachers where you're doing work and power and calculating the work and power of the students going upstairs. And so they go fast. They can go slow. They can carry other things, but basically, we're looking at that… But then they look at the caloric value there, converted to joules, thinking about the amount of work and power they use throughout the day.*

The students participated in a lab where they could apply their knowledge of work and power to determine how many calories were burned.

Jackson's unit is intended to engage students in calculating work and power based on caloric expenditure that connects physics to their daily lives. This activity can be engaging, specifically when students explore how their favorite foods contribute to their caloric intake and energy usage. Many students can find this lesson meaningful in analyzing the calories in meals they regularly consume, which can be a culturally relevant entry point for discussing ideas such as energy transfer and metabolism.

While this activity can be engaging, teachers should be mindful of the unintended consequences of body image, particularly among groups who feel underrepresented in physics. An alternative approach could involve students analyzing power output in various physical activities, such as cycling, lifting objects, or even virtual simulations, ensuring a range of accessible and inclusive options.

While this study focuses on Jackson's lesson, other PLC participants approached cultural relevance differently. For example, Amanda designed lessons where students analyzed physics in the context of earthquakes in southern California, and Jada developed lessons incorporating knowledge systems around a local drag racing culture. Expanding future studies to examine multiple teachers' approaches could provide a more comprehensive understanding of PLC impact and the adaptability of CRP in different classroom settings.

7. Conclusion/Discussion

To make his lessons more culturally relevant and to aid their students in learning physics concepts, a PLC participant named Jackson developed a lesson that integrated aspects of the current sociopolitical climate from the local context in which they teach. This included incorporating large-scale events, such as natural disasters, that students were familiar with to help them understand energy-related concepts. From the analysis of the PLC discussion, we identified four themes that characterized the development of Jackson's lesson: political/social justice, relevance to students' lives, student voice, and merging content with scientific practices. The discussion among the teachers revealed that each had a unique method and specific examples related to the climate and geographical area where they resided. These current events can be linked to equity issues, as resources are distributed unequally. Discussing equity is crucial for illustrating the sociopolitical context of such events.

Efforts towards culturally and contextually relevant approaches to physics, such as what Jackson implemented, have implications for physics teachers. Jackson's lesson offers a starting point for physics teachers interested in developing culturally and contextually relevant strategies for curriculum design. It also suggests future research on how to model a curriculum for cultural relevance.

Much sensemaking or epistemological research in physics education needs to examine the role of context and culture in how students learn and think about physics concepts. Methodologically, there needs to be more current models and frameworks for teachers to reference when developing culture-based instructional approaches. Presently, efforts around multicultural education in classrooms primarily focus on non-STEM areas. From a social standpoint, this work has implications for drawing underrepresented populations into physics spaces.

Teachers interested in using CRP can face systemic challenges such as district-imposed curricular constraints and a lack of training in CRP. To address this, institutions can:

1. Offer professional development workshops that provide teachers with concrete strategies for integrating cultural resources into physics.
2. Advocate for curricular flexibility, allowing teachers to adapt lessons while meeting learning standards.
3. Create Collaborative PLCs: Forming or joining Professional Learning Communities (PLCs) focused on CRP allows teachers to co-develop and test lessons with peer support.

4. Develop mentorship programs within schools where experienced educators support colleagues in implementing CRP.
5. Encourage collaborations with local communities, ensuring that lesson plans reflect students' lived experiences. Institutional commitment to these changes would give teachers the resources and confidence to make physics more inclusive and relevant.

Another common challenge in encouraging instructors to adopt culturally relevant pedagogy is the lack of direct quantitative measures linking student performance and retention. While prior research indicates that culturally relevant teaching can enhance engagement and identity (Ladson-Billings, 1995), more studies are needed to explore its long-term impact on physics learning outcomes. Further research should employ mixed-method approaches, combining qualitative classroom observations with quantitative assessments of student achievement and persistence in STEM fields.

8. Limitations

There are limitations in how Jackson's unit aligns with culturally relevant pedagogy. First, Jackson's lessons on ice storms and wildfires focus more on context than culture. Although these topics are relevant to students' lived experiences, they do not address his students' unique and individual interests and knowledge. We recommend that educators work to understand students' cultural values, norms, and lived experiences and make meaningful connections to physics content based on these aspects. One way to achieve this is using strategies such as the Question Formulation Technique (QFT) to understand what matters to students. Additionally, the examples of student voice shown here represent only a small range of possibilities. We encourage educators to expand their agency to students, including allowing investigations and topics based on students' interests.

Nonetheless, we believe this paper can assist physics instructors interested in developing culture-based instructional approaches by modeling the first steps toward this approach. Few studies focus on developing culturally responsive physics methodologies, and this work can offer practical insights for teachers interested in crafting such lessons. For future research purposes, we need to develop more studies in which teachers create lessons that leverage students' cultural resources. This will help develop a model or framework for educators designing culturally relevant lesson plans.

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