Cultural Resources in Physics Sensemaking: What Students Reveal Through Formative Assessment

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Physics education often omits students whose cultural experiences are not reflected in traditional instruction and assessment practices. While culture-based pedagogies (CBP) have shown promise in making physics more inclusive to diverse learners, limited research has explored how students use their cultural resources to make sense of physics concepts. Additionally, there is limited research on understanding how teachers can identify and effectively leverage these resources. This pilot study examines how undergraduate students from two universities in a general physics 2 class respond to qualitative, open-ended formative assessments intentionally designed to elicit culturally grounded explanations of select physics phenomena related to capacitance, electric field, and power. We examined (1) what cultural resources students draw upon and (2) how these resources support their epistemologies and physics sensemaking. Two analytical frameworks were used to examine student responses: one identifying cultural resources (i.e., personal narratives, community practices, and cultural tools), and another capturing epistemological orientations and modeling strategies (i.e., narrative reasoning, everyday analogies, and gesture-based modeling). Students responded to prompts related to capacitance, electric fields, and energy, using examples from lived experience to interpret phenomena. Findings show that students frequently drew on everyday analogies, personal narratives, and cultural tools to explain physical concepts. Their reasoning reflected diverse epistemologies, including experiential, relational, and narrative modes, that go beyond standard mechanistic or authority-based explanations. Co-occurring codes revealed rich intersections between cultural and epistemic resources, suggesting that students actively integrate their life-world knowledge into physics modeling and sensemaking. This study demonstrates the potential of developing formative assessments to reveal the full range of students' intellectual resources. Implications include new directions for enhancing assessment approaches in physics education that center on broadening learners' participation and valuing students' cultural knowledge as fundamental to learning.

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I. INTRODUCTION

Despite its critical role as a gateway to STEM careers, physics education struggles to effectively engage diverse learners [1, 2]. Physics instruction traditionally emphasizes idealistic scenarios and deficit-based assumptions [3]. For many students, especially those from culturally and linguistically diverse backgrounds, this conventional teaching approach reinforces perceptions that physics is irrelevant to their lives, which can limit their engagement, motivation, and performance in the discipline [4, 5]. Substantial research has demonstrated that when instruction builds on students' personal and cultural practices, they not only engage more deeply in learning, but also begin to see themselves as capable contributors to the discipline [6-9]. This aligns with broader calls for instruction that affirms students' identities and epistemologies [10].

Emerging research highlights culture-based pedagogies (CBP) as effective approaches to bridging these gaps by leveraging students' cultural resources to engage deeply with physics concepts [3, 7]. CBP emphasizes the inclusion of students' cultural resources to create a transformative shift in classroom instruction and assessment, along with centering students' lived experiences and knowledge as integral assets to learning [6-8]. To effectively implement CBP within physics education, teachers must understand how students utilize their cultural resources, particularly in the context of sensemaking [8].

This paper describes a pilot study where undergraduate physics students are given qualitative and quantitative formative assessments to examine two things: (1) what cultural resources students draw upon, and (2) how they use them to demonstrate understanding of physics phenomena. We aim to highlight how students' culturally situated knowledge, epistemic orientation, and sensemaking processes shape and enhance their physics learning. Ultimately, these approaches to assessment can enhance instructors' ability to help students demonstrate and understand various physics ideas and phenomena.

The goal of this study is to design formative assessments that are open-ended and contextualized, prompting students to explain everyday local phenomena using physics ideas. We will use assessments that invite multiple pathways to reasoning, such as modeling, narrative, and analogical. In these assessments, students describe examples from their experiences, communities, or language practices. We designed assessments that not only test content knowledge but also reveal how students reason and what cultural, conceptual, and epistemic resources they draw on to do so.

II. CONCEPTUAL FRAMEWORK

Culture-based approaches to teaching emphasize the value of students' cultural resources, which are the knowledge, skills, practices, and identities that support meaningful engagement with phenomena [11]. Recognizing students' lived experiences, languages, and community knowledge can enhance engagement, foster a sense of belonging, and promote academic achievement [11]. In physics, students draw upon everyday analogies, community practices, historical contexts, and identity-based perspectives to interpret and explain physical phenomena [3, 8].

This study is grounded in the claim that students' cultural resources, epistemologies, and sensemaking approaches influence how they engage in physics. Our conceptual framework integrates culture-based pedagogy, which centers students ' lived experiences and sociocultural practices in instruction [12], epistemological orientations, which refer to the ways students conceptualize knowledge, evidence, and explanation [13], and scientific modeling, a core disciplinary practice that involves representing and refining ideas about physical phenomena [14]. We use this framework to examine how students draw on their cultural and epistemic resources to engage in modeling-based sensemaking tasks.

Although prior research has emphasized the importance of integrating students' cultural and epistemological resources [8, 9], less is known about how students use these resources in modeling and sensemaking. This study addresses this gap by investigating how students draw on cultural knowledge to support epistemic engagement in physics.

III. METHODS

This study involved the design and administration of formative assessments that invited students to use their cultural resources to explain physics phenomena related to capacitance, electric fields, and power. These assessments were developed collaboratively by a faculty learning community (FLC) composed of three physics professors. The FLC met weekly during the term, where all three faculty members taught second-semester physics courses.

The goal was to design *quantitative and qualitative*, *open-ended questions* encouraging students to draw on their lived experiences in making sense of the targeted physics concepts. The intention was to move beyond traditional content recall and instead elicit authentic, culturally grounded explanations of physical phenomena.

The participating faculty members represented a range of institutional contexts. One professor taught at a large research university in the Midwest; another was based at a small, undergraduate-focused university also in the Midwest; the third taught at a Historically Black college and university (HBCU) in the Southeastern United States.

Together with a graduate and undergraduate student, the group collaboratively developed several culturally grounded formative assessments across multiple physics topics. Due to space limitations, this paper focuses on student responses to three selected questions administered at two participating institutions. These questions were chosen for their analytical

richness and the depth of cultural engagement observed in student responses.

This research was approved by the Institutional Review Boards (IRBs) of the two participating institutions. All student data were collected with informed consent and were de-identified before analysis. Participation in the study did not affect students' grades and was entirely voluntary.

A. Question Selection

While the faculty learning community developed a range of assessments over the semester, the following questions were selected for their ability to elicit rich, culturally grounded responses, engaging students in sensemaking around key physics ideas. Each question targeted a different physics concept (capacitance, electric fields, and power) and was intentionally framed to invite students to connect physics to their lived experiences.

The **capacitance question** asked students to develop analogies grounded in their personal lives:

> *"Capacitors are devices that can take in a low current and build charge up over a long period of time. The capacitor can then be used to discharge the stored charge rapidly. This is different from a battery, which keeps a consistent current. Write about an analogy for something that acts like a capacitor and another analogy for batteries that are relevant to your life."*

The **electric field question** was presented in two parts to prompt both narrative storytelling and conceptual comparison:

> *"A. Electric fields are weird. They're invisible, but they influence everything around you. They are why you don't fall through your seat, but also transmit information to your phone. Tell a story from your life where electric fields were important, even though you did not realize it then."*
>
> *"B. We talked about the idea that electric fields are a way to talk about how charges have action at a distance – the source charge creates a field and then the field 'touches' the other charge. Write about an instance where you've experienced or witnessed an interaction at a distance and compare that to what you know about electric forces/fields."*

The **power question** was the most comprehensive, involving multiple components, including personal reflection, interview, energy calculation, and cultural analysis:

> *"Choose Your Favorite Hot Dish. Think about a dish that is meaningful to you. It could be a family recipe, a cultural favorite, or simply something you enjoy. Take a moment to reflect on why this dish matters to you."*
>
> *"Calculate the Cost of Cooking: Using the information you gathered, calculate the cost of preparing the dish based on the energy used. Focus on the kWh (kilowatt-hours) consumed while cooking. You'll need to: determine the electrical appliances used (e.g., oven, stove, microwave) and their power ratings (in watts); calculate the total energy used based on the cooking time; and find the most updated electricity rate (cents/kWh) in your area to estimate the cost of making the dish."*

By focusing on these responses, the study explored how formative assessments can illuminate students' cultural epistemologies regarding their understanding of physics concepts that may differ from the traditional explanations found in a textbook.

B. Analysis

The analysis of findings in this study is unique in that student responses were collected across multiple university contexts, with varying numbers of participants and questions administered at each site. At the first university, a large research institution, responses were gathered from two sections of a second-semester physics course, totaling 96 students (48 students per section). The capacitance and electric field questions were administered at this site. The second university, a smaller undergraduate-focused institution, had 40 students in one section of the second-semester physics course, all responding to the power/energy question.

To analyze students' responses, we used a qualitative coding approach, applying two analytical frameworks collaboratively developed by the authors for this study:

1. *Cultural Resources in Physics Responses*: This framework identifies the types of cultural knowledge students draw upon in their explanations. This framework was categorized into four areas:
   - Everyday Experiences & Analogies: Personal narratives (PN), community practices (CP), and analogies drawn from everyday life contexts (EA).
   - Language & Representation: Multilingual explanations (ME), and culturally embedded terminologies (CET).
   - Sociohistorical & Cultural Knowledge: Historical contexts (HC), cultural artifacts (CAT), traditional knowledge systems (TKS).
   - Identity & Positionality in Science: Students' self-identification as scientists and references to culturally relevant STEM role models (SRM).

2. *Engagement with Physics Ideas:* This second framework focuses on students using their cultural resources to engage with physics concepts. It captures these diverse engagements through three areas:
   - Epistemological Orientations, which are: Experiential (EE), Practical (PE), Narrative (NE), Authority-Based (ABE), Mechanistic (MEC), or Relational (RE).

- Modeling, which is: Culturally Situated Analogies (CSE), Pictorial Representation (PR), Mathematical Modeling (MM), Gesture-Based Modeling (GBM), Code Switching Between Models (CSBM).
- Sensemaking, which is: Problem-solving with Everyday Intuitions (PSEI), Bridging Everyday and Scientific Concepts (BESC), Counterargument or Reframing (CR), Personal Identity Connection (PIC).

Both coding frameworks were applied iteratively through several rounds of analysis by multiple researchers. Each cultural resource and form of engagement was assigned a code using its respective acronym from the coding schemes. The process involved independent coding of student responses, followed by collaborative discussions to resolve discrepancies and refine code definitions. This approach allowed the research team to ensure consistency in interpretation and to strengthen the reliability of the coding.

IV. FINDINGS

In the findings section, we report the frequency of codes for each assessment question, as well as the most common co-occurrences of codes, which are patterns where specific cultural resources and forms of physics engagement appeared together across student responses. These pairings were identified through iterative analysis and helped illuminate how students' cultural knowledge supported different modes of sensemaking.

A. Capacitance Question

Twenty-six students consented to having their responses analyzed.

Cultural Resources: Everyday Analogies (EA) were the most frequently utilized cultural resource, appearing 24 times. Students used familiar experiences to explain capacitance, such as filling up a balloon or a bucket with water, a freezer preserving food to keep it fresh, and a slingshot being stretched before release. These analogies helped bridge abstract physics concepts with tangible, real-world experiences.

> *"A camera flash. When you take a picture with a flash, the camera's capacitor slowly charges up and then discharges all at once to produce a bright flash."*
>
> *"A sprinter at the starting line. They are built up with energy, but can only sustain energy for a short time."*

Community Practices (CP) appeared four times and Cultural Artifacts (CAT) appeared three times. For CP, one example response was:

> *Capacitor: A good analogy for a capacitor is the scrub daddy sponge I use to clean my dishes. The scrub daddy initially soaks up low amounts of water and soap over a period of time, and then when I wash my dishes, it rapidly "ejects" the soap and water as I squeeze the sponge.*
>
> *Battery: On the other hand, a good analogy for a battery is the Pedialyte I drink at my Powerlifting meets. This is because I try to consistently drink it throughout the course of my competition in order to adequately maintain my body's stores of electrolytes.*

Cultural Engagement: Culturally Situated Analogies (CSE) appeared 13 times and Bridging Everyday and Scientific Concepts (BESC) appeared two times. Many other responses included cultural resources without deeper engagement.

Co-Occurrence Patterns: EA and *PN* occurred seven times, highlighting connected everyday analogies with their prior knowledge. Additionally, pairings involving *CP* with *EA* (4 occurrences) and *CAT* with *EA* (3 occurrences) indicate that students frequently integrated community-based knowledge and cultural tools with relatable analogies.

B. Electric Field Question

17 students consented to having their responses analyzed.

Cultural Resources: Students frequently used Personal Narratives (PN, 18 instances) and Everyday Analogies (EA, 16 instances), which were the predominant cultural resources.

> *"When I get out of my car and close the door, it shocks me. The electric field drove electrons from me to the car door."*

Additionally, Cultural Artifacts (CAT) appeared seven times and Community Practices (CP) three times, suggesting significant engagement with culturally relevant tools.

> *"When we send letters for birthdays through the mail, we are sending a "charge" of our emotions out into a field spanning miles away. Eventually, the recipient feels the impact of your letter, despite the distance."*

Cultural Engagement: The most common codes were Experiential Epistemic Orientation (EE) with nine occurrences, Code Switching Between Models (CSBM), and Bridging Everyday and Scientific Concepts (BESC), each with eight occurrences.

Code Co-Occurrences: The most frequent pairing of cultural resources identified was PN and EA, occurring 16 times, highlighting the use of personal experience with analogies. CAT with EA and PN each occurred seven times. Additional

pairings included EA and PN twice and Local Problem Solving (PLC) with PN once.

For cultural engagement pairings, there were consistent co-occurrences among EE, CSBM, and BESC, each appearing together eight times. One rater did not record pairings for cultural engagement.

C. Power Question

For this question, 40 students consented to having their responses analyzed. The task asked them to reflect on the electrical energy and cost required to prepare a personally meaningful dish, focusing on how they used cultural resources in their reasoning.

Cultural Resources: Students frequently drew on deeply personal and cultural experiences when describing the significance of their chosen dishes and the energy required to prepare them. The most common codes were Personal Narratives (PN, 35 instances), which were reflections on family traditions, emotional memories, and experiences related to food. Cultural Artifacts (CAT, 24 instances) were also prevalent, where students referenced culturally specific foods, such as dolma, kibbeh, and sarmale, often tied to intergenerational traditions. These patterns suggest that food can be used as a meaningful entry point connecting cultural identities to physics-related tasks, such as energy.

Cultural Engagement: Students engaged with physics ideas in culturally grounded ways. The most frequently used epistemological codes were Experiential Epistemology (EE, 22 instances), which were based on insights gained from hands-on or observed experiences. Narrative Epistemology (NE, 15 instances), where students used storytelling to connect physics ideas to memories of cooking. Relational Epistemology (RE, 10 instances) where students used relational frames to connect food, energy, and identity.

> *"Corn soup isn't just another soup, but a piece of my culture... this process is a way to practice my culture and traditional ways... I think of my grandparents, my great grandma … and my whole community each time I eat the dish or reminisce."*

This student's reflection drew on multiple cultural resources, including Traditional Knowledge Systems (TKS) and Cultural Artifacts (CAT), as well as Experiential Epistemologies (EE), Relational Epistemologies (RE) and Personal Identity Connection (PIC, among 20 total instances), demonstrating how physics contexts, when made culturally relevant, can validate and amplify students' sense of belonging, purpose, and identity within science learning.

Code Co-Occurrences: The most frequent code pairing was PN and CAT, appearing together in 24 responses. The following most common pairings were PN with EE and PN with PIC, each occurring 22 times. CAT and PIC appeared together 16 times, indicating that tangible cultural artifacts were frequently invoked to express deeper identity ties. Other recurring co-occurrences included CAT with EE (15 times), EE with PIC (12 times), and PN with NE, PE, and CSE (each 6 times). These patterns suggest a robust interplay between students' cultural roots, lived experiences, and cognitive engagement with physics concepts, particularly when prompted through situated tasks such as calculating energy in personal cooking.

V. CONCLUSION

This study highlights the value of culturally grounded formative assessments in revealing the diverse ways students use cultural and epistemic resources to make sense of core physics concepts. Across questions on capacitance, electric fields, and power, students drew on personal knowledge, everyday analogies, community practices, and cultural tools to engage with abstract ideas.

For the capacitance and electric field task, students frequently used everyday analogies and prior knowledge, linking lived experience and formal physics reasoning. Some responses also integrated community practices and cultural artifacts, such as coffee machines or traditional cooking tools, showing how students connect familiar, embodied knowledge to physics principles.

In the power task, where students calculated the energy cost of cooking a personally meaningful dish, we observed the richest expressions of cultural and epistemic diversity. Students drew on personal and ancestral stories, hybrid food traditions, and professional work experiences to contextualize concepts such as power, energy, and efficiency. These findings indicate that when assessments invite students to draw from their own cultural knowledge systems, their responses reveal a wide range of epistemologies, narrative, experiential, procedural, and relational that are typically marginalized in conventional physics classrooms.

There are growing calls within physics education research to design instruction and assessment tools that not only affirm students' identities but also broaden the disciplinary epistemology itself. Future work should continue to explore how culturally grounded assessments can be implemented at scale, how they impact students' sense of belonging in physics, and how teachers can be supported in interpreting and responding to culturally rich forms of student reasoning [10].

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