Students attribute myriad cultural factors to their sense of physics

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When students describe physics, they often associate this science with facts, formulae, and objectivity. Unfortunately, STEM classes often overlook cultural influence or describe culture as a historical and static phenomenon. This can inhibit connecting physics to students' experiences. In our research, we asked students to reflect on their sense of the nature of physics and how their own experiences influence their perception. We used a phenomenographic qualitative analysis to investigate introductory physics students' reflections at a two year college, identifying emergent themes. Students described four cultural factors including connections to mathematics, media, humanities, and social upbringing as impacting their perspective of objectivity in physics, but only social upbringing for subjectivity. We hope to show students that their individual background is key to shaping their learning, which could lead to a more inclusive environment for a broader population of students.

2024 PERC Proceedings edited by Ryan, Pawl, and Zwolak; Peer-reviewed, doi.org/10.1119/perc.2024.pr.Carter

I. INTRODUCTION

Physics is commonly perceived as an objective science, justified and explained by mathematical principles and empirical evidence [1]. This view implies that physics is free from human influence and ruled by universal laws. However, this common perspective, found propagating through many classrooms, overlooks the cultural background that shapes humans' understanding of physics [2-3].

Researchers have long studied the "culture" of various groups. Often, those researchers presume to be observing from "outside" the culture and feign objectivity in their studies. Historically, culture has been defined as a static "complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of society" [4]. Research methodologies such as this neglect the perspectives of the members of the group and assume a static definition of culture that neglects the range of elements that add to someone's cultural identity. Today, researchers like Ladson-Billings embrace a more dynamic view of culture, recognizing it as an "amalgamation of human activity, production, thought, and belief systems" [5]. This broader interpretation gives us an adaptable understanding of culture, by acknowledging that it is more than just traditional concepts related to groups of the same nation-states, ethnicities, or religions. We use this expansive view of culture, including a broad range of experiences in school and community, to account for evolving perspectives that can change with a person's life and societal events.

Recently, several preliminary investigations delved into how physics instructors understand cultural connections appearing in their classrooms, and how they can implement culturally responsive pedagogy (CRP) [6-8]. Grassroots efforts to change the dominant narrative of whiteness in physics have also emerged from physics instructors in recent years [9-13]. However, past research has done little to investigate how students' own cultural backgrounds, including their experiences with the current educational system, affect how they interact with physics content and culture. In this paper, we present the result of a preliminary exploration asking, what, if any, aspects of students' culture affect their view of physics?

II. RESEARCH METHODS

We explore how students' culture shapes their perceptions of physics, with the goal of elucidating the possible influence of our students' cultural backgrounds on their idea of physics. Our preliminary study employs a small-scale, phenomenographic research design with emergent theming of written student reflections from the first, second, and fifth authors' work [14]. We initiated a pilot study, collecting responses from the nine total students in a second quarter, calculus-based engineering physics class at a two-year college in the Pacific Northwest. Prior to any explicit discussion in class about physics culture, we asked the following questions:

1. What is your sense of physics in your own words?
2. Do you think physics is objective (fact-based) or subjective (influenced by humans)?

Students then mark on a spectrum from 0-100% objective/subjective where they believe physics is located.

3. Why? What aspects of your background may have influenced your answer (e.g., past school, how you were raised, etc.)?

The first two questions come from the Underrepresentation Curriculum (URC) [13], and we designed the third question to investigate students' perceived cultural influences on their first two answers. Based on the responses from the pilot study we adjusted the third question to elicit more robust responses. However, in the subsequent study of 26 responses, we found little difference in the interpretation of the revised third question, which included the parenthetical addition in #3, and we therefore analyzed the 34 total responses together. Table 1 combines student self-reported demographics from both classes. We redacted students' names, and binned multiple races including all students who identified as Black, Middle Eastern or North African, Asian, mixed race, or no answer into a single "Other races" category for anonymity.

TABLE I. Race and Gender Student Demographics.

Demographics	Percentage of students
Male	82%
Female	18%
White	33%
Vietnamese	36%
Other races	31%

We acknowledge that all five authors have been in a past physics course at a two-year college where the URC was implemented and thus we have attempted to bracket our own sense of physics and cultural influences while trying to understand the student responses. We see having several authors from the same TYC student population in which the data were collected as an additional form of validation.

We created themes until data saturation was achieved [15], allowing us to iteratively categorize and interpret the data, and identify the pattern of influence of cultural facets on students' views of physics. The first author read and categorized all reflections. These categories were then shared with the other authors and the data was independently coded. We refined our codes by separating students' reflections into categories in which different facets explain their perception of physics as objective or subjective. We achieved an interrater reliability of 83% of all data for our final theming process and resolved any discrepancies through discussion with the authors. For two

responses, we used member checking to clarify with students the meaning of their explanations [16]. Many responses contained more than one idea about their cultural background and in some cases, students identified one facet as justifying objectivity and another facet as supporting a sense of subjectivity. Our categories reflect ideas found in the responses, not singular responses themselves. When a student's response was not explicitly tied to objective or subjective, we referred to their answer in question #2 for clarification.

III. RESULTS

Students described myriad ways in which they saw their culture influencing their perspective of subjectivity and objectivity in physics. In the following sections, we share four cultural themes used by students to explain why they perceived physics as objective or subjective. Table 2 shows the percentage of student responses that explained physics as subjective, objective, or both. We include Table 2 to show general trends, but want to emphasize that the research goal is to identify the existence of students' perceived cultural facets, not to quantify them.

TABLE II. Student's perceptions of the nature of physics.

Category	Percentage of students
>50% Objective	56%
>50% Subjective	18%
50/50 Equally Both	26%

A. Students' cultural facets supporting perceptions of objectivity

1. Strong math connection to physics

Math terminology (e.g.,equations, measuring) appeared in 62% of students' descriptions of physics alongside objectivity. These associations we see as part of students' cultural background in how mathematics is taught and learned in the United States. One student, and all students hereafter are anonymized as "S#," said,

> ***S25:*** *I think that I was raised to search for knowledge and to use logic to tell what is true from not true. I recognized that Physics is mostly objective because of numbers.*

Here, this student "was raised" to associate "numbers" with objectivity, and that because physics uses numbers, it is "mostly" objective. Many other students shared this association by describing physics as: "a mathematical explanation," as "calculating the movements," things that "can be quantified," and as having "facts and equations associated with it." These quotes represent just a few of numerous examples that contain mathematical terms.

2. Media's portrayal of physics

Various media appeared in multiple student reflections. The reflections that shared examples of media influencing their perception of physics all used examples to articulate why they see physics as objective. For example, one student wrote,

> ***S15:*** *I was exposed to science/physics in various ways as a kid: PBS kids cartoons, Highlights magazines, watched MythBusters and Bill Nye in class sometimes. All of these just focused on the concept themselves; didn't really talk about who discovered them.*

This student describes how exposure to science via media "just focused on the concept" and the media neglected to include information about the history of how those concepts were discovered. Media mentioned in other reflections included sci-fi movies, fictional astronomy movies, kids' academic cartoons, magazines, science-related TV shows, and YouTube channels. Recent work studying the relationship between media and science identified media as potentially influential in multiple STEM contexts [17-19].

3. Contrast between humanities and STEM

In our data, physics was contrasted with subjects such as art, philosophy, and English, to emphasize its objectivity. Students referred to their experience with the humanities as subjective - in direct opposition to physics. One student shared,

> ***S2:*** *Most formulas and reasoning occurs due to how things in life work. In learning, most STEM classes are objective and have a correct answer and reasoning, but other topics like English or Art are subjective because anyone can like or dislike it. But math [as a] study has a strict formula. The only thing that we can really control about it is the variables in activities. But formulas are always the same.*

This student uses both the ideas about math from Section A.1 and its contrast with humanities to explain how physics is objective. The emphasis that physics and math have "strict" formulas and "correct" answers is presumably implying that these are not present for English or art, where "anyone can like or dislike it."

Another student, whose self-described background is "one of art" uses similar examples, describing art as "significantly more" subjective and physics as "infinitely" more objective in their response. A student who associated strongly with STEM also used a similar comparison:

> ***S14:*** *I think that physics is mainly objective, because it is about concepts and things that are widely applicable and useful, reproducible, and that focus on numbers and equations. I think there is subjectivity in what we focus on and find are important to study with Physics. My background that influences this could include that I've always been more comfortable with science related subjects than Art (especially English).*

This student has "always been more comfortable with science". They describe physics as mainly objective and describe reproducibility and the use of math as reasons. This perspective of clear contrast was mirrored in multiple

responses, where physics was placed against a said "less objective" subject, such as art and English, to underscore the view of objectivity in the field.

4. Social upbringing

Student reflections indicated a strong influence from family and social dynamics on their perceptions of physics. They employed terms/phrases such as "people say," "I was raised," or "in general," that convey the notion of a general belief or a social norm influencing their view. These factors include familial influences, and various social groups or beliefs, such as political views. Our data shows that students describe people in their lives as shaping their view of physics as objective. For example, this student first described physics as mostly objective, then wrote,

> ***S16:*** *I think common vernacular about physical phenomena, like gravity, weight, force, repel, etc. have influenced what I think physics is. Most of my family has gotten a post high school education so I noticed physics vocabulary isn't uncommon to hear at home. Classes in school have made me think physics is what explains why everything happens around us.*

Having a familial background in the field helped to construct their view of physics, as did previous classes emphasizing physics as a tool used to explain phenomena.

Another student described the explicit, unifying culture of the military as influencing their perspective of physics:

> ***S29:*** *A lot of the training in the military is A + B = C, meaning it has been tested and tested, so you do it this way to get your desired result. This can be from the different angle you shoot a different size round, to a mortar round. It's just angles, gravity, velocity.*

This response illustrates how specific environments, like the military, have shaped their perception of physics. Here, physics is related to mathematical equations that are rigorously and specifically applied to produce consistent outcomes, focusing on reproducible results. These responses demonstrate a strong influence from their social upbringing on their views, citing family or social group.

B. Students' perceived cultural facet supporting subjectivity: Social upbringing

Social upbringing, described in detail in Section A.4., is the only cultural facet that appeared in student reflections connecting subjectivity to physics. Many students who recognize subjectivity in physics cite social factors as significant influences on their perception such as political beliefs, and the impact of technological advancements during their upbringing.

A few students described physics in terms of math and then expanded on these ideas by introducing human influence or interpretation as subjective. For example, one student wrote:

> ***S11:*** *All the physics are developed by humans, so all the equations are based on the understanding from the humans. Maybe they are not always correct, but they are the best answers so far. Taking science classes in middle school or high school and my brother is an electrical engineer - that also affects my interest in physics.*

In this quote, there is a recognition of the possibility of humans being incorrect or limited in understanding, and that the equations used in physics are "based on the understanding of humans." They describe their science classes and brother as influencing their interest (and presumably thoughts about the nature of physics).

A second student more explicitly identifies bias as a part of physics:

> ***S25:*** *...[Physics] becomes partly subjective however because opinionated people interpret those numbers, experiments, etc. Explanations, which are a big part of physics, are subject to the opinions and beliefs of the explainer.*

Opinions, beliefs, and interpretation are all presented as aspects of subjectivity in this quote that builds on their description in IV.A.1. All of these ideas come from how they "were raised to search for knowledge."

Another student discussed how political ideology affects their view of physics, emphasizing the influence of human constructs within academic disciplines. The student stated,

> ***S6:*** *I have leftist politics that tends to acknowledge the human influence in social constructs like an academic discipline. I definitely would have answered differently before developing that kind of worldview.*

Here, the student connects their perception of subjectivity in physics to their political views, which favor a recognition of human impact on fields perceived as objective.

An aspect of social upbringing brought up by only one student was the role of economical and technological changes in shaping understanding of the subjective nature of physics. One student wrote,

> ***S34****: I believe [physics is] directly influenced by humans, because it's due to our ingenuity that these advancements can occur. The desire to make our standard of living more comfortable, while also increasing productivity. Growing up during the Great Transitioning (the era of mobile phones and internet). I saw firsthand the impact it has on society.*

This student writes that humans' "ingenuity" influences physics, describing a positive subjective aspect of physics - humans' interest to make living conditions better. They also describe the conception of "mobile phones and internet" as impacting society. This quote, and others above, showed how family, secondary education, human interest, and other ideologies in which students are raised influence their identification of subjective aspects of physics.

IV. DISCUSSION & IMPLICATIONS

Student reflections about the cultural facets of their background that shaped their perception of physics fit into four themes: physics is connected to math, media's

portrayal of physics, the contrast between humanities and physics, and social upbringing. All these categories were used as justification for objectivity in physics with the exception of social upbringing, which was the only category that students identified as impacting their views of the presence of subjectivity in physics. These preliminary results indicate that a majority of students perceive physics as an objective science, which they closely tie to its quantitative and empirical nature, aligning with previous research [2, 20].

Mathematics is often used by these students as a foundational justification for the presence of objectivity in physics. They describe the precision and universality of the formulae and principles as objective. This aligns with traditional educational settings where math is typically taught as a static, acultural set of prescriptive rules to follow and "after at least 40 years of scholarship…research and practice in mathematics education rarely moves beyond a surface suggestion that culture might be relevant." [21] However, viewing mathematics as objective overlooks human elements involved in the discovery, development, and application of mathematics created using people's own perspectives, models, biases, and cultural backgrounds [22]. We infer that the abstraction from its cultural and historical contexts in learning environments may be inadvertently upholding a false sense of objectivity and reinforcing the misleading idea that mathematics is acultural, thereby ignoring the diverse ways in which different cultures understand and apply mathematical concepts [21].

Students also describe the media's portrayal of physics as objective, with precise, immutable answers. Depictions of physics in the media are often simplified and take away the explorative and imperfect reality of scientific pursuits. The media's distillation of science, without situating it within historical and societal contexts, may lead to misunderstandings or misrepresentations of complex scientific concepts. Such presentations in the media neglect the subjective decisions involved in scientific work, such as interpretation of data, the choice of which questions to pursue, the framing and the application of experiments and results, and the long-standing eurocentricity of the field [9].

Students contrasted STEM with humanities, an example of subjectivity, characterized by personal interpretation. These students did not write about aspects of art that are objective, (e.g., correct techniques and material use). While they brought up the idea that someone could "like or dislike" art, they did not apply that subjective lens to scientific concepts or lines of research. Students instead noted that unlike art, physics is perceived to operate with strict formulas and definitive answers. All of these ideas reflect back to us the way in which the current educational system, and our larger society, portray humanities in contrast with STEM. This juxtaposition of art and STEM highlights the prevalent educational emphasis on specific outcomes within STEM disciplines, often neglecting human creativity and interference.

Students holding both objective and subjective views of physics described social upbringing as influential, citing family discussions about science, an emphasis on empirical evidence in their educational experiences, or household ideologies that value empirical validation as cultural examples. One student described how their military training reinforced the view of physics as objective due to procedures and protocols being designed to have reliable and predictable results. These perceptions indicate that social environments can lead students to view physics as a fundamentally objective field. In contrast, other students pointed to social upbringing as foundational for recognizing subjectivity in physics. Most of these reflections involved discussions of personal biases, cultural contexts of scientific discoveries, and political views.

Students that recognized the role of human influence in all fields were more likely to view physics as subjective. However, Table II shows the majority of reflections did not include acknowledgement of subjective aspects in physics. These students more readily identified cultural facets that support a belief that physics is an objective field.

V. CONCLUSIONS

This work indicates that personal histories and cultural contexts can significantly influence how students see the field and position themselves with respect to it. Students bring to classrooms diverse cultural associations with physics that are both contextual and continually evolving. Attention to both students' culture outside of the classroom, as well as physics culture, can support instructors in better understanding the perspectives of their students.

Using this activity as a starting point, instructors can promote conversations about cultural facets in physics and help in undoing the notion of objectivity in physics. This can support students' identification of the malleable and changing biases, norms, and cultural values in physics. It is crucial for students to be exposed not only to scientific concepts, but also to the historical context in which these concepts were developed, the subjective nature of current research, and the role of political and social issues in science. We see this connection to cultural experiences as emphasizing the necessity of integrating CRP into physics education. Future work can explore how this connection between physics culture and a student's culture might affect those with nondominant identities in learning and research environments.

ACKNOWLEDGMENTS

We gratefully acknowledge Chris Gosling, Kai Bretl, Jackie Dippre, Mathilda Smith, and Patricia Kane for their substantive feedback.

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