Instructors' equity-focused goals shape undergraduate women's experiences in physics

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Using synergistic frameworks such as Standpoint Theory, Domains of Power (DoP), and the Holistic Ecosystem for Learning Physics in an Inclusive and Equitable Environment (HELPIEE), we analyzed how those in the position of power, e.g., instructors, can play important roles in establishing and maintaining safe, equitable, and inclusive environments for students by comparing three studies. This is especially important for historically marginalized students such as women and ethnic and racial minority students in physics. The first study is Johnson's 2020 study using DoP framework to investigate physics culture and identity of students and faculty at a small predominantly White liberal arts college. This study describes a physics department that other departments should try to emulate. The second study is Santana and Singh's 2023 study which utilized Standpoint Theory to understand the experiences of undergraduate women at a large predominantly White research institution and revealed a masculine physics culture in which women felt marginalized. The third study is Santana and Singh's 2024 study which combined Standpoint Theory, DoP, and the HELPIEE frameworks to investigate undergraduate women's experiences at a mid-sized physics department at a small predominantly White private liberal arts college. This comparative case study highlights the differences and similarities amongst three US institutions of different types with regard to their physics cultures and the role of instructors' equity-focused goals in shaping undergraduate women's experiences. These findings can help physics departments contemplate how to improve their own physics culture and make it equitable and inclusive.

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I. INTRODUCTION AND FRAMEWORK

Physics is not only notorious for the marginalization of certain student groups, but also for the masculine nature of its social culture [1–5]. Among the natural sciences, physics has strongly entrenched stereotypes regarding who belongs in it, who can excel in it, and what a "traditional" physicist looks like [6, 7]. For example, based on stereotypes, a traditional physicist needs to be a genius, thus physics is associated with brilliance which is typically attributed to men [8–20]. This masculine culture continues to harm women and ethnic and racial minority (ERM) students who feel isolated from lack of role models and a community that could provide support to them [20–23].

The unsupportive physics culture that does not take into account students' lived experiences exacerbates the negative impacts of stereotypes and biases about who belongs in physics as well as lack of role models. To create a safe and inclusive environment for students, physics instructors must be committed to these issues. Instructors have the power both within the classroom and beyond it. For example, instructors are responsible for setting the tone of what is acceptable behavior for students, how students should be treated, and establishing classroom norms for peer interactions. Studies have also shown that instructor recognition impact students self-efficacy and thus learning [24]. Thus, we aim to investigate the physics culture in different departments through this brief comparative case analysis by using Collin's Domains of Power (DoP) and Standpoint theory, which allows us we take women's lived experiences as evidence to reveal these domains.

II. METHODOLOGY

Here, we compare three qualitative studies using an analysis similar to the one used by Johnson in Study 1, using the DoP and other synergistic frameworks. The goal of this comparative case study is to highlight the differences and similarities amongst these three US institutions of different types with regard to their physics cultures so that physics departments can contemplate how to improve their own physics culture. In addition, making this comparison allows us to situate our previous studies with the work presented by Angela Johnson.

Standpoint theory is a critical theory that focuses on the relationship between the production of knowledge and acts of power [25–27]. It is related to other critical theories which center around the standpoint or voices of underrepresented groups that do not have the same privilege as the dominant group in order to gain a clearer understanding of their struggles. In this framework, the emphasis is placed on the experiences of undergraduate women in physics to understand what physics departments and instructors can do to improve the physics culture such that they feel safe and supported [28]. Thus, their perspective is key for identifying inequities.

Collins introduced four domains as useful to understand how power is organized in a particular context [29]. These contexts are essential for understanding who belongs or who has opportunities. She argued that the four domains to consider are: interpersonal, cultural, structural, and disciplinary. In the context of physics learning environments, the interpersonal domain refers to how students communicate with each other and how students and faculty interact; the cultural domain refers to the physics culture; the structural domain refers to the structure of a physics learning environment; and the disciplinary domain refers to how instructors discipline students in the physics courses and in the physics learning environments in general, if their conduct does not conform to the expected norms.

The HELPIEE framework posits that those in the position of power, e.g., instructors in physics classrooms, have the power to help all students feel supported by carefully taking into account students' characteristics and implementing effective pedagogies in an equitable and inclusive learning environment [30]. Within this framework, if students from different demographic groups in a course do not have similar positive experiences and feelings of being supported, the learning environments are not equitable because those in the position of power did not provide adequate support to level the playing field.

Study 1: Johnson conducted open-ended interviews at a small liberal arts college with 6 undergraduate women majoring in physics, 4 physics faculty, and a focus group consisting of junior physics students. Out of undergraduate women who were interviewed, three were women of color (WOC) and three were White. At this institution, 25% of physics majors are women. During the individual interviews, she asked open-ended questions such as "Tell me your life story in physics." During faculty interviews, she asked questions such as: "What does it mean for someone to be a good physics student? What do you do as an individual to support and teach students?" For focus groups, she asked about students' trajectory in physics, what they like about their physics classes, what could improve, and what ideas they might have for attracting more women to physics. Johnson used the DoP framework to understand the physics culture from the perspective of both students and instructors. She also illustrated elements of a highly supportive undergraduate physics program that support students, especially WOC [31]. This study is of great interest because of the positive elements that both students and faculty describe that other physics departments should try to emulate.

Study 2: Santana and Singh conducted semi-structured, empathetic interviews with 16 undergraduate women physics and astronomy majors at a large research university. At the time when the interviews were conducted, this number of women interviewed represents approximately 60% of the women students in the physics and astronomy department (23% women). Six out of 16 interviews were analyzed for the range of their expe-

riences. Some of the main overarching protocol questions were about students' high school experiences in physics, experiences with college peers and instructors, who or what supported them, and suggestions that might help improve their experiences. These interviews utilized Standpoint theory to highlight undergraduate women's experiences and investigate the physics culture. Study 2 and revealed a masculine physics culture that did not support undergraduate women [32, 33].

Study 3: Santana and Singh conducted semi-structured, empathetic interviews with 7 undergraduate women physics and astronomy majors in a mid-sized physics department at a small liberal arts college in the US. At this college, women are underrepresented in physics, but not to the extent as they are underrepresented at the national level [1], i.e., they make up about one-third of the physics majors. The methodology for Study 3 was the same as Study 2, and used the DoP and HELPIEE frameworks in addition to Standpoint theory. Study 3 showed how women with intersectional identities have greater challenges in navigating an undergraduate physics program in a mid-sized physics department at a small liberal arts college [34].

In order to make this comparison, we began by re-analyzing data from Study 2 using the DoP framework as a lens to analyze the data. Studies 1 and 3 already used this framework during the analysis. During the re-analysis, we discussed how the interview data from Study 2 fell under each of these domains within the DoP framework. Then, we continued to categorize the quotes from each study to describe the four domains and what these data from the three studies tell us about the overall physics culture.

III. FINDINGS AND DISCUSSION

Below we provide examples from each study within each domain of the DoP framework. Study 1 is the only study to also conduct interviews with faculty, which we also summarize.

A. Interpersonal domain

Student-student interactions: In Study 1, one student summarized her interactions with other physics students: "Sometimes I'll be in [the physics building]. So I can just like ask a question. Maybe not my class, but it could be an older physics student that could help me. They're super nice! I think I could ask any of them. We're kind of all in it together, why wouldn't they help me?" It is clear that students can seek out other physics students, whether they are in their cohort or not, to ask for help. It seems like there is this camaraderie amongst all physics students. This peer support can have a large impact, in addition to the peer community being welcoming. Students have a good understanding of what other physics students are experiencing, so they can relate to them. We also see that the physics culture in this department is such that women have positive interactions with other physics peers regardless of their gender, describing them as friendly, and super nice.

In Study 2, there are many accounts of women having negative experiences with their male peers in different contexts. For example, one woman described a male peer as condescending and not someone she would have chosen to work with because he ignored her inputs and "mansplained" concepts to her [35]. She says, "I would say something and he'd ignore it and I would end up being right and he wouldn't acknowledge that...he ignored me, or I would say something... then he would...explain it to me, like the same thing that I said in different words." In this environment, there seems to be a lack of acknowledgement of this woman's contribution towards the physics problem-solving process.

On the other hand, women viewed their female peers as sources of support. One woman says: "...my saving grace that... gave me like confidence and, like the resources that I needed to do well in the major...[is] my group of friends that I have... we've all been in the same class together... [those] people are like my rocks and my support." From this student, we see how women lift each other up and form support systems. The dynamics between these women contrast with those between female and male students. Thus, there is a clear dichotomy between male and female students in this regard.

In Study 3, many women described having preferences for working with female peers, or occasionally male peers only if the two were friends. For example, one student explains that she mostly works on homework with other female students because of the negative experiences she has had with male peers, "I would generally choose a woman because... if me and my partner had different answers... he'd automatically assume that he was right, which wasn't always the case, and to me that just felt like a very male thing to [do]..." Thus, we get a sense that male peers have this aversion or lack of reception toward their female peers' input during the problem-solving process, similar to Study 2. We can infer that in the type of physics culture manifested in this department, female students recognize this masculine behavior and choose to not surround themselves with it.

We also emphasize that in Study 3, a WOC felt perceived negatively by her peers. She claims that not only men who perceive her this way, but also other women. She says, "even amongst a group of other women, there's also been this expectation that I am just not up to par with them, because [of] my racial background...". Thus, this student feels judged by both White male and female peers. Since she is one of the few people of color in her program, it may be extremely difficult to navigate this type of physics culture as this student constantly thinks about how others are perceiving her.

Student-faculty interactions: Several women in Study 1 reported that both female and male faculty are

accessible and used words such as "nice" and "helpful" to describe them. One student said that their research advisor "is like the nicest professor I've ever met." From this student's account, it seems like the physics culture is such that faculty are kind when students make mistakes and help them. Johnson remarked "this accessibility is not a coincidence; the faculty make a deliberate choice" [31]. One faculty member said: "I try and make myself really open to if they have questions – just trying to be around the department, so they can find me and ask me if they have questions." The physics culture in this department is such that the faculty are making an active attempt to be accessible to students, e.g., by being in their office so that students can drop by and ask them questions.

In Study 2, many women discussed how their male instructors created and fostered negative environments in several settings, similar to male peers. For example, a male instructor enforced negative stereotypes about women in the classroom by calling out a group of women who did not complete an assigned reading. She recalled him saying, "*What, so all of you are just in college for the social aspect?*" She added he was "suggesting that they're only going to school...because they want the image... or that they're not really passionate, hardworking scientists." This accusation by the instructor may reveal biases or negative stereotypes about women. On the other hand, a few women reported that they had supportive instructors. For example, one senior student describes how her quantum professor made her feel supported. She described another instructor in a similar way, thus revealing that there are a few instructors that are perceived positively by female students.

Women in Study 3 had more positive perceptions about their instructors than in Study 2 but some students had mixed experiences. For example, one student described her lecture instructor intervening when she was working with a condescending lab partner, but her lab instructor did not. She recalled: "The instructor for my class actually did notice that the student was being very difficult to work with and that he wasn't collaborating with the group, and she spoke to him about it." She explains that her lab instructor did not notice. From this student's quote, we get a sense that some faculty may not go out of their way to check in on students, thus leaving them unaware of any issues students face.

Some women in Study 3 felt comfortable around their instructors and perceived them as helpful. For example, one student explained that she doesn't attend office hours unless she has a specific question. However, whenever she did go, she had positive experiences. She said that going to office hours, "was definitely helpful." After an exam I had a question [about] something I did wrong, so I went and she helped me explain why it was wrong and then guided me through the correct answer." Thus, we also see some variations in the experiences of women in this study. Some instructors are helpful but some are unaware of student issues.

B. Cultural Domain

In Study 1, Johnson reported the culture of students working together in a supportive environment. From the focus group it was clear that students loved the physics building. She asked students "What characterizes majoring in physics?" Some of their responses were: "The physics building." and "Is there life beyond this building? That's the question." Thus, something about the physical space and the physics culture creates a positive environment in which students love to be. Quotes from faculty reveal they believe there are different ways to be a good physics student but in general think they should be able to ask questions, be resourceful, be productive, and happy. Faculty do not expect students to end up as professional physicists, but do expect them to work hard and collaborate with others.

In Study 2, we understand what the physics culture is like not only from student and faculty interactions, but also from how instructors teach their courses. For example, one student explains that in her intro physics courses, her instructors used disparaging language such as: "*This is trivial, and you should know this, right?*" She added: "I felt like the...disrespectful behaviors that compose the culture and physics were taught in my first year at [my college], through professors using this language in their lectures that other people started to pick up on from their use." From this account, we get a sense of how certain negative behaviors can be propagated by professors.

In Study 3, we earlier illustrated through student interactions that the physics culture has several masculine elements such as condescending behaviors towards their female peers or mansplaining. For example, a student shared that despite many of her male peers being helpful, some of them are condescending: "there are others who act like they know it all... they're mansplaining so often in and outside the classroom, there is definitely a culture of mansplaining."

Several women in Study 3 described collaborative work with their peers and some show preference for working alone. However, it is concerning when marginalized students, such as women and WOC, are excluded from these collaborative opportunities. For example, one WOC who was alienated by her peers provides some insight. She explained during group work, "there's usually not a lot of listening happening on their behalf. I think there's this assumption that because I am a woman of color, I don't necessarily have the same background or knowledge as they [do], so a lot of the times I'll bring [up] points and it'll just be ignored." Thus, it may be part of the physics culture in this department that other students do not take WOC or students of color seriously which may further exclude them in group settings.

C. Structural Domain

In Study 1, students reported that their classes are interactive and incorporate group work. One student said: "it's very interactive, instead of just being talked at. It's more a conversation with everybody in the class and the professor than information being thrown at you, because that's not helpful. I think that's...why I enjoy it and I have learned so much from it." Thus, the student enjoys the interactive elements that are structured into class and finds them to be useful in their learning.

In Study 2, most faculty taught in a traditional style, i.e., lectures, while few faculty incorporated collaborative work, such as group problem solving or clicker questions.

In Study 3, many of the women described opportunities for group work during class. However, some women called for their instructors to encourage and incorporate more peer collaboration into the class structure. One student suggested that instructors should change how in-class groups are formed by: "assigning people to different groups and having rotations where people aren't always stuck with the same group but also have enough time working with other people to break down these barriers..." She argued that implementing these rotations would allow students to get to know many people in class and can introduce them to students with different backgrounds, thus "break down these barriers" that may arise due to differences in background or identity.

D. Disciplinary Domain

In Study 1, Johnson reported many instances where faculty were "reprimanding students who failed to work equitably in groups." Faculty members valued that everyone learns during group work, as opposed to working efficiently. One faculty member recalled working with a student who was dominating group work during a lab. She said the student was controlling all the materials and told him that he had to let others participate. She emphasized, "It can't be "I'm either in charge or I'm out of here, guys." " This is an explicit example of faculty members taking action when students do not work according to norms modeled by faculty members.

In Study 2, there is a lack of disciplinary actions from faculty members. The women explicitly call this out in their suggestions for faculty members. One student suggested that instructors should be responsible for establishing and maintaining a positive learning environment. She said, "I want [instructors] to be obligated... to confront the students who [engage in microaggressions] because the problem just isn't with professors, it's with professors and students. Students feel like they can do these things after they see their professors do it." She suggested that instructors should be responsible not only for their actions, but also to confront students who commit microaggressions in their classrooms.

Through faculty interactions and class structure, some women from Study 3 feel that faculty members are not aware of issues of student misconduct and thus cannot take disciplinary action. One woman described how faculty members seem surprised if a student speaks up about not feeling represented in the learning space. She said the student and professor would have a conversation and during the next class, "[professors will] try to make it known to students "*Hey, we should be engaging with each other*," or trying to discretely say...there should be more interactions with individuals that aren't necessarily White or ...women... but a few weeks later it kind of goes back to what it used to be." This suggests that when faculty take any disciplinary action (if ever), the effects are temporary and students revert to their old behaviors. Also, this disciplining may only occur when students complain about something and it is not reinforced.

IV. CONCLUSIONS

We compared three qualitative studies about women's experiences in physics and astronomy and how they reveal different types of physics cultures. Study 1 illustrated an overwhelmingly supportive and positive physics learning environment where students work together and faculty are encouraging and supportive. Study 2 revealed a very unwelcoming physics learning environment where many male students and male faculty members negatively impacted undergraduate women. Lastly, Study 3 illustrated a physics culture and corresponding domains of power fell in between Study 1 and 2.

The three frameworks used in these studies highlight instructors' equity-focused goals in shaping undergraduate women's experiences and can be valuable for contemplating how physics instructors and departments collectively can improve the physics culture and recognize their critical role in improving interactions with students as well as interactions among students with different identities in physics learning environments. Based on the DoP and HELPIEE frameworks, we emphasize that physics instructors have a lot of power not only in their classrooms (structural domain), but also in the physics cultural domain to empower students. Standpoint theory suggests that it is important for physics faculty to listen to women's experiences in physics in order to address inequities. Faculty should utilize this power in and outside of the classroom to support students. The physics department described in Study 1 can serve as a model to transform physics departments, like in Study 2, to be inclusive and equitable for even the most marginalized groups. Furthermore, elements of Study 1 such as having faculty be on the same page regarding how to identify disruptive and condescending student behavior and disciplining students accordingly, and a class structure supporting all students can be incorporated in physics departments of any size.

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