Effects of male-dominated physics culture on undergraduate women

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This research focuses on the experiences of six undergraduate white women who are physics and astronomy majors. Specifically we conducted semistructured, empathetic interviews that reveal how uncomfortable physics environments inside and outside of the classroom, which were often propagated by male instructors and peers, excluded undergraduate women. The women give accounts of the behaviors of their male peers and instructors that influenced the physics culture. We use standpoint theory to focus on the experiences of undergraduate women to provide a holistic perspective of physics as well as identify key issues that these women faced in their undergraduate physics program. We also share the suggested strategies, provided by the undergraduate women, to implement in the future to support current and future undergraduate women in physics and astronomy. Their suggestions are divided between individual and departmental actions. Some of the departmental actions include providing mentoring for women, training sessions, and establishing a code of conduct.

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I. INTRODUCTION AND FRAMEWORK

The underrepresentation of women in physics has been a focus of researchers for decades. Despite this focus, the number of physics bachelor's degrees granted to women has remained stagnant at approximately 20% [1–3], indicating that barriers for women still exist in the field. Many barriers for women and other underrepresented students in undergraduate science, technology, engineering, and mathematics (STEM) disciplines have previously been documented [4–16]. Research also shows that women in many STEM disciplines have lower self-efficacy than men [17–20].

Physics has the worst stereotypes among the natural sciences pertaining to who belongs in it and can excel in it [21]. These stereotypes can be detrimental to performance [22–24]. The history of physics is narrated to students through the stories of brilliant men so that women continue to lack role models. Prior research shows that compared to men, women have lower perceived recognition as a "physics person" from peers and instructors [25–31], which can hinder their academic performance [32] and influence female students' decisions to leave the field [4,5,33,34]. In particular, if women believe that their instructors or peers do not see them as being capable of excelling in physics, it impacts their own beliefs about whether they can excel in physics [30,35–37]. Prior studies have also found that sense of belonging and self-efficacy in physics are closely intertwined [38–40]. Because improving self-efficacy is a multifaceted process [41], creating an equitable and inclusive learning environment that increases underrepresented students' sense of belonging may help increase their self-efficacy and improve their retention [18,19,42–47]. An equitable and inclusive learning environment is critical to ensure that all students succeed in physics [48–53]. Thus, physics instructors and peers play a critical role in a woman's sense of belonging in the physics classroom and, more generally, as a physics major. Since men make up the majority of physics majors and physics professors in a department, they play a large role in establishing the physics culture whether that be inside or outside the classroom. Prior research supports the idea that the physics culture is geared towards a masculine culture, one that perpetuates stereotypes such as *only men can understand physics* [6,22,24,54–62]. This masculine culture disadvantages women as they become isolated from lack of role models and a community that supports them [63–66].

It is crucial to investigate women's experiences in physics learning environments in order to improve the physics culture. Quantitative data are useful for understanding the scope of the inequities, but qualitative data allow researchers to uncover the mechanisms via which inequities are perpetuated. It is through student interviews that we uncover a contextual understanding of how women experience and navigate the physics culture. Previous studies that utilize student interviews revealed that women in physics and astronomy experience hostile environments within physics departments [57,67–69]. In this study, we interview three undergraduate women who are physics majors. Based on their accounts, we investigate the physics

culture, e.g., who the key players are that influence and propagate the culture and how it affects undergraduate women majors.

Our theoretical framework is based upon standpoint theory, which is a feminist critical theory that focuses on the relationship between the production of knowledge and acts of power [70]. It is related to other feminist and racial critical theories in that it centers around the standpoint or voices of the underrepresented groups that do not have the same privilege as the dominant group in order to gain a clearer understanding of their struggles. By using standpoint theory as our framework, we can highlight the voices of undergraduate women in physics and directly receive their input about how to improve the culture in a way that supports them [71]. Standpoint theory is our theoretical framework specifically due to the fact that women in physics are underrepresented and their perspectives can provide more useful insight towards improving the physics culture and undergraduate student experiences [72,73]. This framework will be used to guide our analysis (e.g., the formation of codes and analytic themes). In this research, we focus on how male peers and instructors can contribute to a negative physics culture inside and outside the classroom, which negatively affected undergraduate women in physics. We also focus on the suggestions provided by these undergraduate women on how to improve their experiences in physics.

II. METHODOLOGY

We conducted semistructured, empathetic interviews with 16 undergraduate women physics and astronomy majors at a large research university. At the time of 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).

For this paper we analyzed six interviews out of 16. We chose to include these six interviews in order to obtain a full range of experiences from women who were further in the major (i.e., senior students) who spent more time and thus had more experiences. We also included women who were at the beginning of their physics trajectory (i.e., sophomore students). It is important to note that the university recommends students to declare a major by the beginning of their sophomore year.

Other criteria that we used were to include transcripts from women who mentioned negative interactions with both male peers and male instructors, made suggestions to improve their experiences, and who elaborated on their experiences. 12 out of 16 women mentioned some negative interactions with male professors and 12 out of 16 women mentioned at least some negative interactions with their male peers.

Each interview was an hour long in duration. The interviews followed protocols set by the group prior to conducting the interviews [74]. Each student received a $25 gift card for participating in the interview. We call these interviews empathetic interviews because the goal of the interviews is to understand the experiences of women in physics and astronomy in order to improve equity and inclusion, and the interviews focused explicitly on understanding how the physics culture impacts them. Importantly, with regard to the positionality, the interviewer was a woman of color, whose identities may have encouraged the female students to be more open in sharing their experiences.

We coded the interviews using hybrid coding methods [75]. One of the authors coded the interviews and both authors agreed on the codes developed based on the student interviews. Initially, deductive coding was used based on the interview protocols, but after reading through the interviews, we incorporated inductive coding to encompass different aspects of these women's experiences [75,76]. The codes themselves are inspired by our theoretical framework, the standpoint theory [72,73], in which we center the experiences of undergraduate women in physics in order to understand how to support them and improve the physics culture. The analytic themes (AT) that we used in this paper are as follows:

AT1. Uncomfortable environments created by male peers
AT2. Uncomfortable environments created by male instructors
AT3. Sources of support
AT4. Suggestions for improving women's experiences

These themes lay the foundation for describing the experiences of these undergraduate women in the context of an alienating physics culture inside and outside of the classroom. In this paper, we recount interviews from six female physics and astronomy majors, whose pseudonyms are provided: Mary, a sophomore major, Elaine, a sophomore major, Samantha, a senior major, Maya, a senior major, Hailey, a senior major, and Evelyn, a senior physics major, all of which are white women.

III. RESULTS AND DISCUSSION

A. Uncomfortable environments created by male peers

All six women give various accounts inside and outside the classroom in which their male peers' comments alienate them and cause them to feel inferior. We share the various spaces in which women have unpleasant interactions with their male peers, including the classroom, office hours, study groups, and other shared academic spaces.

1. During classroom discussions

Classrooms are important for incoming students to learn about their peers and expectations for the course. It is concerning when students learn that their peers dominate

classroom discussions, for example, Elaine says that, "all the class discussions are usually like dominated by guys and there wasn't a lot of girls in the class to begin with, so it kind of made sense that the guys would like dominate the conversations… but that kind of really discouraged me from participating, and I feel like my learning suffered because of that." Here we see that women feel disadvantaged in the classroom by not having the opportunity to or not feeling comfortable enough to participate. When women are a minority in the classroom, it may be difficult for them to speak up and make contributions. She adds,"it's kind of intimidating when like the guys are like dominating the conversation… it was always like guys asking the questions and like asking about like certain topics and like to clarify certain things… it's hard because [I felt like] a lot of them were smarter than me and I couldn't even like follow their questions." She felt intimidated by her male peers' overparticipating during classroom discussions.

According to Samantha, another behavior that isolates women is men's high sense of confidence in speaking about physics topics. She shares that men in her cohort "either have the same level of knowledge on something, or maybe I'm even a little more knowledgeable than them, and they will be really confident about speaking about something that they don't have complete knowledge about, whereas I feel like I need to have a really good level of knowledge before I can like talk about something." She believes that her male peers' high confidence can influence an alienating environment which can also perpetuate stereotypes that men understand physics better than women do. This is concerning because students in the class may interpret men's confidence as a sign that stereotypes about who belongs in physics are true, even though this confidence is not based on performance.

Samantha explains other ways her gender affected her experience in the classroom. One reason is because she believes that women are more likely to admit when they have difficulty with physics. Specifically, she states that "the men in my class are a lot more likely to conceal the fact they're struggling than women." When men outnumber women in a learning environment (as in calculus-based courses like Samantha took), struggling with physics concepts becomes an isolating experience. Samantha shares, "it makes me feel like I'm one of the few that's struggling with things, with certain problems." According to Samantha, men did not openly share their struggles; we suggest that this may be attributed to men's pride and the masculine culture of physics.

2. During office hours

Office hours are another space where students can interact with each other and their course instructor. However, male students might dominate these spaces as well. Elaine recalls during her instructor's office hours when "there was also a lot of boys there trying to show off and they asked like very like deep questions… and like stuff that wasn't like really important…" According to Elaine, office hours are essential for asking for help on the homework; however, this is interrupted when male peers derail the conversation to ask questions that might not be within the scope of the class: "I go to office hours to get help with the homework that I needed help with and they'd be asking like totally random questions about like one very, very specific thing and so… I was just kind of like annoyed that they were like talking about something so irrelevant when I needed help with something more tangible but also like kind of was annoying with the professor spending so much time answering their irrelevant questions when I had like actual problems with the material, we were learning in class…" She feels that instructors unequally distribute their time between helping with more concrete questions regarding homework problems and content covered in lecture versus answering other questions that might not be directly related to the course. Thus, the actions of both male peers and instructors can push female students away from instructors' office hours if they do not focus on the actual purpose of office hours for asking questions associated with a course and on creating an inclusive learning environment."

3. In study groups

With regard to study groups, Mary recalls studying with her male peers outside of class. During their study session, she felt that they were ignoring her inputs, not acknowledging them, and that they were not "really interested in what I had to say, or just like, assume their [idea] was gonna be better than mine." Her experiences suggest that male students' biases towards their female peers may interfere with their participation in group discussions. She also describes that as a woman, she feels that she has to prove herself to the men in her cohort, "I feel like I have to prove myself to the boys in ways that they don't have to prove themselves to each other and I feel like I don't necessarily immediately pass the test." Her experience corresponds to physics being a 'boys' club' in which male students push women out of learning spaces. Mary also suspects that her male peers do not see her as a physicist because of her traditionally feminine presentation. She says, "I'm like pretty girly… I like to wear dresses, like do my hair, do my makeup and stuff…and I think those things combined kind of… like right off the bat, you wouldn't immediately assume that I'm good like at doing physics." In her opinion, her appearance does not match that of a traditional physicist and therefore she has difficulty identifying as one. Thus, the masculine culture of physics in which female students feel like they have to "prove themselves" as worthy of studying physics, combined with ideas of who can do physics pushes away students like Mary [69].

Elaine shares a similar experience during which she used to collaborate with male peers in a larger study group. However, she felt that, "…my opinion is never very valued

I feel like if they like asked a question, I would answer it and they would like double check with a guy like wouldn't take my word for it, whereas if, like they asked the guy to begin with, they would have just you know, [trusted them]." Elaine regularly experienced this type of gender bias from her male peer group as they did not trust her input and second-guessed her ideas.

Maya describes how whenever she struggled with concepts, she would use various resources and work within study groups. However, she notes in the past that, "if I ever got stuck on homework problem I probably would never ask most of the male students here… In the past there have been incidents where it's like, '*You're kidding, you don't know that?*' stuff like that, that makes me feel like I should [know], and then I since I don't, I [feel] like don't belong there I'm like, '*Why am I studying physics if I don't know this simple problem that suddenly everyone seems to know?*' " Clearly, these condescending remarks decreased Maya's self-confidence and made her question her own ability and whether or not she belongs in physics. In addition, we see how comments like these made by male students can affect who women choose to study with.

4. In shared spaces

Not only are these undergraduate women excluded from study groups which are composed of their male peers, they also are pushed away from common spaces, such as the physics lounge, a space where undergraduate physics and astronomy students can study and socialize.

Samantha explains that the student lounge is intimidating for her female peers because it is, "men's home base for like doing work and so [female students] know like, '*if I go there, this person is going to be there and I have to like interact with them.*' " She implies that this study space attracts students who use the space to socialize and potentially perpetuates a masculine culture and could prove to be a negative space for women. Evelyn adds that whenever she went to the student lounge to study, she encountered students who would badger her with questions. She describes a specific experience with a male student in which "he always like, wants to talk about… what class you're in and he'll be like, '*Oh, that class is very easy.*' or like, '*Oh, this subject's very easy, I'm taking the grad level of that class.*' and like, '*That's easy.*' or '*I took that class and… I read all these extra textbooks*,' and like, completely unwarranted too. It's like, you can't really escape these comments." Here we see how undergraduate women avoid common spaces due to male peers dominating the space both physically and with an '*I'm better than you*' attitude.

Hailey shares a similar experience, where she recalls whenever she went to the undergraduate lounge, there would be students who show off. She said there were students "carrying around books on like string theory and like never opening them up and just acting like, '*Oh, I know all this stuff about physics like let's have a bunch of like pointless debates… [and] show how smart we are*,' and stuff like that, particularly with the men… I don't know a single woman in the department that goes in that room and does that; I can't stand to be around it." It's clear that this type of environment in the student lounge, which Hailey describes as a "toxic learning environment," is a very unpleasant one. She says that whenever she used to go to the physics lounge as a younger student, "I would have doubt about myself whenever I was like a freshman and I didn't like know any better that these conversations were just like meaningless like I feel doubt about myself and then like whenever I started to learn better it was still really distracting. So yeah, I don't go in there, at all… I try to avoid it at all costs." It was clear from discussions that if younger students, especially younger women, attempted to tread in this space, it doesn't seem as though they would benefit from it and in fact, may be harmed. This might also be one of the initial spaces where women might go to engage with their physics peers; however, it is very alienating and dominated by male culture that includes "show offs" who always feel the need to engage in debates about their intelligence.

Maya also provides more insight about how men can insert themselves unsolicited into women's discussions. For instance, she says, "That's one aspect of the culture and that's uninviting to us working there, especially if we're like a group of us females sitting there, working on physics problems, specifically for a course that like maybe everyone in the undergraduate lounge is in and we're discussing certain problems there are frequent interjections from male students trying to explain to us how it's working… in a demeaning tone and we didn't even ask them, we're working on it on our own and we're having a private conversation…" In her experience, her male peers felt the need to dominate the conversations even though they were not prompted for help. Maya admits that male peers interject because, "trying to help us but it's not helping at all…" Even if intentions of the male peers is not to show-off necessarily, it may be very uncomfortable for women whenever male students interrupt their study groups to provide their insights on problems.

5. In research groups

Women also had negative experiences with male peers in research groups. Evelyn shares how her gender affected her research experience. She describes a male peer as condescending and not someone she would have chosen to work with because he would ignore her inputs and "mansplain" (mansplaining is a term that describes men explaining something to a woman in a condescending or overconfident way [77–79]) concepts to her. 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 and he would go, '*No, no, no, no,*'

and then he would… explain it to me, like the same thing that I said, like in different words." It is clear that from Evelyn's experience, her male peers did not like receiving input from their female peers even if they were correct. She also recalls a similar experience while working on homework sets with her male peers, during which she suggested different ideas, "if I said I got different answers, [they were] always like, '*No, you're wrong*.' And a lot of times I wasn't wrong, I was right. So it was like, frustrating to have someone constantly, like project that onto me like, '*you're wrong, you're wrong, you're wrong*.'… even when I was right, I never felt as good as I should because it felt like there was still someone who was just like, first instinct was to think that I was wrong." From Evelyn's experiences, we see that the masculine culture of physics is so toxic that male peers have implicit biases against women and their academic contributions. Whether or not male students are aware of their biases and behaviors towards women, the effect is harmful and makes women feel uncomfortable to occupy the same spaces in physics whether in research groups or elsewhere as discussed in other sections.

6. One-on-one conversations

These undergraduate women also experienced alienation from male peers whom they considered friends. One might expect that even though women usually have male friends, that these friends would be supportive of one another. However, these male friends might not be aware of the negative impact they inflict onto women. For instance, Hailey recalls an experience where she talked to her male friend about graduate school admissions, which can be a very intimate conversation for some. She says, "I was talking to a friend about like the possibility [of] getting accepted to grad school and… I …feel …decently like confident about myself as an applicant and I like talked to my… male friend about it yesterday and, just like the way he was talking about like how confident he felt… just the way he spoke like-it seemed like he, like felt pretty …self assured, [that] just like made me doubt myself …a lot…" What was even more troubling for her was that she had expected that the conversation would be empathetic and they would share their apprehensions about applying to physics graduate programs. Based on Hailey's experience, we can speculate how the way male students talk about their struggles may not appear sincere or supportive because they may still be conveying how well-off they are compared to their women friends. In addition, if female students feel marginalized, they might further project their lack of confidence with regard to their success in various physics contexts (e.g., graduate school admission) within private conversations with their peers. Hailey explains that sharing struggles with another person can create solidarity; however, she says, "I was like trying to have an actual conversation with a friend and not just [listen to] someone… talk themselves up but, like in other scenarios like there are a lot of men in the department, who I'm aware of that do things like that, that I just don't engage in conversation with because… I don't feel like sitting there listening to them like how great they are." Hailey indicates that men in the department may not be aware of when they overstep their boundaries or the effect that their words have on female peers. This is alarming especially because many physics programs have men as the majority, so they are influencing one another to continue this behavior. What is important is not their intention but the impact they are having on their female peers.

B. Uncomfortable environment created by male instructors

The students we interviewed were not only affected negatively by peers, but instructors as well. This is particularly concerning, because instructors have the ability to influence the learning environment which affects their students. Unfortunately, instructors can negatively impact the physics culture by perpetuating stereotypes about underrepresented students such as women in physics and astronomy. In this section we share many of the women's perspectives and experiences with male instructors and how they influenced their views of an intimidating and isolating noninclusive masculine physics environment. We wish to note that 12 women mentioned negative interactions with male instructors and no negative interactions with female instructors were mentioned [however one student described not wanting to go to a female teaching assistant (TA) for help].

1. During office hours

An instructor's office hours are an important space for students to be able to ask questions and obtain guidance. Attending office hours might be a barrier for women based on how they perceive their instructor's focus on creating an inclusive space and how they think their instructor perceives them in terms of whether they can excel in physics. Mary recalls that after taking an exam for one of her introductory physics courses, she attended her instructor's office hours for clarification on a problem she struggled on. She says that her instructor tried to help her by prompting her with many of questions, in a similar style to the Socratic method, to help her learn how to approach problems she didn't know how to do. She explains, "he had been talking about… '*you should answer questions until you don't know how and then you should look for ways to figure out how*.' " According to Mary, another student attended his office hours and the instructor, "would [also] ask him questions until he didn't know stuff and then he could go like, learn it and so I was like, intimidated by this other kid in there doing that." Her experience shows that being subjected to an approach similar to the Socratic method can be intimidating for women especially when another student was present and they may become anxious about their ability to

answer questions. Mary may have felt pressured to go through the method, which could be overbearing for some students, even though they see how another student from the dominant group was also being asked similar questions. Had the instructor provided more support during his office hours and created an inclusive environment, Mary might not have felt as intimidated as she felt, which resulted in her not wanting to go to his office hours again.

Elaine shares a similar experience about attending her instructor's office hours. She explains the way he conducted office hours did not result as a positive experience, "I felt embarrassed because I didn't know the answers to the questions he asked me… and I'd have to ask him to explain it in a more basic way because I couldn't follow what he was saying, or like I'd ask him a question and [he would say] '*Oh this person [male student] can explain it to you instead*,' and that was like really embarrassing for me… it made me feel like lesser than people who were supposed to be my peers in some instances and… I felt embarrassed because of that and… logically, I know I should have like stayed to like get help because I needed help with my homework but it just felt like I wasn't supposed to be there that wasn't the right course for me." She adds that having her questions answered by male peers was demeaning: "it felt kind of like degrading having like a [male] peer explain something that I asked like a professor… it felt like my question wasn't like important enough to be answered [by the professor]." It was clear from the interviews that the way that instructors conduct their office hours can impact students even beyond the course, so it is especially important to make sure to encourage students to participate and create a safe learning environment.

Hailey also explains how she felt about attending her instructor's office hours for her introductory electricity and magnetism course. In her account, she describes feeling afraid of asking questions due to her instructor's attitude. She says, "I just did not feel comfortable like with [my instructor] at all. I didn't feel like I could like ask him questions without [the] fear of like being mocked… if I have any questions about [physics], I would talk to my friends… It didn't really seem like [my instructor] cared." This type of attitude pushed her away from directing questions to her instructor. She also describes her instructor's attitude towards humanities majors. Hailey explains that he would make mocking remarks such as, "*They're not as hard as physics*." Hailey also points out another problematic behavior from her instructor, "…he was also the kind of professor that would say… '*All this information is trivial… let me just like say it really fast and like assume that you know it*,' so like I-I just felt like… I didn't want to go and like ask a stupid question to him… even though he's like, '*Oh yeah… come ask me… questions*,' he didn't really seem like he was interested in like helping me, he … seemed like he was interested in… answering like what he considered to be like good… questions about physics whereas… I just wanted to know… how to do homework…" According to Hailey, this attitude exhibited by her instructor during his office hours seemed intimidating, frustrating and confusing: on one hand, encouraging students to seek help but undermining them when he perceived that certain questions are not "good".

Evelyn gives an example in which her instructors belittled her when she attended their office hours, "I've had teachers like mock me almost, or like, scoff when I asked a question." It was clear from discussions with her as to how this type of behavior is alarming and may affect how a student (any student but particularly one from an underrepresented group in physics such as women) views themself in regard to being able to do physics and their sense of belonging in physics. Evelyn provides another example about attending an instructor's office hours. She says that whenever she asked questions, their response would be, '*Well… did you read the book?*' Although she did read the textbook, a concept was still confusing her and she felt that, "… they don't want to help you or… they feel like making you feel bad about not knowing … which in my experience, is not [good] because it just feels bad when your teacher thinks you're dumb." Again, Evelyn's experiences show that instructors can make students feel guilty about not understanding physics concepts and questioning their effort.

2. In the classroom

Within the classroom, instructors can have the most influence over the physics culture via their attitudes and behaviors as they address the entire class. Evelyn explains how instructors' language affects how she felt in the classroom. For example, instructors using condescending language which implies that physics is easy, in addition to classes being mainly composed of men, can affect women's confidence. Evelyn explains, "if you don't think [that physics is easy], you immediately are like, '*Oh, there's something wrong with me… I'm missing this super obvious thing*.' So that's frustrating." Her experience gives insight into how instructors can make students feel guilty and how what they say results in shifting the blame onto students for not understanding physics concepts when it is the responsibility of the instructor to create an equitable and inclusive learning environment in which all students can thrive. In addition, condescending language can cause students, especially women, to internalize these messages and make them not want to communicate with the perpetrators and feel isolated even more.

Evelyn also recalls when one of her male instructors enforced negative stereotypes when he accused a group of women in her class, who did not read an assigned reading, that they were not interested in studying physics for truly developing a deep understanding of it. She says, "called on one of [the women] and she didn't know the answer. And he was like, '*Did you read the book?*' And she said,

'*No, I haven't read it yet.*' And she said no, just like everyone else in the class had and then he was like, '*What? So all of you are just in college for the social aspect?*' And … everyone was just like… Oh, that was a really weird thing to say to a group of girls who were like friends like suggesting that maybe like they're only going to school… because they want like the image or that they have ulterior motives or that they're not really passionate, hard working scientists, which they absolutely are." During the interview, Evelyn's insights suggest that instructors may have implicit biases towards women and stereotypes about why they pursue higher education. She suggests, "… there is some part of him that maybe thinks that women don't take it as seriously as men do and he might not even be aware that he feels that way." This could be the case for other instructors as well and voicing these negative opinions about female students in front of the entire class would be detrimental due to their behaviors enforcing negative stereotypes.

3. Advising sessions

Undergraduate students are required to participate in advising sessions with an undergraduate advisor whose main role is to guide them in choosing courses during their undergraduate trajectory.

Interviews suggest that although these faculty advisors are supposed to help students, some of them might hinder them from enrolling in courses that they are qualified for. Evelyn retells an experience from one of her female friends who is a physics major. She said that her friend anticipated enrolling in a computational methods in physics course in addition to other core physics courses. Evelyn said that their undergraduate male advisor was, "telling her like she's really going to struggle with it like it's really difficult and like he doesn't think that she should take it with like another core class… and she was really offended because… he like doesn't typically say that to [men]." Here Evelyn notes that this advisor explicitly treated male students in this situation differently from female students. She explains that the friend responded, '*why does he think that like, I'm not gonna be able to handle this like coding class*?' Again, we see subtle hints of negative stereotypes against women in physics. Even though this might appear as a normal comment from an academic advisor, Evelyn shares that, "it's particularly strange because… her [undergraduate] research [involves] coding. She codes in Python, you know, every day for hours, and she's really, really good at it. So it was, it was weird that he would like, kind of assume that she's gonna really struggle with this class and [that] she couldn't handle the workload with other things." Thus, in this case, despite having justification for enrolling in this coding course and having experience in coding, the advisor discouraged her from enrolling. This could be due to some implicit biases against women or simply not trusting the female student's own research experiences that justify her in enrolling in the course at that time. Unfortunately, an academic advisor can influence not only the trajectory of a student's degree, but can also enforce stereotypes about them, such as women not being able to succeed in STEM courses. Evelyn also adds, "…he did it again this semester, he was like, '*I think you should wait on that class, because… coding is very difficult*' and she's [taking] it now and [she says] it's a breeze.' " Evelyn's female peer was able to take this course albeit later than she wanted, and she excelled in it. However, not every women has been fortunate enough to overcome such biases and persist despite their pervasiveness.

4. Creating culture

Samantha noticed that before she began her undergraduate career, she never encountered instructors' disparaging language. She explains that when she began her introductory physics courses during her first-year, she noticed that her instructors used phrases such as "*This is trivial, and you should know this, right?*" We note that it is the impact of these phrases that matter, not the intention of the instructors. She also observes that after her instructors used phrases like these in her classes, her peers began using them as well. Furthermore, Samantha adds, "I feel like it's something that's almost like, also taught along with the curriculum is like, this is how physics culture is in those first, like, couple of physics classes you take in college." Her insight implies that instructors have a large influence in setting the tone and environment, i.e., physics culture, in classrooms and even perpetuate stereotypes that physics is easy. This can make students, in particular, those from underrepresented groups such as women, feel like they do not have what it takes to excel if they are struggling to solve physics problems. Samantha also emphasizes, "I felt like the… disrespectful behaviors that compose the culture and physics were taught in my first year at [my college], through like, professors using this language in their lectures that other people started to pick up on from their use." She emphasized that male students might see their instructors as role models to some extent. Therefore, when instructors use words or behaviors that are derogatory towards students who are at risk of being excluded, male students can adopt and propagate the same words and behaviors. Despite instructors having a responsibility to create a safe learning environment, their behaviors can be harmful towards women.

C. Sources of support

1. Female peers in physics and astronomy

Many of these undergraduate women noted that they found comfort and support from their female peers. Not only would these women support each other academically, but they formed friendships which they said sustained them throughout their undergraduate program. Support systems can be crucial in keeping women in physics [80].

Maya says that her friend group, which Hailey is a part of, has developed over the four years that she has been at her college. She explains, "…over the years, like there was maybe four of us [women] who stuck together from intro physics and now that we've come into the later years [of our degree]… we've added the other three [women]… mostly we work together, and now we have [shared] classes so like we know each other, so it's all worked out." Forming these friendships has benefited her and helped her succeed in classes.

In Hailey's interview, she shared that her female friends were a major source of support for her during her undergraduate career. She explains the validation and positive recognition working with her female peers and how they increased her self-confidence, "I definitely do notice a difference whenever I talk to my women friends about [physics] because… I always feel like very… uplifted and like supported and… confident whenever I work on it with them." Working on physics problems with her female friends was a positive experience for Hailey and the dynamics between these women was such that Hailey felt confident in her ability to do physics problems after having studied with them.

She compares working with one of her male friends versus working with her female peers. She says, "I consider to be… close friends [with him], like I don't think they were trying to put me down or anything like that, like the one who made me… feel doubt[ful]." Although she didn't elaborate further as to why working with her male friend didn't seem to have similar positive affects as working with female friends, there may be a variety of reasons for this phenomenon.

Hailey also delves into how much emotional and academic support her female peers provided her throughout her years at a large research university. She says, "…my saving grace that… gave me like confidence and, like the resources that I needed to, to do well in the major… overall [is] my group of friends that I have. I have such an amazing group of four girls that we've all been in the same class together… [those] people are like my rocks and, like my support." Again, we see how the group of friends that Hailey and Maya were part of have acted as a support group for one another through physics and other college courses. Hailey further explains that within her group of female friends, they became role models to each other which boosted her self image, "…these four girls that like I look up to like academically…there's like a lot of mutual respect that we all have for each other, and… they have always been there for me like if I ever need help… not only like were they there to help, but… [they were] really supportive and… saw potential in me that I didn't see in myself and like they believed in me… my… intelligence and… my ability and, … my work ethic, and… I basically just… lived up to the standard… that I felt that they saw me as." It seems like women friend groups had a large impact in fostering inclusive learning emotional spaces for Hailey and her friends.

2. High school friends

Another source of support that women reported was high school friends. Having friends from high school can be beneficial because these friends might have supported them before through hardships so there is some sort of foundation for their friendship as they transition and continue through college.

Elaine emphasizes the role that her high school friends had in supporting her through college. She admits, "I don't know if I'd still be here if it wasn't for my friends from high school too, because… I'd be like, '*I want to major in physics and astronomy*,' and they'd be like, '*Yeah that's so great! You're so smart, like you can totally do it!*' It was always just really good to feel like people believed in me and like supported me… everyone at my school was like really close because we [had] a small class, so I like kind of knew everyone, and they knew me and we were all like real supportive of each other and like what we wanted to do with their future but …it's different in college." Here we see how the close-knit friendships from her high school encouraged her to continue to pursue an undergraduate physics degree. She also elaborated on how these close-knit friendships differ between high school and college.

Hailey also highlights how the support she received from high school friends sustained her. She shares, "…my friend group that I hang out with a lot in college, like, I have, like, my physics friends who, like, those are separate and like, from other organizations I'm in, like, I have like my main friend group is almost entirely comprised of people that went to my high school." More specifically, many of her high school friends were in her AP physics class and went to the same university as she did, "…we stuck together but yeah, we've been friends for a long time and we just all ended up coming to [my college]." She credits these friends to making her transition from high school to college easy in the sense that she had a supportive community in college from the very beginning even before she got to know others.

3. Instructors

The undergraduate women also shared that some of their physics instructors, specifically professors, provided encouragement to them during their office hours which they appreciated.

Evelyn explains when one of her physics instructors supported her during her struggles. She says, "I had told him how I had like a rough freshman year and stuff and he was just always so supportive, and was proud of me for doing well in this class and stuff… he made me feel so much better. And then he had me as a undergraduate teaching assistant (UTA) in his class." Encouragement and support from an instructor can improve how students

perceive themselves and for Evelyn, this improved while she was in his class as both a student and UTA. According to her, he implemented a type of mentoring program where, "people who like felt anxious or like insecure in class, or feel like they might struggle could get to, like, have someone to just talk to about stuff." Evelyn became a part of this mentoring program as a role model. Her instructor perceived her as one, and she explains, "…he just felt that since I'd struggled and then… found my way back, like, I'd be a helpful… comeback story for other students who might be in the same position, like, if they had had a rough freshman year or had failed the class before and were scared about it now and feeling bad about themselves, like he totally like changed the course of my physics career." Thus, instructors having positive perceptions of and interactions with their students can result in students feeling confident about themselves in a way that can encourage them to succeed in physics.

Hailey explains how one of her physics instructors encouraged her and reassured her. She shares that her quantum professor does, "…an excellent job at like, seeing like, what the students want and like making sure that they're understanding what he's saying, so I feel like really supported in that environment, especially like [when I] go to office hours, and they are encouraging." According to Hailey, this instructor is receptive to his students and this could make it easier to attend his office hours. She further explains, "…this professor literally said to me, '*I think that you're… struggling with some of... the complex …math stuff but you're like good on the concepts, like you're doing well, like for where you should be*' ". Here the instructor not only identifies the areas where Hailey struggles in the class but assures her that she is doing well. She says that talking to him, "…was really encouraging because… quantum is like difficult for me at this time and, like it would definitely be easy to just like feel overwhelmed and like feel like I wasn't capable [of] doing it, …the fact that this professor literally was like, '*No, like you, are doing well…and you're capable of doing this*,' like it just makes me want to like try so much more, and it makes me feel like I really am capable of doing it…" Hailey's self-efficacy might have increased during this interaction since she felt supported by her instructor, someone who has influence in the classroom and can make an impact on her identity as a physicist.

It is also important to note that Hailey said that this type of positive attitude and behavior was more common among her astronomy professors. This dichotomy may be due to the fact that the culture that astronomy fosters may be more inclusive and supportive than the physics culture based upon representation of women, even though there is room to improve the astronomy culture as well [81]. She said that because this attitude was exhibited by one of her core physics course instructors, it felt unusual but it encouraged her such that, "…I like enjoy the class so much more and like I feel really motivated to study, especially compared to like my other … core physics classes…" She also notes that her math methods instructor was very similar in this way by being supportive when students had questions. Overall in Hailey's words, the effect that these types of instructors had, "…just like makes a difference in how well I feel like I can do [in] the class." Thus support from instructors can influence students' self-confidence, interest, and mindset in the classroom and help them feel supported academically.

D. Suggestions for improving the experiences of women in physics and astronomy

When asked about how the physics and astronomy department could be improved, the women provided several suggestions. Here we separate the actions into two categories, individual actions (what the women can do to potentially improve their experiences in physics and astronomy, recognizing that there is a long road ahead to improve the physics culture) and departmental actions (what physics instructors and departments can potentially implement to improve women's experiences in the major). First we address individual actions that the women suggested and endorsed.

1. Individual actions

Working one on one: Although not very confident, Elaine suggests that it might be easier to work with male peers individually at least sometimes rather than in a group. She says this based on her experience working one-on-one with a male peer, during which the peer did attempt to express his opinions although "…he makes an effort to like be good… if that makes sense, which is what I appreciate… certain times where [we] will like disagree on a problem, and he, like will try to see my side of it and just explain like what he did…" This can be beneficial in some cases; however, Elaine suggests that working one on one with male peers may not always work based upon her overall experiences with them.

She feels conflicted about her initial suggestion and further explains, "I don't know [if] it's easier to work like one on one with like one guy as opposed to being talked over by a group of guys that can reinforce each other."

Sitting in front of the lecture room: One of the suggestions that Maya makes is to sit in front of the lecture room. She implies that it can relieve women from feeling anxious by looking at men and watching their antics in the classroom. She says that her friend group including herself sit together in the front of the room, "…I think also that's one thing that will help any woman coming in just go sit in front, because you won't see anyone… and you can just focus on learning the material, I found that super helpful." Sitting in the front row can eliminate the feeling of being surrounded by peers, especially if the majority of them are men. It also can remove distractions from male peers so that the women can focus on the content better during lectures.

She also shares that sitting in the front of the class leaves positive impressions on the instructors. She explains that when a student sits in the back of the classroom, "… maybe you're not paying attention and professors don't see you as much." In contrast, "When you're in the front, they know you're attending class, they know you're engaging in the… discussion, and, you know, it's more likely that they remember you." Thus, according to Maya, sitting in the front of the room can improve how instructors perceive their students. For Maya, recognition and acceptance from an instructor is positive experience, "…it's always nice to get to know your professors. They at least know that you're like engaging [in the material or] class, [then with regard to] end of semester …grades, you know if you're on the verge and they know that you've been trying and asking questions …it always helps to have like known face."

Attending office hours: Maya also suggests attending instructors' or TAs' office hours as a way to connect with others and hopefully be a part of a positive learning environment. In her experience, going to office hours introduced her to other students in the classroom, thus increasing her social circle. Also being at an instructor's or TA's office hours (when the learning environment was supportive) was a place in which, "…you're all working on the same thing with your TA and it actually like opened up the atmosphere to like you,… you know, you're all struggling on the homework assignment, so it makes it easier to ask questions and engage with other students who you might not have just gone up to ask a question." In a way, attending instructors' and TAs' office hours can clear the air and show them how they aren't alone in their struggles. For instance, she says, "…everyone tries to make it like they understand what's going on in classes… you really try to make it seem like you know what's going on and usually, when you walk out of that room or go to office hours, you realize that no one really understood what was going [on], and then you kind of have something to go off and work together on." This can be a good way to break down students' confusion and struggles as a normal part of learning physics to the point where they can voice their current state of understanding about homework problems during the office hours. This can also combat the negative stereotypes about physics if even male students were more willing to admit their struggles during the office hours and thus make the physics learning atmosphere more inclusive and comfortable to engage in.

Connecting with other women in class: Maya suggests that reaching out and connecting with other undergraduate women in class can improve their well being and sense of belonging. She says that for her, this was an intuitive act because, "…as a woman, you try to go immediately [and] talk to the other women that are in the room… most of us prefer it just because the [current physics] atmosphere… it's not as welcoming." She implies that these social circles that are composed of women encourage a positive culture and supportive atmosphere. Hailey and Maya both eluded to this when they explained how their friendships with other female physics peers improved their experiences in physics.

Instructors being mindful of phrases: It is clear that instructors' words can have a large impact on women, in both a positive (supportive culture) and a negative way (negative culture). Hailey suggests that instructors should be mindful of specific phrases they choose during lectures. She suggests that, "… telling [instructors] to never use the word *trivial* in class because,… the simplest of things…like something small, that a person just isn't like [knowledgeable or aware] of, [and] the professor like dismisses it as trivial…" She implies that it also is not fair for instructors to skip over pieces of information that students might not remember or know, which could be essential when discussing a problem. Hailey also explains the lasting impact that the phrase "trivial" has, "…in a second [it] has the power to make a student feel like, like they're like missing something that everyone understands, which just makes you feel isolated, like it can bring self doubt, like that attitude I just think like never belongs in the classroom." Eliminating these types of phrases can encourage a more inclusive learning space, especially if instructors are intentional and aware of the impacts they have on their students.

2. Departmental actions

Restructuring office hours: According to Elaine, instructors and TAs can make a positive impact by restructuring their office hours in a way that allows them to be more aware of their actions. She hopes that office hours could, "…focus on like the material that we learned in class…" She justifies this as an essential action to implement because she had a similar experience to Elaine, during which she had to sit through her instructor address a student's question that was not relevant to the lectures and, "I just sat there for an hour like trying to interject but, like my TA just kept like going on and on about this like irrelevant subject… I just feel like… those questions shouldn't be prioritized… I feel like there should be a way to prioritize… homework questions or like an alternative." If instructors were able to set boundaries on the types of question they were willing to answer or more evenly distribute their time amongst the types of questions that were asked, this might be a more equitable and inclusive use of office hours. She says that this would work when the instructor, "not accidentally embarrassing anyone or making them feel dumb for asking [the instructor] a question, or… answering it completely instead of giving just a tiny bit of information." This inclusive approach to office hours may validate more women and encourage them to ask the types of questions they would like to ask.

Mentoring and increasing visibility: Since undergraduate physics programs are composed of roughly 20% women, it may be common for women to feel isolated

as they may have difficulty meeting other women. Mary suggests that it would be beneficial to get to know more women in the department. She explains that this could be done as part of the mentoring program that the SPS chapter at her university could implement. She says, "if you like match the upperclassmen women to the younger underclassmen women, then like, first of all they would know that there's other women in the department and there's other women who are like being successful in being in the department." By matching more experienced undergraduate women with less experienced undergraduate women, novice female physicists and astronomers, such as Mary, will benefit from meeting other women in their cohort. The physics department can provide advice and guidance on topics that include tutoring, careers, research, etc., and form a community in which women feel safe. These women will also be introduced to other women such as graduate students and women faculty who can serve as role models and help them navigate physics, and thus help them develop a stronger physics identity.

In addition to one-on-one mentoring, Samantha mentions a social support the physics department had already begun to implement: a club for women in physics and astronomy. Specifically, she views involving men to be important because it may educate them on what women in the department experience. Samantha explains, "I'm hoping that more men… become aware about it, because I think addressing it is very… polarizing like, '*we are women and we're fighting this problem*,' is going to make a lot of people defensive and so I think the fact that we are also inviting men is really good, because I think that it is going to help solve the problem more." Clubs and programs such as these may inspire change within the physics culture by educating students about women's struggles in physics and astronomy.

Accountability for students and instructors: When asked about what the department can do to support women in physics and astronomy, Samantha suggests that instructors should be responsible for establishing and maintaining a positive learning environment. She says, "I want [instructors] to be obligated, when they witness what happens in their classes with other students, to confront them, 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 that-these things after they see their professors do it." She suggests that instructors be held accountable for their actions as well as report microaggressions that may occur within their classrooms. Samantha hints at establishing regulations (e.g., a code of conduct) that would outline how to address microaggressions in the classroom, especially towards marginalized students such as women. Currently as of 2022, the department which these women were part of has implemented a code of conduct to keep its members accountable.

Feedback for instructors: In addition to having regulations about how to hold department members accountable, Evelyn suggests a method for communicating with instructors about their behaviors. She mentions that "there have been times where professors have like said things that I did not think were appropriate and… I've never really said anything, because I was like, '*Well, what's it gonna matter?*' But now I try and use the OMETS [to] be genuine with my feedback and be like, '*this is how I felt in your class and like, this is how I felt other people might have felt.*' " OMETS, short for Office of Measurement and Evaluation of Teaching, are teaching surveys used to gain student feedback about teaching effectiveness. Being able to provide instructors feedback about their course and behaviors may be beneficial by informing instructors about their harmful behaviors that negatively affect women and other minoritized students. This could be a way for students to directly give instructors feedback without putting students in jeopardy before the course grades are assigned. Providing feedback may present challenges if a student knows they are likely to have another course with the same instructor.

Training for students and instructors: Samantha adds that members of the physics department could be required to attend training sessions in order to identify microaggressions. She says, "I think everyone needs [microaggressions] explicitly explained to them, because it's really complicated and people don't get it, whether they're the people… who like are the cause of the [microagggressions] or the people who are the victims of this stuff…people need to learn how to identify it better from the start of their physics career." Both instructors and students should have access to resources and thus be able to identify microaggressions. By educating members of the physics department about microaggressions, it may become easier for students to report acts of discrimination or even stand up for their peers (e.g., via bystander training). Samantha reveals that "if people were talking that way to me [disparaging me]…I kind of confused it with me not being knowledgeable enough about something or like… it was my fault." Properly educating students about harmful behaviors encountered would reduce ambiguities so that female students do not question their abilities in an unsupportive and often toxic physics culture.

IV. CONCLUSIONS

By analyzing empathetic, semistructured interviews with standpoint theory as our framework, we focus on women in physics and their experiences in an undergraduate physics and astronomy program. Empathetic interviews reveal how these women navigate the physics major and the barriers they face. Interviews suggest that for these six women, both male students and instructors often created a physics culture that was dominated by traditional beliefs about who can do physics and who belongs in physics. As a result of condescending attitudes, which are sometimes enabled by

male instructors and carried through by male students who often take cues from the instructors, undergraduate women in physics are constantly made to feel isolated and uncomfortable.

Despite being subjected to an unwelcoming physics culture and environment, the undergraduate women provided suggestions for how women can combat their male peers' and male instructors' hurtful and demeaning behaviors when they encounter them. Their suggestions include the formation of programs and clubs that bring together women to mentor younger women and educate both men and women to work towards reducing bias and discrimination. Another suggestion is to hold physicists accountable in the classroom by creating a method by which students can provide feedback for instructors to inform them about how their actions affect students and what they can do to improve. The final suggestion discussed here is to provide access to training sessions that would educate members of the physics department in order to help male students and peers realize the negative impact their actions have on women. Educating women within the department would also benefit them, e.g., by providing examples of discrimination that they may potentially experience or witness during their undergraduate career and what actions they can take in response to them.

Regardless of whether or not some men in physics intentionally alienate women through their actions, they play a critical role in bringing about change within the physics culture. Based on women's experiences discussed here, men have significant influence in setting a negative or positive tone both inside and outside of the classroom. Thus, one can argue that men potentially have the means by which to improve the physics culture by reflecting upon and combating their harmful actions and learning how to be allies to women.

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