Changing person-environment fit among underrepresented undergraduate physics students: Successes from a small department

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(Received 14 October 2022; revised 10 July 2023; accepted 12 February 2024; published 29 March 2024)

Female students, Latinx students, first-generation students, and transfer students often feel uncomfortable in science, technology, engineering, and mathematics (STEM) environments. However, some departments have been making progress in changing that. Guided by double consciousness and person-environment fit theory, we investigated the lived experiences of historically marginalized undergraduate and masters-level physics students at a large state university to understand how this particular department provides an environment encouraging all students they fit in physics. Graduated students and faculty were interviewed from California State University, Long Beach. Through the interviews, we gained an understanding of significant student experiences and their perceptions of fit in this physics environment. Department community members perceived the department environment to be open, which contributed to broadening fit and supporting diverse students to thrive. The importance of faculty agency in creating a welcoming and supportive physics environment is highlighted. Finally, we found students in this department take with them an approach to physics that they see applicable to other areas of study and their lives. We called this a physics state of mind. We include suggestions for other STEM departments based on the findings and previous research.

DOI: 10.1103/PhysRevPhysEducRes.20.010118

I. INTRODUCTION

In 2018, women earned 22% of physics bachelor's degrees and Native American, Black, Hispanic, and Asian Pacific Islanders earned 11.9% of the bachelor's degrees (excluding international students) [1,2]. One can compare these rates with national bachelor's degree trends. In 2017–2018 academic year, women earned more bachelor's degrees than men for every racial-ethnic group [3] and 24% of bachelor's degrees were earned by Black, Hispanic, and Native American students [4]. So, physics degree attainment is not reflective of the overall bachelor's degree attainment proportions. Some institutions are having more success in supporting female students and students of color than others. One such program was investigated and reported by Posselt *et al.* [5]. The University of Michigan's Applied Physics Ph.D. program has been successful in recruiting, training, and producing a significant proportion of the nation's Black and Latinx physics Ph.D. degree holders. However, as discussed in more detail below, efforts possible by a prestigious Ph.D. program are not applicable to many institutions.

In this study, we contribute to the field's understanding of effective support for underrepresented minority bachelor's and master's students in physics by investigating another physics department. Compared to both the abovementioned national averages and its own past, this department has been successful in attracting and supporting a greater proportion of female and Latinx students. Additionally, the department has been successful in attracting and supporting, as well as increasing the graduation rates of first-generation students and transfer students similar to that of their white, male, continuing generation, first-time freshmen peers. Students who are the first in their families to go to college (referred to as first-generation students and their counterparts referred to as continuing generation students) and students who transfer from 2-year, associate's degree granting community college to a 4-year, bachelor's degree granting university (their counterparts referred to as first-time freshman students) are demographic groups gaining attention by institutions of higher education in general and by science, technology, engineering, and mathematics (STEM) disciplines [6,7]. Through interviews with alumni and faculty and a review of the department's self-study, we identified how the department was creating an environment that was welcoming to the diverse students admitted to the university and the department. This study contributes to the field of education research in two ways.

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First, we highlight the efforts of a department that (mostly) successfully serves bachelor's degree and master's degree physics students, which in turn has contributed to increasing the number of those who pursue Ph.D. degrees and diversifying the STEM workforce. Second, we present recommendations, based on the efforts of this department and connected with previous research, for ways in which other STEM departments may make deliberate changes to their programs.

II. LITERATURE REVIEW

The field of physics education has seen a significant increase in research applying an identity lens to examine the experiences of underrepresented and minoritized students in physics. In a review of physics identity research on university students, Johansson and Larsson highlight that the way researchers conceptualize identity highlights some problems in physics and deemphasizes others [8]. Specifically, when researchers consider identity as a trait or characteristic that one possesses and then in turn questions why some groups fail to develop a physics identity or not enough of a physics identity, the burden of changing falls on the student in physics. In turn, the field or departments of physics are not held accountable for the role that they play in encouraging some and discouraging other students. In this study, identity is conceptualized as developing through interaction within a structural, social, and political context [9] and with that understanding the physics environment is examined to identify the positive forces that pull diverse students toward physics and support them to graduation and beyond.

A. Theoretical frameworks

In efforts to examine the environmental contributions of student physics experiences, this study was guided by two theories. The first theory framing this study is double consciousness [10]. In order to properly research inequities, including racial inequity, it is important to apply a theory centering on race [11]. Double consciousness refers to "this sense of always looking at one's self through the eyes of others" [10]. In other words, the individual is aware of how one is perceived by others. Double consciousness provides an insightful framework for understanding the experiences of historically marginalized students in STEM because students' personal and social identities can contribute to feelings of double consciousness. STEM environments have been recognized as being marginalizing for female students [12] and students of color (see Ref. [13] for postsecondary persistence rate differences among different race-ethnicity groups using longitudinal data). For instance, Black and Latinx STEM students report negative experiences regarding others devaluing their contributions and questioning their abilities, even those who are high performing [14,15]. For these students pursuing STEM, they also have to deal with others perceiving their gender and/or race-ethnicity to be mutually exclusive with someone who is successful in STEM.

Additionally, STEM environments can be uncomfortable for students with other background characteristics. For first-generation students, the traditional competitive culture of STEM classrooms has been linked to their feelings of being an imposter, later dropout intentions, and lower course grades [16]. Also students who start their postsecondary careers at 2-year community colleges often face obstacles when transferring to 4-year institutions [17]. Once students successfully transfer, their adjustment is impacted by faculty interactions and the perceptions of transfer students at the university [18]. Pursuing STEM can be challenging for students with these characteristics and experiences in part due to having to combat the negative expectations held by others, thus dealing with situations that trigger feelings of double consciousness.

Research specifically investigating physics identity has identified the challenges of double consciousness without naming it as such. According to Hazari *et al.* [19], physics identity is informed by one's interest, competence, performance in physics, and recognition by others as a physics person. Recognition, the fourth dimension of physics identity, refers to professors, classmates, friends, and family seeing the individual as a physics person. For underrepresented students in physics (i.e., Black and Latinx, female, first-generation, transfer), regardless of their academic preparation, they are often faced with others holding negative perceptions of their academic abilities (e.g., stereotype threat, biases, and microaggressions) or their other identities are seen as not compatible with being a physics person. In a case study of a Muslim, female, physicist, Avraamidou [20] described Amina, who had chosen to position herself as a "forever-outsider," as a response to not giving up on femininity despite her pursuits in physics. In addition to Amina's gender, her religion was identified as hindering her recognition as a physicist by others. Feelings of recognition inform and are informed by feelings of belonging [21], and one's physics identity is linked to being aware of how others think about one's involvement and place in physics. Therefore, in order to understand underrepresented students' experiences in physics, it is important to understand student perceptions of and experiences with their environment.

There is a dilemma that comes with experiencing this two-ness of double consciousness and Du Bois articulated the reconciliation he would like to see achieved,

> … to merge his double self into a better and truer self. In this merging he wishes neither of the older selves to be lost. He would not want to Africanze America, for America has too much to teach the world and Africa. He would not bleach his Negro

> soul in a flood of white Americanism, for he knows that Negro blood has a message for the world. He simply wishes to make it possible for a man to be both a Negro and an American [10].

Du Bois's desire for the individual to be "both a Negro and an American" represents the way in which all students should be able to exist in STEM, being their whole person regardless of gender, race-ethnicity, first-generation status, transfer status, and more.

In this study, we sought the conceptualization of double consciousness reconciliation in STEM through the lens of person-environment (P-E) fit theory [22], the second theory used to guide this study. P-E fit theory was developed in the field of vocational counseling [22] with the aim to understand placing individuals in employment settings where the individual and the environment are compatible to result in a happy employee who stays with the employer. Over the years, more specific frameworks have grown out of P-E fit theory. One used for this study was the attraction-selection-attrition framework [23]. The core of this framework is to examine "the process by which people are attracted to, selected by, and either leave or remain in organizations" [22]. In other words, students who are attracted to physics will discover whether they are selected by physics through the experiences they have in physics environments, which in turn will determine if they leave or remain in physics throughout college and beyond.

Overall, 26% of STEM students who leave the major fall into the high-achieving category [24]. This statistic suggests that students leave STEM and physics for reasons beyond poor academic performance. The common physics environment in college has tended to equate masculinity with intelligence [25], to value intense competition and individual, solitary work [26,27], and to demand high levels of intelligence that were in the past considered to be unattainable by women [28,29]. Having such an environment limits the kinds of people who feel they fit or are selected by STEM. Interested and talented individuals may not join or stay in the field if they feel they do not have those characteristics or hold the same values. There is support for investigating the kinds of culture and values majority members hold, as research finds both women and men tend to prefer STEM environments that are less stereotypically masculine [30] and less sexist toward women [31]. This extends beyond gender and to other stereotypes as well, such as feeling like only a particular kind of nerd is welcome in computer science (see Ref. [32] for an experiment comparing stereotypical and nonstereotypical lab objects and decorations). By identifying what is harmful to supporting students of diverse backgrounds, we can start to consider what changes can be made.

As far as we have been able to find, there has been only one paper that has examined and reported on a successful physics program. In their paper, Posselt *et al.* discussed an applied physics Ph.D. program that made significant changes to attract, retain, and graduate Black and Latinx students. The program made many direct efforts to change the kinds of students who would come to their program. For one, the program reassessed how they thought of who "the best students" were and reinvented their admissions process. Rather than accepting traditional metrics like grades and standardized test scores, faculty questioned what those high scores represented and looked for "intellectually adventurous students" to admit to the program [5]. Over time, the program director had built connections with minority serving institutions for outreach and recruitment. The program also made a commitment to admit students with nontraditional academic trajectories into a master-Ph.D. bridge program where students received mentoring, financial support, research experience, and gained credit for courses taken [5]. There is significant value in demonstrating that such efforts are possible and have positive consequences. However, for many institutions and departments, these efforts can be difficult to apply or adopt because of the lack of financial and institutional resources and other institutional characteristics, such as possibly not attracting as many applicants as The University of Michigan or not having the same degree of control over admissions because of admission responsibilities to the local community (discussed later in Sec. III as it pertains to the institution for this study). Therefore, more investigations at diverse institutions and departments are needed.

B. The current study

In this study, we examine how students of different background characteristics and identities feel they fit and how faculty perceive student fit in the physics department, as well as how students feel the environment encourages or discourages their academic pursuits in physics. This expands understanding of what a successful physics department may look like and provides the basis for recommendations for other departments interested in implementing change. The study was guided by the following research questions:

RQ1. What departmental characteristics are highlighted by former students as having contributed to their physics success?

RQ2. What were the changes made in the department highlighted by the physics faculty?

RQ3. How do the changes highlighted by faculty correspond with the student experiences mentioned to answer RQ1?

III. METHODS

A. Context

The physics department is housed in California State University, Long Beach. The university is comprised of approximately 86% undergraduate (57% female) and 14%

graduate students (64% female) [33]. The racial-ethnic makeup of the undergraduate students at the university was recorded as 46% Latinx, 21% Asian, 16% White, 5% mixed-race, 4% Black, 6% nonresident alien, and 2% unknown race and/or ethnicity [33]. Among the new students in Fall 2020, 51% were transfer students and 49% were first-time freshmen [33]. The university has a unique commitment to the local community in that 50% of all students admitted are from the local community [33].

The physics department is one of the smaller departments in the college. There were 26 new students enrolled in Fall 2020. About 16 of the students were first-time freshmen and the other 10 were transfer students. In this class, there were 21 male students and 5 female students. The race-ethnicity makeup of the department was 16 Latinx and 10 of another race or ethnicity. As for the graduate physics department, there were 18 new students enrolled in Fall 2020. The majority of the students were male (14 students) and there was no one ethnic-racial group greater than 10 to constitute a majority. Over the past 15 years, this department has made many efforts to support all students: removing bottleneck courses, increasing opportunities for student research opportunities, redesigning lab courses with engagement in mind, and creating a physics student club to help encourage a sense of belonging. These efforts were intended to broaden student enrollment, support student graduation, and encourage postbaccalaureate physics pursuits. According to institutional research data from the department's self-study, in Fall 2014, 50% were categorized by the university as an underrepresented minority which refers to Black, Latinx, and Native American/Pacific Islander students and 27% were women. This was an increase from 2007 when the proportions were 24% and 19%, respectively.

B. Data collection and analyses

To examine the success of the department, the study proceeded in two phases. In phase 1, interview data were collected from graduated students. In phase 2, interview data were collected from faculty. The alumni interview protocol was designed to prompt thinking about the participant's different schooling and later work environments and experiences: starting with high school, moving through community college (for those who attended), undergraduate years, graduate school (for those who attended/attending), and then work. Questions about school were broad ("What do you remember about your physics classes?"). We asked whether the participant was interested in and good at physics. We also asked what kinds of reactions participants received from their friends and family regarding their interests in physics in order to understand the forms of support or lack thereof.

The faculty interview protocol was developed to get an understanding of the individual faculty member's ideas and values as well as information on departmental efforts and faculty perceptions of their role in these departmental efforts. Therefore, the protocol included broad questions like, "What kind of students does the program graduate?" and specific questions like, "What kinds of (intentional, department-changing) efforts did you decide to work on?" Follow-up questions were asked ("Was it a lot of work?" and "Did it cost any money?") to gain a sense of faculty or department investment, financial and otherwise. Once the ethics of the research project were approved by the institution, participant recruitment began.

1. Phase 1

Participants for the alumni interviews were recruited through various social media platforms such as LinkedIn, Facebook, and Reddit for one-on-one interviews via Zoom. Seventeen alumni interviews were conducted using a semistructured interview process. See Table I for pseudonyms and background characteristics. During the interviews, participants were asked about their past physics and other STEM experiences in high school and community college if they had attended, their time as an undergrad, and now (graduate school or workplace, whichever is relevant). Fifteen interviews were audio recorded (one participant did not consent to being recorded and there was technical difficulty with the other participant that prevented recording). The audio recorded interviews ranged from 21 min to 95 min, with the average interview being roughly 51 min.

2. Phase 2

Next, four semistructured faculty interviews were conducted. The department chair suggested six faculty members to contact. Four responded (two women and two men) and were asked about their perceptions regarding the changes in the department and their involvement in the changes. All interviewees had been with the department for 14 years or longer. Interviews were all conducted online and recorded via Zoom. Interviews ranged from 46 to 53 min.

3. Data analyses

All audio recorded interviews were transcribed and coded using descriptive coding and hypothesis coding [34]. Descriptive coding identifies the basic topics in qualitative data passages and is used to get familiar with participant perspectives [34]. The research team examined the transcripts to code for similarities and differences among the participant experiences. This created the basis for understanding what was happening in the department and answering RQ1 and RQ2. In the next round of coding, hypothesis coding was applied. Hypothesis coding refers to coding qualitative data with predetermined codes generated by theory to answer the researcher's hypotheses. Using codes informed by double consciousness and P-E fit theory, student interviews and faculty interviews were compared to answer the research question RQ3.

TABLE I. Participant information table. The three center dots denote “not reported”.

<table>
<tr><th></th><th>Gender</th><th>Race-ethnicity</th><th>First-generation</th><th>Transfer</th><th>Graduation year</th><th>Current situation</th></tr>
<tr><td>Beatrice</td><td>F</td><td>Latinx</td><td>Yes</td><td>No</td><td>· · ·</td><td>Is teaching physics as a graduate student.</td></tr>
<tr><td></td><td colspan="6">Took one physics class in 9th grade and dropped AP physics in 12th grade; physics was her second bachelor’s degree at [blinded]; participated in research during undergrad; finishing master’s degree in physics.</td></tr>
<tr><td>Jasmine</td><td>F</td><td>Latinx</td><td>Mom went to community college</td><td>No</td><td>· · ·</td><td>Currently 4th year in a biophysics Ph.D. program.</td></tr>
<tr><td></td><td colspan="6">Has a BA in physics and a BS in biochemistry from [blinded]; research during undergrad; University Honors Program.</td></tr>
<tr><td>Justine</td><td>F</td><td>White</td><td>Mom did not go to college</td><td>No</td><td>Finished thesis in 2003</td><td>Used to work for an engineering company in CA. Working overseas.</td></tr>
<tr><td></td><td colspan="6">Dad is a physicist with a Ph.D.—had a lot of support from parents; has a master’s degree from [blinded].</td></tr>
<tr><td>Mina</td><td>F</td><td>Southeast Asian</td><td>Yes</td><td>No</td><td>2020</td><td>Starting Ph.D. program in physics</td></tr>
<tr><td></td><td colspan="6">Has bachelor’s degree from [blinded]; would watch aerospace YouTube videos on her own; participated in research during undergrad.</td></tr>
<tr><td>Michelle</td><td>F</td><td>South Asian</td><td>Yes</td><td>No</td><td>2020</td><td>Starting MS program in physics</td></tr>
<tr><td></td><td colspan="6">Has bachelor’s degree from [blinded]; part of a bridge program.</td></tr>
<tr><td>Nancy</td><td>F</td><td>Latinx</td><td>Yes</td><td>No</td><td></td><td>Starting a Ph.D. program</td></tr>
<tr><td></td><td colspan="6">Online high school; participated in research during undergrad; has bachelor’s degree from [blinded].</td></tr>
<tr><td>Stacy</td><td>F</td><td>White</td><td>Mom does not have a college degree</td><td>No</td><td>2018</td><td>Working in finance.</td></tr>
<tr><td></td><td colspan="6">Independent high school experience; Dad was a physics teacher and classmate’s mom was a math teacher; has bachelor’s degree from [blinded]; participated in an REU one summer.</td></tr>
<tr><td>Alex</td><td>M</td><td>White</td><td>No</td><td>No</td><td>· · ·</td><td>Currently working at a boat retail store.</td></tr>
<tr><td></td><td colspan="6">Mathematics and physics double major at [blinded]; participated in research during undergrad; University Honors Program; 2 REUs; has a Ph.D.; Dad is an engineer; Used to work at a school that was “in line” with his educational philosophy. Also used to work at an AI company.</td></tr>
<tr><td>Jeff</td><td>M</td><td>White</td><td>No</td><td>No</td><td>· · ·</td><td>Is teaching at a community college.</td></tr>
<tr><td></td><td colspan="6">One physics class in private high school; has a film degree and completed prerequisites at community college to get into master’s program; completed master’s in physics education.</td></tr>
</table>

(Table continued)

TABLE I. *(Continued)*

	Gender	Race-ethnicity	First-generation	Transfer	Graduation year	Current situation
Charles	M	⋯	Grandmother got a bachelor’s at age 60.	No	⋯	Currently in a Ph.D. program in electrical engineering.
	Has a bachelor’s degree from [blinded].					
Danny	M	⋯	⋯	No	⋯	Currently in graduation school for aerospace engineering and accepted an offer letter to work for an engineering company.
	Originally enrolled in mechanical engineering and decided to double major in physics in his second year at [blinded].					
Greyson	M	⋯	Sister got her degree in math	No	2012	Currently a software engineer at a gaming company.
	After a year at [blinded], dropped out of college for 4 years to join the military; master’s degree in computer science; published 3 physics papers but shifted away from physics because he did not want to do research.					
Hector	M	Latinx	⋯	Yes	⋯	Currently a test specialist at aerospace company
	Did not take physics in high school. He started taking physics classes in community college. Has a BS in mechanical engineering and a BA in physics from [blinded].					
Jose	M	Latinx	⋯	Yes	⋯	In a STEM Ph.D. program
	Was originally a music major; did not take a physics course till sixth year in community college; has a master’s from another institution.					
Mateo	M	White	Parents have associate’s degree	Yes	⋯	Doing postdoc
	Expelled in 7th grade; started learning physics in community college; bachelor’s degree in mathematics and physics; master’s degree from [blinded].					
Mathew	M	Southeast Asian	Said that he was not sure	No	⋯	Working as an engineer for an analytical instrumentation company.
	Family wanted him to pursue computer science; watching YouTube videos changed his mind; looking into astrophysics graduate programs.					
Michael	M	Latinx	Yes	Yes	2019	Working at an IT/engineering company.
	Took his first physics class around his 3rd year of community college; part of numerous programs for physics students and for minority students in STEM; has a bachelor’s and a master’s degree from [blinded].					

TABLE II. Study themes and descriptive quotes.

Themes	Summary	Descriptive student quote	Descriptive faculty quote
1. Openness in the department contributed to broadening fit.	The open environment supported students from diverse backgrounds to thrive.	"…these are really hard classes that if I sat at home, I'm not going to figure this stuff out… But like, together in a room where we can challenge each other and bounce ideas off each other and try things out and fail and try again, you know, it led to our understanding of the material at a much, much better level."	"This is a way for people early on, just after they've taken one or two classes to see themselves as someone who could teach physics in a university or high school, community college, which is, you know, 1/3 of what a typical academic physicist does."
2. Faculty played an active role in resolving double consciousness.	Faculty can make efforts that contribute to resolving student feelings of double consciousness.	"I also noticed that the professors in, for physics in Long Beach, were pretty like, encouraging to students to kind of their, they made the course like, more approachable, especially for students who never had physics in high school."	"The traditional way of physicists is to set up these kind of secret things, right? They're not secret, but you know, the way they perceive it is, if you're smart enough, then you'll figure it out. Of course, you don't have to be smart. You have to be kind of connected to the right people. If you're not connected to the right people, then, you can't find the access door. And so, entire populations have been left out because they're not connected to anybody."
3. Students took on a physics state of mind.	Students developed an approach to physics that they took with them and applied to other disciplines and other areas of life.	"Really what my physics education taught me was how to approach problem solving, methodically and carefully with some structure."	"And I can figure out what's going on with the galaxy, with a star, with a person, with a dog, with a planet. … I only want to remember the simple things that I know are right, and then put them together."

The research team consisted of one faculty researcher and five undergraduate research assistants. All faculty interviews were conducted by the faculty researcher. The alumni interviews were conducted by the research assistants and the faculty researcher. Undergraduate research assistants were trained in interviewing and qualitative coding. Once the interviews were completed and transcribed, the team met over several meetings to discuss the codes and the themes identified through descriptive coding. After this first phase of descriptive coding discussions, there was a second phase of hypothesis coding discussions. The full manuscript was shared with the faculty participants and the current department chair as it was drafted. These individuals were invited to give feedback on accuracy or provide additional context.

IV. RESULTS

Below, three themes from the interviews are presented: (i) openness in the department contributed to broadening fit; (ii) faculty played an active role in resolving double consciousness; and finally, (iii) students took on a physics state of mind. Together they help to reveal aspects of this physics department that contributed to supporting students of diverse backgrounds (racial-ethnic, educational, and gender) to be academically successful and feel that they belong in physics. These findings provide the foundation for the recommendations in Sec. V. The themes are summarized in Table II. Quotes are presented minimally edited for ease of readability.

A. Openness in the department contributed to broadening fit

Participants reported a general openness in this physics department, and we saw this openness in two significant domains. The first domain was that the students and faculty alike openly recognized the curricular content as difficult. This open recognition of the material being difficult seemed to create a culture where peers helped one another. Alumni interviewees recalled their classmates and peers being collaborative and helpful. Greyson was a nontraditional student who had dropped out of his first year of college to join the military. He enrolled in this department after he had come back from his service.

> I'd say, the only way I got through some of my classes were because of my classmates. At one point, I had reserved a classroom for like, five of us to get together in for about an hour a week. And we would sit in there and do all of our homework together on the whiteboard. And these are really hard classes that if I sat at home, I'm not going to figure this stuff out. Most of them, if they sat at home they wouldn't be able to figure this stuff out. But like, together in a room where we can challenge each other and bounce ideas off each other and try things out and fail and try again, you know, it led to our understanding of the material at a much, much better level.

Greyson credited his study group partners for his success. Additionally, he pointed out that none of them would have been able to be as successful on their own due to the difficulty of the course material. His claim of "our understanding" conveyed the sense of being in physics together. Another student described how she was "never alone in those classes" and that her classmates would text each other at 3 am before the exam.

This open recognition also seemed to create opportunities for diverse students to thrive. Michael had the following to say,

> I had really great experiences with a few professors who were engaging, who, I guess catered to students' natural curiosity. And understood that this subject takes an extreme amount of time and effort. And I really enjoyed that they were very clear that this has little to nothing to do with intellectual capabilities, and more so with how much time and effort you're willing to spend on this subject.

Michael took away that faculty were open about the fact that the course material will be difficult and that difficulty will be only temporary with time and effort. This same interviewee had shared that in high school he was not allowed to take science classes because of his poor behavior, not because of his academic qualifications. He repeated the same Algebra class all four years of high school and took his first physics course during his third year in community college, where it was "completely overwhelming." He noticed that a lot of his classmates had taken physics classes in high school, and throughout the interview, Michael described himself as "completely underprepared," "just behind…in terms of academics," and "never really had strong confidence in my math skills." Transferring to the 4-year university brought additional challenges: class times were shorter, class sizes were larger (initially), and he felt there were greater studying expectations compared to his community college courses. Despite these experiences and feelings, Michael graduated, earned a master's degree in physics, and is working in the STEM industry.

The second domain of openness was broadening the definition of who successful physicists are and the path to becoming one. In this department, students could feel proud of pursuing various career paths related to physics. A faculty interviewee explained that traditionally an undergraduate physics program is only evaluated as successful by the number and proportion of students who gain admission to physics Ph.D. programs. This faculty member had spearheaded efforts to change this acceptance of only valuing Ph.D. pursuits. She was new to the department at the time of these efforts and had gathered support for this change by applying for the department to become part of the PhysTEC program organized by the American Physical Society. The PhysTEC program encourages physics graduates to consider a career in physics teaching. By adopting this program, the acceptance of determining the success of a department through Ph.D. program admission was challenged. For the past 15 years, the department has been presenting to students the pursuit of physics teaching and industry jobs to be as valuable as pursuing a Ph.D. They do this by offering a learning assistant program intended to expose students to teaching. In addition to considering teaching as a profession broadly, another male faculty interviewee pointed out,

> And that winds up being such a powerful sort of positive experience that you then, 'Okay, I can see myself doing this' and go on. This is a way for people early on, just after they've taken one or two classes to see themselves as someone who could teach physics in a university or high school, community college, which is, you know, 1/3 of what a typical academic physicist does.

Here he articulated how the learning assistant program serves a dual purpose for the student. It can be an opportunity to test out teaching and if one likes it, the student may consider getting a teaching credential and teach high school or the student could also consider getting a master's or Ph.D. to teach in postsecondary institutions. Students could feel safe and proud of their career pursuits, even when it is not pursuing a Ph.D. program. One alumna participant shared at length and with pride how much work he put into his master's thesis in physics education, showing that he considered the efforts something to be proud of.

In addition to physics teaching, there were open discussions of how there are many ways to become a successful physicist. Matthew shared the following about the interactions he remembered with the faculty:

> They did give me suggestions on what to do to give me more options going further. Like trying to find a research interest, maybe be in a research group. So maybe that would help me gain some experience into working hands on into the material that I'm learning in class, and things that would be helpful if I do decide to go, perhaps for a master's or a Ph.D. program or just to go into the industry itself.

Matthew was an immigrant from Southeast Asia whose parents had associate degrees. Matthew had moved to the United States 12 years prior to the time of the interview. He remembered the faculty offering career support and at the same time, the faculty were communicating that they see Matthew as someone capable of pursuing these various future paths. Since not all students have clear ideas or convictions on their next steps after graduation, we saw how important it was that faculty provided them with advice and suggestions on all the options (master's, Ph.D., and industry). This student expressed he may pursue all those future paths in another part of the interview Matthew mentioned he is currently working as an engineer and was considering pursuing a postsecondary degree in astrophysics. Matthew's case serves as a reminder that any conversation can become the idea seed that sprouts later and efforts to broadening fit in STEM need to happen everywhere at every opportunity.

B. Faculty play an active role in resolving double consciousness

A second theme we identified from the interviews was that faculty played an active role in helping students resolve double consciousness and eliminating areas for double consciousness to reside. In this section, we describe the four areas where we found this to happen. We start with how in classrooms faculty recognized and supported students with differing physics preparation by emphasizing the value of effort and putting that value into practice by modifying their course policies and teaching strategies. Next, we highlight other learning spaces outside the classroom, namely the student organization and interactions with the undergraduate advisor, where faculty engaged actively in eliminating the potential for double consciousness experiences. Third, we include how faculty welcomed personal differences in physics, and finally, we include how the department is still a work in progress when supporting female physics students to feel welcome.

First, one commonly held assumption in and about physics is that one must be smart "enough" to study physics or become a physicist. However, each faculty interviewee discussed how they did not believe this to be true and they had no doubt that any student could learn the material and have a successful career in physics. They made efforts to confront this assumption of inherent intelligence or ability by first recognizing that students started in the department with varying degrees of physics preparation ("students will never touch the physics book [in high school]… you still graduate and it's totally normal. And then maybe in the college you start, you have to take engineering, or you have to take physics and they pick up the interest late." from female faculty interviewee). The faculty also recognized that students came from diverse home environments and with various work and life experiences, such as attending community college or being in the military. This was true as several participants revealed they had not taken Advanced Placement (AP) physics in high school or took their first physics course in community college. Students cannot change these past experiences and holding expectations of already knowing physics is not helpful for learning.

And then, the faculty did not ignore these differences in physics exposure or preparation with the hopes that the students would catch up on the material on their own. Rather, they were supportive of students who did not have previous physics education. This was felt by the students as it was echoed in the alumni participants' interviews. Danny noticed the professors acknowledged some students did not have the opportunity to learn physics prior to coming to university and that was not used to exclude students.

> I also noticed that the professors in, for physics in Long Beach, were pretty like, encouraging to students ..., they made the course like, more approachable, especially for students who never had physics in high school.

Differences in academic exposure or experience can make one feel that they do not belong or that they cannot be a physicist due to the mismatch in desire and academic training: in other words, a student can feel double consciousness. Faculty eliminated differences in preparation to function as a source of inner conflict or to question one's belonging in this department.

Further, the department placed a clear emphasis on effort and this value was put into practice through changes in course policies, such as grading schemes that included multiple "second chances." Alumni interviewees felt the faculty emphasis on the idea that anyone can learn physics (see Michael's quote in the previous section). This emphasis on effort was also coupled with the acknowledgment that department grades are not accurate predictors of future success. A faculty interviewee pointed out, "When you are in a team, and solving a problem the person who contributes well and best, bring the best idea is not necessarily the person who has the highest [grades]." In this quote, she recognized that a low grade does not determine or predict whether someone will be a successful physicist or not. Attitudes such as this one can provide faculty reasons to continue to support all students.

Additionally, groupwork was encouraged so that students could support one another. Interviewees talked at length about how this was beneficial because it helped them learn and understand the concepts ("especially being a transfer student … pair up with other students or talk to study working groups. And that really helped me" from Jose) while helping each other ("in a lot of cases, it was very helpful to have someone there for you and help you" from Nancy). What students may not have noticed is how the groupwork was scaffolded. One faculty interviewee, who was also mentioned explicitly by several of the student alumni participants as a significant professor during their time in the department, explained how he assigned roles within the group (i.e., principal investigator, researcher or investigator, the executive who synthesizes all the work, and a skeptic who independently checks the work) and group members would alternate roles to ensure that everyone got an opportunity to learn from being in each position and one person was not stuck holding one position.

In addition to eliminating the potential for double consciousness that stems from differences in precollege preparation and differences in how quickly one may learn in class, the faculty rooted out other areas where harmful subconscious messaging could reside. One faculty member recalled how as advisor of the physics student group he made the meetings more public and welcoming because,

> the traditional way of physicists is to set up these kind of secret things, right? They're not secret, but you know, the way they perceive it is, if you're smart enough, then you'll figure it out. Of course, you don't have to be smart. You have to be kind of connected to the right people. If you're not connected to the right people, then, you can't find the access door. And so, entire populations have been left out because they're not connected to anybody.

This faculty member saw how even something seemingly trivial like participation in a student group had the potential to communicate who belongs and does not belong. As the advisor to the student group, he changed how the group operated, and by doing so, it reduced the possibility that a student would doubt their belonging in the department due to not being able to participate in the student group.

Another faculty member discussed how he changed students and faculty understanding of the role of the department's undergraduate advisor. He had noticed students previously treated the undergraduate advisor as someone to hide from because the advisor was there to "kick them out" if and when the student struggled. He changed this so that the advisor was someone students and faculty could go to as early as possible so that the impact of struggling in a course could be better managed, such as connecting the student with resources sooner and identifying how performance in this course will impact the student's curricular pathway to graduation. This understanding of the department advisor's position as someone helpful rather than punitive is being carried on in the department even after this faculty member is no longer the department advisor. A different faculty interviewee mentioned that she will seek out the current undergraduate advisor if she has a student who struggles in her class. This change in understanding of the advisor's role enhanced the messaging that struggling in physics does not have to be evidence that one does not belong in physics. This department-wide approach can decrease the root causes of double consciousness, as we will discuss more in Sec. VA of this paper.

Third, students felt faculty created space for individual differences to belong in physics as well. Nancy, a Latina participant, recalled how amazing it was to work with a Latina professor. Charles recalled a professor who admitted to being socially awkward and not liking being around other people. This confession made the professor more relatable and approachable, and although we do not know whether faculty were aware that students identified with these more personal aspects of their faculty, students seemed to welcome these explicitly shared social identities and personalities as another signal that different people can belong in physics.

Finally, it is worth noting that not all of the experiences expressed by the interviewees were positive. One female participant recalled another female friend who was also a physics major having a negative experience with a male classmate. The friend received satisfactory support from the department chair, who was a male faculty member at the time. She also had a negative experience with a male classmate who was condescending to her. She shared during her interview that she confronted the male classmate and although he did not change, she felt she had spoken her piece. One male interviewee who had been part of the department as a master's student talked about how he had to remove himself several times from other graduate students because he found them talking in inappropriate ways and one time confronting a peer for being inappropriate to another female colleague. Thus, while negative experiences were reported, there were efforts to confront wrongs to prevent such issues from becoming evidence of certain groups feeling they do not belong.

C. Students took on a physics state of mind

The third theme from the interviews was related to the kind of students who graduated from this department. Here we describe an attitude we are calling a physics state of mind. We present what it is, that it includes resilience and confidence, how it may have been cultivated, and where alumni found themselves applying it.

The physics state of mind is an attitude on *how* to do physics described by alumni participants. Stacy articulated it by describing the progression in her physics education,

> Your lower-level classes where there's, there's non physics majors in the classes, you know, like, your freshman, sophomore physics. After that, you kind of get to the point where you're not just applying an equation anymore. Like, it's not algebra or like, you just know the equation and you have to plug in x and y, it's much more. Like you have to look at the situation and kind of make up an equation. I remember that being such a hard bridge to cross and like, changing the way you think. And it was kind of a change that happened all at once. And I feel like in those upper-level classes where that change started, the teaching was very heavy on like, giving us a scenario and then just like, over and over again, doing different scenarios, and like how you would approach it and teaching more like, deductive reasoning instead of like equation, giving you a list of equations. So, it was much more like bigger picture. Teach you how to fish instead of giving you a fish, I guess.

She talked about how understanding the "bigger picture" became important in her later courses and that students were expected to learn how to approach problems using "deductive reasoning." She concisely stated that felt she was learning "how to fish." Her understanding of the physics approach matched closely to one faculty interviewee's articulation of his scientist identity.

> I'm a pretty good example of academic physicists in the United States, because I'm arrogant, and I'm lazy. … the scientific arrogance is … I just need to know three things. And I can figure out what's going on with the galaxy, with a star, with a person, with a dog, with a planet. And then there's laziness. … I don't want to remember 40 equations that I could derive if I needed to. I only want to remember the simple things that I know are right, and then put them together.

The faculty member articulated simply that he has an approach that he believed he can apply to any situation ("galaxy," "star," "person," "dog," and "planet"). This articulates this professor's view on *how* to do physics and not *what* to study in physics.

This way of thinking was coupled with a resilient and confident attitude. Alumni participants expressed finding it gratifying and satisfying to take on difficult concepts and solve problem sets. Jasmine stated "Like, yeah, it's hard, but I don't care. It brings me satisfaction actually working through the problems … gave me time to like, go back and learn a lot of stuff that I couldn't pick up if I had not done physics." Several other participants who were working in or pursuing Ph.D.s in other disciplines such as engineering expressed confidence in being able to learn anything because they had proven to themselves that they could learn physics.

> I started honestly, just looking for avenues of what you could do with a physics bachelor that was like, interesting and challenging, and that would like, you know, interest me. I'm currently finding that it's pretty typical for there to be physics people in finance, because it is very, like quantitative heavy and math heavy. … basically just came to the decision of like, I did not want to pursue grad school right now. And like, I could see myself going back and doing a Ph.D. later. … I found this finance job. And I started reading into it. And I just realized I thought it was really interesting. A lot of what we do is very quant heavy. So there's a lot of like math and financial modeling, and basically just problem solving.

The above quote is from Stacy, and during her undergraduate career, she worked in a research lab, completed a research experience for undergraduates (REU) opportunity at a prestigious private university, and considered pursuing a Ph.D. She had decided to take a break before graduate school and found this job that was interesting. She aligns herself as a physics person as she talks about how it is typical for physics people to be in finance. And she claims she can do the job because it is "basically just problem solving," something that was valued and emphasized in this physics department.

The physics state of mind seemed to develop from the department's focus on process, rather than final product or answer. Due to the varying ages of the alumni interviewees, we suspect the department valued this for some time. However, one faculty interviewee pinpointed a recent occasion when the department explicitly challenged how they taught physics.

> So, after the guidelines that AAPT, the American Association of Physics Teachers guidelines came out in 2014, they recommended that we move, that inquiry-based laboratories are more or better for, for students' learning, rather than using some kind of cookbook. They call it cookbook approach where you say, "do A and then do B and then record the length and then write down the length multiply with two." It's kind of like a tax form. So, we had that for a long time. And then my task was to revamp, so I had to create new experiments, because, you know, obviously, it was incompatible. So, I wrote, I made two new experiments. I wrote the laboratory manual.

After understanding physics education research, this faculty member changed the lab assignments to be inquiry based. The emphasis on acquiring new knowledge through active learning, such as hypothesis testing and engaging in scientific methods, seems to have contributed to focusing on how physics is done, rather than what kinds of physics is done.

Consistent emphasis on learning from engaging in processes was expected from lab teaching assistants as well.

> And then I have to train the [lab teaching assistant] students, because now that's inquiry based, this teaching students, is much more difficult for them, right? Because previously, the graduate students who taught those courses because it's cookbook, they don't prepare at all. They just show up and they're there. And they wait for a problem. And then students say, I don't know how to multiply line two, and then they go and read or multiply and they pick it up. But the new inquiry based they don't have instructions like that. So, we, I trained the instructors for the laboratory classes.

In this quote, the faculty member clearly recognized graduate-student lab instructors as part of the physics department. Therefore, for the department to accomplish this change, the graduate-student lab instructors needed materials that reflected the values of the department with regard to what students needed to learn and needed to be properly trained to be able to teach these newly developed lab course materials.

Finally, beyond course content, alumni interviewees saw that how they approached physics could be applied to other parts of their lives. Justine, who had not seen herself as the smartest student in her classes in high school and was now working in an engineering firm abroad, said, "Really what my physics education taught me was how to approach problem solving, methodically and carefully with some structure." Jasmine echoed this, "I think approaching things from a physics approach is always going to be a good thing, because you're always going to get down to the foundation of it." Later she added, "The approach kind of seeped itself into every other area of my life." Hence, this way of thinking showed up as more than an academic skill.

V. DISCUSSION

The two goals of this paper were (i) to present a successful physics department that has made progress in supporting different historically marginalized student groups and (ii) to connect those efforts with previous research to make recommendations for change in other STEM departments. The study applied the attraction-selection-attrition theory which created an opportunity to interrogate who the department was attracting, who was feeling selected, and what helped them stay (the opposite of attrition). Overall, this department attracted students who had vastly different educational pathways, with some not experiencing a physics course until they were in community college. The commonality they shared was that they were all interested in learning physics. Once interested students were in the department, there was an openness that the course material was difficult and that is the norm. In turn, it seemed that students could feel safe regardless of their prior physics experience or lack thereof. The students reported feeling comfortable about openly helping one another, which contrasts with typical STEM environments that are commonly described as competitive. In competitive environments, students are discouraged from helping one another, especially if grading is done on a curve [35] or if there is fear of getting one's idea stolen (such as in the common myth of Charles Darwin and Alfred Russell Wallace). This was not the kind of environment students were experiencing in this department.

This open attitude throughout the department is significant because although having more preparation in STEM has been connected to persistence in STEM among women and racial-ethnic minority students [36], not all university students attended schools with rich physics opportunities, such as access to AP physics courses and high school faculty who can support advanced STEM learning. Additionally, in a study examining the identity trajectories of latecomer Canadian students in science, Jackson and Seiler [37] foregrounded academic expectations of taking direct paths through schooling despite the reality that many students do not take the direct, traditional pathways through education (Ref. [38] cited by Ref. [37]). These different education pathways can contribute to some questioning whether some students fit because they took a path that is different from the traditional direct path through schooling. This department demonstrated that students who have not had much exposure to physics before entering university are not predestined to be excluded or leave physics.

The study also investigated this physics department through the theoretical lens of double consciousness and examined the learning environment for areas where there could be conflict between how students view themselves and how others view them. Differences between the two can result in feeling like one does not belong. One area where this could happen is if members of this physics community adopted the idea that one has to enter the space already smart enough. Faculty combated this by recognizing differences and emphasizing effort. The emphasis on effort echoes findings from Johnson's work investigating physics identity components identified by students and by physics faculty in a nonprototypical physics department [39].

The department created opportunities for students to experience fit in the department and the discipline through curricular changes as well. Faculty offered multiple second chances to demonstrate learning of the material. Reducing the stakes tied to exams has been linked to improvement in physiological and affective states [40]. Additionally, faculty created opportunities where students were expected to work in scaffolded groups, and through group work, students could build a sense of community with others who may be different from them. The interactions through group work not only supported their physics learning but also may have lowered their physics anxiety [41] and increased their self-efficacy [42]. Being a good physics student involves doing group work [39] and having opportunities to work together can combat the stereotypical perceptions that physics is individualistic and competitive. Another important aspect of the group work was that in some courses, faculty assigned the roles within the groups and students rotated through the roles. This assigning of roles was a critical part of a good group work because female students often end up relegated to the secretarial tasks which negatively affects their physics identity development [43]. Hence this level of scaffolding is needed because when groups are left to freely delegate work often traditional gender boundaries end up dictating role expectations.

Beyond the classroom, personal interactions and sharing of personal stories served as opportunities for students to feel the department welcomed them. In the process of this research project, we learned 3 years ago the department started an organized lunch meeting for new students to meet and interact with faculty, staff, and senior students. Students finding faculty approachable has been recognized as one of the most significant qualities of a teacher [24] in general, and connections with faculty are identified as valuable for transfer students [18].

The negative gender-related experiences mentioned by the alumni participants can be understood in the context of a general trend in physics. A recent study reported that approximately three out of four undergraduate women in physics have experienced at least one type of sexual harassment [44]. One consideration point for this discrepancy in female student experiences compared to other historically minoritized groups may be informed by critical mass theory [45–47] and self-selection bias. Critical mass theory proposes that when one subgroup comprises 30% or greater of the whole, it can create change in the group's culture. In this physics department, Latinx students, transfer students, and first-generation students comprised more than 30% of the student body, respectively, whereas female students had not passed that 30% threshold. With the small number of female students in the department, those who had positive experiences likely self-selected to participate in this study. Until female student proportions reach 30% and higher, the department will need to work on ensuring female students feel they belong so that they may continue to develop a strong physics identity.

The outcome of being in this physics department were young professionals with confidence, resilience, and a philosophy to approaching problems and situations. We referred to this as a physics state of mind, and it relates to a way of thinking or problem-solving. The curriculum was intentionally designed to be inquiry based, including lab assignments, and these changes were rooted in recommendations by physics education research. Other scholars may refer to this physics state of mind with different names. Mindset, "a situationally contingent perspective that creates a readiness or cognitive orientation to act intellectually in a particular manner" [48], could be one way to refer to this way of thinking. Other scholars refer to this as a disposition, behaviors one tends to apply when engaging in situations [49]. A type of disposition, critical thinking disposition, has been investigated in the context of physics learning [50,51].

A. Recommendations for other STEM departments

Based on this department's success and previous research related to those successful aspects of the department, below we present some recommendations for other STEM departments interested in supporting students with diverse backgrounds and educational experiences. This is not an exhaustive list and we are not claiming that these are the only areas for change. These recommendations are intended to be concrete starting points for other departments to begin conversations on areas of the department they consider possible to tackle and make change.

First, we recommend making efforts to understand the kinds of students a department is attracting and also graduating. If the students who are leaving before graduating are the ones with lower high school grades or have taken fewer mathematics and science courses, the department needs to question where faculty are placing the blame. When the explanation commonly adopted is, "they were weak students who would not have been able to succeed" then faculty are accepting and upholding the idea of innate ability and faculty being powerless to respond to the situation. As seen by the efforts of this department, placing emphasis on effort rather than innate ability, which aligns with ideas of growth mindset, creates space and opportunity for faculty to support student learning. Growth mindset refers to believing that ability can be developed or grown through various efforts such as hard work, good strategies, and help from others [52]. This contrasts with having a fixed mindset, which refers to thinking that ability is innate. Decades of research on teacher expectations and teacher bias have demonstrated that teacher attitudes are connected with student achievement (see Ref. [53] for review). Specifically, research from a longitudinal, university-wide sample found greater achievement gaps and students reporting less motivation in classes taught by STEM faculty who maintained the belief that ability is fixed [54].

The second recommendation is to use research-based teaching practices, as it is a characteristic of a good physics faculty member [39]. This department adopted inquiry-based learning in the faculty-led lectures and the graduate student-led labs and was successful. Inquiry-based learning is connected to increased physics problem solving and scientific literacy [55]. Inquiry-based learning values students engaging in practices used by professional scientists to construct knowledge (see Ref. [56] for a detailed explanation). Pedaste *et al.* introduced several meta-analyses that show that inquiry-based approaches are better for learning than traditional instructional methods. Additionally, when implementing group work, we recommend doing so with care and intentionality, as seen in this department. In a recent study with female students taking on managerial roles in physics lab courses, Stump *et al.* [57] also recommended instructors being watchful of group dynamics as a group could have a domineering member. These group dynamics left unchecked can unintentionally exclude women and other minorities from important learning opportunities.

The third recommendation comes from an area that is work-in-progress for this department as well and is in regard to the sexism often found in STEM environments. Departments need to actively address this issue, and it needs to be taken on by everyone in the department. Johnson highlighted a department where male faculty were aware of the challenges of being a woman in physics and female faculty felt their male colleagues "take responsibility of gender issues" [39].

Ultimately, by learning about this department, we encourage other physics educators to envision efforts that can be good for many and possibly all students. Research often focuses on interventions for one specific group and reports how the other control group was (un)affected. For instance, an intervention to encourage physics identity among female physics students reported no negative intervention effects on male participants [58]. This implies some are concerned that if an effort is intended for one group that it somehow takes away or will harm the other group. However, this department demonstrated that it is possible to implement changes that can positively support many different groups of students the department attracted, including the majority of students. In other words, broadening who fits in physics does not inevitably exclude those who were already there.

B. Limitations and suggestions for future research

There are a few noteworthy limitations in the study. The data were collected from a small group of former students who graduated at different times. Their recollections of experiences are difficult to compare. We also did not interview current students. It is possible that meaningful recent insights were missed because we did not interview them. One suggestion for future research specifically examining diverse student experiences would be to apply a critical physics identity framework by Hyater-Adams *et al.* [59]. With regard to the interview participants, all participants self-selected to be interviewed. We are unable to determine how representative the opinions shared by the interviewees are. We have confidence that the findings are not unique to this group of participants we recruited because the experiences reported by the participants overlapped. However, we are still cautious of the findings and present them as aspects and not the complete picture of the department.

Limitations of the data make it also difficult to conclude whether mindset or disposition fully captures what we heard from our participants. Future research is needed to examine the disposition or mindset qualities that are important for physics learning. Furthermore, combined with one faculty interviewee's recognition that good grades do not predict effective problem solving later, we propose including a physics state of mind as a component of having a physics identity. Future research might examine how this relates to other aspects of physics identity, such as whether this way of thinking is a higher-order construct from competence or performance, interest, and recognition or related to these other constructs in the same order.

VI. CONCLUSION

The task of diversifying STEM is complicated which makes it challenging, and solutions to this task need to reflect that complexity. In this paper, we laid out how faculty demonstrated agency in changing the physics environment. This is deserving of much positive recognition. Too often P-E fit theory is focused on how the individual fits with an environment which can result in putting fault on the student [60]. This is often the case in higher education as well, with institutions asking whether students are ready for college. When a department or discipline is a difficult environment, students have little power and awareness to make changes, and faculty and administration need to be responsible for making changes. This work is significant in highlighting a positive example of a STEM department successful in making changes. Many of the faculty efforts were good for all students regardless of minority status, demonstrating that faculty have the power to create an environment where various students can fit in physics. Although the sample is small and may seem to have limited generalizability, the findings are encouraging as they give us an idea of what changes can be supportive of student experiences and fit in physics. We invite other STEM departments to think about the students they currently attract, who they would like to attract, and how they might encourage those students by changing their respective departments. This is moving toward being a student-ready institution [61].

ACKNOWLEDGMENTS

This project was funded in part by CSULB's College of Liberal Arts faculty small grant and RSCA awards to the first author. We would like to thank the undergraduate research assistants, Dr. Katherine McLoone, and the incredibly encouraging blind reviewers with their help. We would also like to thank CSULB's Department of Physics and Astronomy for letting us in and ask about their department.

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