ABSTRACT

THOMAS, DANA CHRISTINE. Exploring the Contextually Situated Experiences, Perceptions, Beliefs, and Intentions of College Physics Majors Enrolled in Physics Courses that Incorporate an Interactive Instructional Approach. (Under the direction of Dr. Joy Gaston Gayles).

Physics is known for its emphasis on innate brilliance as a prerequisite for disciplinary membership and success. Women, Black, Latine, and Indigenous individuals remain vastly underrepresented and marginalized in physics spaces, a reality that is due in part to oppressive stereotypes that position them as less inherently intelligent than their male, white, and Asian peers. Traditional lecture-based college physics courses often contribute to this marginalization by fostering competitive cultures that elevate inherent, exceptional ability over intellectual growth and malleability. In recent years, physics educators have implemented a variety of interactive instructional approaches to both enhance student learning and reduce competitive classroom cultures. This dissertation consists of three studies, each focused on discerning factors that influence the experiences, beliefs, perceptions, and intentions of undergraduate physics majors enrolled in courses that incorporate an interactive instructional approach. The first two studies utilized multilevel modeling to examine the contextual dynamics of students' physics ability beliefs, sense of belonging, disciplinary identification, and persistence intentions over time. The third study employed dynamic narrative inquiry to explore the lived experiences and disciplinary identity development of physics students with marginalized or multiple marginalized social identities in the context of the power dynamics of their physics learning environments. Quantitative analyses indicated that students' physics ability beliefs shifted and changed over time in accordance with both individual and environmental factors. In the short term, the malleability of students' physics ability beliefs related to the extent that they felt recognized by others as an exemplary physics student. Over a longer time period, students with more malleable

physics ability beliefs conveyed a greater sense of belonging and intent to persist in the physics major. Students who perceived innate brilliance as required for success in physics, on the other hand, conveyed a lower sense of belonging and intent to persist. Perceived recognition and a sense of belonging in physics positively related to students' level of disciplinary identification. The magnitude of these quantitative trends varied in meaningful ways by students' gender, race, ethnicity, and course level. In addition, women, Black, and Latine students reported a lower sense of belonging in the physics major than men, white, and Asian students, even after accounting for individual-, environmental-, and disciplinary-level ability beliefs and perceived recognition. Qualitative analyses provided a richer context for these findings. Narratives revealed common course and programmatic norms, values, structures, and practices, some that disrupted and others that reproduced the discipline's white, masculine, heteronormative, able-bodied, middle- and upper-class traditions. Taken together, findings from these three students offer important scholarly and practical insight into how undergraduate physics programs can foster diversity, inclusion, equity, and justice in physics learning spaces by intentionally dismantling and reshaping oppressive dynamics that deter students with a diversity of social identities and backgrounds from growing, belonging, and persisting in the field as their authentic selves.

Exploring the Contextually Situated Experiences, Perceptions, Beliefs, and Intentions of College Physics Majors Enrolled in Physics Courses that Incorporate an Interactive Instructional Approach

by
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DEDICATION

To my great-grandmother, Reba Stutson Hill (1884 – 1958), charter president of the East St. Louis Branch and later the Illinois Division of the American Association of University Women. Her love of learning, independent mind, and outspoken commitment to social justice as detailed in her book, *Just Remembering*, have inspired me throughout my life.

BIOGRAPHY

Dana Christine Thomas is a native of Haymarket, Virginia. She completed a Bachelor of Arts in Biology from Vassar College in 2006 with general and departmental honors and was inducted into Phi Beta Kappa. After college, she worked briefly for the National Park Service before pursuing a Master of Science in Ecology and Evolutionary Biology from the University of Michigan. In leading discussion sections for an introductory biology course as part of her graduate assistantship, Dana discovered a passion for teaching and mentoring undergraduates in the sciences. This realization inspired her to add a second master's degree in education. Since September 2014, Dana has served as an academic advisor to sophomore through senior students in the Department of Biological Sciences at North Carolina State University. In May 2020, she became the department's Coordinator of Advising. As an advisor, she is committed to guiding, supporting, encouraging, and advocating for students as they navigate their development as students, future professionals, and individuals. On top of her advising and coordinating duties, she teaches and co-teaches several departmental courses, implements programming for current and prospective students, oversees a transfer student peer mentor program, manages an undergraduate research database, participates in numerous committees, and co-leads several assessment initiatives.

Dana's professional experiences inspired her to pursue a Ph.D. part time in Educational Leadership, Policy, and Human Development with a specialization in Higher Education Opportunity, Equity, and Justice. Her research interests broadly center on diversity, equity, inclusion, and justice in postsecondary STEM education, with a focus on how learning environments can better support the success, well-being, disciplinary identity development, and persistence of students with identities and backgrounds traditionally marginalized in STEM

settings. As a Ph.D. student, she has co-authored several publications, presented at four conferences, completed and presented three departmental and university assessments, and co-taught a doctoral research and writing course with her advisor. Upon graduation, she will continue to build her career as a scholar, leader, advisor, and teacher.

Outside of work and research, Dana can generally be found running and hiking near her home adjacent to Eno River State Park, tending to her garden, backpacking on the Appalachian Trail, exploring the Rocky Mountains, or spending time with her wife Elisa, her friends, and her pets Fiver, Juniper, and Osito.

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CHAPTER 1

INTRODUCTION

This dissertation consists of three studies that explore factors that influence the beliefs, perceptions, intentions, and experiences of undergraduate physics majors during college physics courses that incorporate an interactive instructional approach. While the number of physics bachelor's degrees awarded annually in the United States has practically tripled in the last 20 years, this growth trend is not universal across students with various gender, racial, and ethnic identities (Mervis, 2022). Of all science, technology, engineering, and math (STEM) fields, physics consistently remains one of the least diverse (NSF, 2023; NRC, 2013). Postsecondary credentials are required for most physics-related jobs though the percentages of women, Black, Latine, and Indigenous students graduating with bachelor's degrees in physics remain disproportionately smaller than those of men, White, and Asian students (Fayer et al., 2017; Porter & Ivie, 2019). Data documents that LGBTQ+, lower socioeconomic status, and disabled students also experience barriers to inclusion and persistence in the discipline, though far less is known about the experiences of students with these social identities in physics spaces (Atherton et al., 2016; Barthelemy et al., 2022; Miller-Friedmann, 2020; Traxler & Blue, 2020). Understanding and addressing factors that influence diversity, inclusion, equity, and justice in undergraduate physics spaces is essential for both broadening access to high-paying STEM careers and improving the discipline of physics as a whole.

Investigations into representational disparities in undergraduate physics settings traditionally characterized "gaps" in women, Black, Latine, and Indigenous students' physics preparation, performance, and attitudes compared to white men (Traxler et al., 2016). Numerous scholars have challenged the utility of emphasizing gaps when studying the dynamics of

underrepresentation and marginalization in postsecondary physics programs (McGee, 2020; Nissen et al., 2021; Traxler et al., 2016). Such a focus promotes a deficit perspective that places the onus on marginalized students to resolve their apparent shortcomings in the discipline (McGee, 2020). A growing body of work centers instead on exploring how aspects of physics learning environments support or discourage the persistence of college students' various social identities by communicating the characteristics necessary for success, belonging, and disciplinary identification (Hyater-Adams et al., 2019; Kalender et al., 2019; Li & Singh, 2021; Ong et al., 2018; Rosa & Mensah, 2021).

At the undergraduate level, physics programs traditionally rely on a lecture-recitation course format in which students passively take notes and complete structured problem sets (NRC, 2013). Physics education research suggests that this instructional format helps to fuel a *culture of brilliance* in undergraduate physics programs that encourages competition among students and elevates a mythical ideal of high inherent intellectual talent as a requirement for success (Mervis, 2011; NRC, 2013). This culture of brilliance is particularly detrimental to women, Black, Latine, and Indigenous individuals who, due to oppressive stereotypes, are unjustly positioned as less innately intelligent than their white, Asian, and male peers (Leslie et al., 2015; Murphy & Zirkel, 2015; Steele et al., 2002).

In an effort to disrupt the culture of brilliance and improve the learning environment in undergraduate physics courses, physics instructors have increasingly developed and implemented numerous interactive instructional approaches in college physics classrooms (NRC, 2013). While they vary in structure, scope, and practice, these approaches seek to enhance students’ cognitive and affective growth by employing collaborative engagement techniques that support their scientific thinking, problem-solving, and metacognition capabilities (Freeman et al., 2014; Karim

et al., 2018; NRC, 2013; Theobald et al., 2020). Evidence suggests that while interactive instructional approaches carry the potential to improve the persistence of college physics students with marginalized identities, these benefits are not universally observed (Theobald et al., 2020; Maries et al., 2020; Pollock et al., 2007). Collaborative learning can actually increase instances of exclusion and stereotype-driven anxiety among women, Black, Latine, and Indigenous physics students (Maries et al., 2020; Pollock et al., 2007). When investigating the potential benefits of interactive instructional approaches, it is important to examine how various aspects of students' course experiences influence their beliefs and perceptions about their intellectual abilities, their sense of belonging, and their disciplinary identification in physics (NRC, 2013). To date, these dynamics remain underexplored in the literature.

The three studies in this dissertation contribute novel insight into the contextual dynamics of undergraduate physics students' beliefs, perceptions, and experiences during major-specific physics courses that incorporate an interactive instructional approach. The first study utilized multilevel modeling to examine how temporal, student, and environmental factors influenced changes in students' physics ability beliefs, sense of belonging, and intended persistence over the course of three semesters. The second study employed multilevel modeling to examine how the weekly dynamics of students' physics ability beliefs, perceived recognition from others, academic task type, and perceived academic struggle related to changes in their sense of belonging, physics identity, and intent to persist in physics during a semester. The third and final study used dynamic narrative inquiry to explore the lived experiences and disciplinary identity development of undergraduate physics students with various, often intersecting marginalized social identities in the context of the interpersonal, cultural, structural, and disciplining power dynamics of their postsecondary physics learning spaces. Together, findings from these three

studies contribute to scholarship and practice that improves the environment of undergraduate physics courses for physics majors with a diversity of social identities and backgrounds.

Study 1

The first study employed a correlational, longitudinal survey design to examine the contextual dynamics of undergraduate physics majors' physics ability beliefs, sense of belonging, and persistence intentions over the course of three semesters. Participants included 125 undergraduate physics students enrolled in courses that incorporated an interactive experimental lab activity at a large, public, predominantly white institution (PWI) in the Southeastern United States (Southeastern University). This study was guided by a conceptual framework that combined concepts from three theoretical perspectives: implicit theories of intelligence (Dweck & Leggett, 1988; Murphy & Dweck, 2010), the field-specific ability beliefs hypothesis (Leslie et al., 2015), and Lewis & Hodges' (2015) model of academic belonging. My specific research question asked: *On average, are there significant linear changes in a student's' physics ability beliefs, sense of belonging, and intended persistence in physics over the course of three semesters? Do these changes depend on a student's gender, race, ethnicity, academic level, academic struggle, and perceptions that innate brilliance is required for success in the discipline?*

This study relied on multilevel modeling to evaluate the extent to which changes in outcomes of interest varied within and between students during the three semesters (Raudenbush & Bryk, 2002). Overall, the malleability of students' physics ability beliefs decreased over time. This trend was most apparent for students who experienced ongoing academic struggle in their physics courses and for students who perceived that innate, high level of intelligence is required for success in the discipline. Students with more malleable beliefs about their physics abilities

reported a greater sense of ability and social belonging in the physics major, though the magnitude of these relationships varied by students' gender, race, and ethnicity. Ability belonging, moreover, mediated the positive relationship between students' incremental physics ability beliefs and intended persistence in physics. Students who perceived innate brilliance as required for success in physics conveyed a lower academic belonging and lower persistence intentions. Importantly, women, Black, and Latine students reported a lower sense of belonging in the physics major than men, white, and Asian students, even after accounting for individual and disciplinary-level intelligence beliefs.

Study 2

The second study utilized a time-series survey design to investigate the contextual dynamics of undergraduate physics majors' beliefs and perceptions over a finer timescale. Specifically, it examined weekly variation in students' physics ability beliefs, perceptions of academic struggle, type of academic tasks encountered, and perceived recognition from peers and instructors over the course of a semester. In addition to this weekly data collection, participants completed three slightly longer surveys at the beginning, middle, and end of the semester that asked about their sense of belonging, physics identity, intent to persist in their major, and perceptions of their instructor's physics ability beliefs. Participants included 54 physics majors enrolled in an introductory or advanced major-specific college physics course at a large, public, research-intensive, PWI in the Southeastern United States that incorporated an interactive experimental lab activity. This study relied on a conceptual framework that combined concepts from three theoretical perspectives: implicit theories of intelligence (Dweck & Leggett, 1988; Murphy & Dweck, 2010), Lewis & Hodges' (2015) model of academic belonging, and Hazari et al.'s (2020) model of physics identity development. Specific research questions asked:

On average, are there significant linear changes in a student's' physics ability beliefs and perceived recognition over the course of a semester? Do these changes depend on a student's gender, race, ethnicity, course level, perceived academic struggle, type of academic task encountered during the week, and perceived instructor ability beliefs? On average, are there significant linear relationships between a student's physics ability beliefs, perceived recognition, sense of ability and social belonging in physics, physics identity, and an intent to persist in a physics major? Do these relationships depend on a student's gender, race, ethnicity, course level, and perceived instructor ability beliefs?

This study also used multilevel modeling, which accounted for the time-series, hierarchical structure of the dataset. On average, the malleability of students' physics ability beliefs decreased over the course of the semester. Changes in students' own incremental physics ability beliefs depended on both their course level and on aspects of their physics courses, including their perceptions of their instructor's physics ability beliefs and the type of academic task(s) they encountered in a given week. Notably, while students in the introductory physics course conveyed more incremental beliefs about physics abilities than students in the advanced physics course, introductory students reported a significant decline in the malleability of their physics ability beliefs during the semester relative to advanced students. In addition, students reported less malleable physics ability beliefs both on average and over time when they perceived that their course instructor held less malleable beliefs about undergraduates' physics abilities. The malleability of students' physics ability beliefs related to their perceived recognition as an exemplary physics student. Perceived recognition, in turn, positively related to students' level of social belonging and disciplinary identification. Students' perceptions of their instructor's physics ability beliefs related to their level of ability belonging in the physics major.

Ability belonging and social belonging positively correlated with students' level of disciplinary identification. Greater social belonging, moreover, corresponded to stronger persistence intentions in the discipline. At the same time, women, Black, and Latine students reported lower levels of belonging in the physics major than men, White, and Asian students even after accounting for the effects of physics ability beliefs and perceived recognition. Such findings emphasize that students with marginalized social identities contend with threats to their belonging in physics courses that incorporate an interactive instructional component above and beyond the impact of intelligence beliefs and external recognition.

Study 3

The third study employed dynamic narrative inquiry to explore the lived experiences and disciplinary identity development of undergraduate physics students with various, often intersecting marginalized social identities in major-specific physics courses that incorporate an experimental lab activity. In dynamic narrative inquiry, the researcher implements narrative activities relevant to the specific time, space, and purpose of one's research questions (Daiute, 2014). One intentionally solicits narratives from various relevant stakeholders, recognizing that their narrations of various topics or events will most likely differ in meaningful ways. As such, participants included 17 undergraduates at Southeastern University who completed at least one major-specific physics course that incorporated an experimental lab activity during the 2021-2022 academic year as well as 3 physics faculty and 2 graduate teaching assistants (TA) who led or supported such courses. This study applied Collins' (2009) Domains-of-Power Framework to investigate how students characterized their lived experiences and physics identity development in the context of the interpersonal, cultural, structural, and disciplining dynamics of major-specific physics courses. My specific research question asked: *How do undergraduates with*

marginalized or multiple marginalized social identities perceive and interpret their lived experiences and physics identity development in the context of the interpersonal, cultural, structural, and disciplinary power dynamics of major-specific physics courses that incorporate an experimental lab component?

Paradigmatic, value, and significance analyses within and across participants' narratives yielded 9 major themes and 22 subthemes that I further categorized into the four power domains. Narratives collected from physics program members with a variety of social identities and roles revealed common classroom and departmental norms and practices, some of which contested the discipline's white, masculine, heteronormative, able-bodied, middle- and upper-class traditions in ways that supported students with both marginalized and privileged social identities. At the same time, narratives from women and women of color highlighted the permanence of sexism and racism in physics spaces, which took the form of imposter syndrome, negative intelligence stereotypes, implicitly and explicitly exclusionary interactions and cultures, and gender-based harassment. In addition, course, programmatic, and university structures and practices at times disproportionately harmed neurodivergent and lower socio-economic students. Most undergraduate participants entered the physics program with a strong formal and informal foundation in STEM, which greatly supported their success and belonging in their physics courses. And while male and female LGBQ+-identified students saw the physics program as an overall inclusive space for LGBQ+ individuals, the one non-binary participant described unsupportive interactions with male peers. Findings emphasize the importance of undergraduate physics program members, particularly those in positions of power, to remain knowledgeable and aware of the dynamics of marginalization in physics learning spaces and to intervene in ways that continuously support and improve diversity, inclusion, and equity in the major.

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CHAPTER 2

CHARACTERIZING THE LONGITUDINAL DYNAMICS OF COLLEGE PHYSICS STUDENTS' PHYSICS ABILITY BELIEFS, SENSE OF BELONGING, & PERSISTENCE

Undergraduate physics programs prepare students for well-paying careers in a range of sectors (NRC, 2013). Physics' laws and theories are foundational for many fields of science, technology, engineering, and mathematics (STEM), and its applications contribute to a number of important spheres such as renewable energy, medical diagnostics, and information technology (NRC, 2013). Postsecondary credentials are required for most physics-related jobs. At the same time, physics consistently remains one of the least diverse STEM disciplines (NRC, 2013; NSF, 2019). In 2020 women earned just 24% of bachelor's degrees in physics, a percentage that has changed little over the past few decades (APS, 2023; Fayer et al., 2017; Porter & Ivie, 2019). Black, Latine, and Indigenous individuals earned 3.4%, 12.4%, and 3% of physics bachelor's degrees respectively, while women with these racial and ethnic identities together earned just 2% (APS, 2023). Each of these percentages only declines as one moves through higher levels of education (APS, 2023; Porter & Ivie, 2019). Understanding and addressing factors that contribute to the persistent underrepresentation of women, Black, Latine, and Indigenous students in postsecondary physics spaces is essential for both broadening access to high-paying STEM professions and strengthening the STEM workforce as a whole (NRC, 2013).

A growing body of work points to individual and shared belief systems regarding intelligence as contributing to the ongoing lack of diversity in physics (Bian et al., 2018; Leslie et al., 2015; Meyer et al., 2015; Storage et al., 2016). Physics is widely regarded as being the most intellectually challenging scientific field (Archer, 2020a; Cheryan et al., 2017; Frances et

al., 2017; Hughes, 2001; Traweek, 1988, p. 162). Popular portrayals of physicists depict a lone, socially awkward genius who is almost always white and male. Members of the discipline itself often ascribe to this *lone-genius* myth and tend to identify a high innate intelligence as a prerequisite for success in the field (Cheryan et al., 2017; Gonsalves & Danielsson, 2020; Law, 2020; Leslie et al., 2015). Physics' association with exceptional, solitary intellectual talent fosters a *culture of brilliance* in its disciplinary spaces, a culture that encourages competition over collaboration and elevates a mythical ideal of high inherent intellectual ability as a prerequisite for academic success and disciplinary membership (Leslie et al., 2015; Little et al., 2019; NRC, 2013).

This *culture of brilliance* is harmful to individuals with a wide range of backgrounds and social identities (Laws, 2020; NRC, 2013). At the same time, it is particularly exclusionary for women, Black, Latine, and Indigenous individuals who, due to oppressive societal stereotypes, are unjustly positioned as less innate intellectually talented than their male, white, and Asian peers (Bian et al., 2018; Leslie et al., 2015; Storage et al., 2016). Negative intelligence stereotypes situate women, Black, Latine, and Indigenous individuals in fundamental opposition to cultural notions of the prototypical brilliant person. As a result, instances of bias and discrimination against individuals with these marginalized social identities are higher in disciplinary settings that emphasize innate brilliance over dedication and hard work (Clark et al., 2021; Leslie et al., 2015; Rattan et al., 2018). When internalized, negative intelligence stereotypes can also lead women, Black, Latine, and Indigenous individuals to question their own capacity to succeed, belong, and persist in brilliance-focused fields such as physics and math (Archer et al., 2020a; Bian et al., 2018; Dar-Nimrod & Heine, 2006; Leslie et al., 2015; Murphy & Zirkel, 2015; Steele et al., 2002). For example, women are more likely than men to

experience anxiety when studying in brilliance-focused academic settings, in part because they do not visualize themselves as a prototypical brilliant person (Bian et al., 2018). Qualitative work further suggests that regardless of their degree of academic success, both white women and women of color studying physics often perceive themselves as being at odds with celebrated notions of "ordinary" and "effortlessly clever" physicists (Archer et al., 2020a, p. 18; Ong, 2005, p. 600).

Postsecondary educational environments play an important part in (re)shaping and communicating the intellectual characteristics required for membership and success in various disciplines (Meyer et al., 2015). Explicit and implicit cues from instructors, mentors, peers, and curricula convey the notions of intelligence valued in academic settings, and these cues influence the beliefs, perceptions, and behaviors of college students studying in particular fields (Good et al., 2012; Murphy & Dweck, 2010). College STEM courses, particularly those at the introductory level, often promote a survival-of-the-fittest atmosphere that encourages competition among students to prove their intellectual talent and superiority (Seymour & Hunter, 2019). Such a learning environment reinforces the notion that success in STEM fields requires a certain innate level of intelligence (Mervis, 2011). Indeed, empirical evidence documents that as undergraduates move through college-level STEM courses, they often adopt increasingly fixed beliefs about their intellectual ability in specific STEM subjects (Dai & Cromley, 2014; Flanigan et al., 2017; Limeri et al., 2020a; Malespina et al., 2022; Marshman et al., 2018; Shively & Ryan, 2013). Students with fixed ability beliefs (known also as entity beliefs or a fixed mindset) view their intelligence as largely inherent and unchanging (Dweck, 2012). In contrast, those with malleable ability beliefs (known also as incremental beliefs or a growth mindset) view their intelligence as capable of change with strategic effort and experience. In undergraduate STEM

settings, students with entity beliefs about their intellectual ability in a particular domain report less confidence, lower academic performance, and greater attrition in their STEM courses and majors than those with incremental beliefs (Dai & Cromley, 2014; Shively & Ryan, 2013). While several studies have isolated factors that contribute to observed changes in undergraduates' ability beliefs during college STEM courses, existing research focuses primarily on student-level variables (Flanigan et al., 2017; Kalender et al., 2022; Limeri et al., 2020a; Little et al., 2019). Much remains to be learned about how college STEM students' intellectual ability beliefs shift and change as they engage with various aspects of their disciplinary environments (Little et al., 2019).

The beliefs about intelligence that are conveyed in college STEM settings are particularly influential on the academic experiences and trajectories of college students whose gender, racial, and ethnic identities are marginalized by negative intelligence stereotypes (Canning et al., 2019; Good et al., 2012; LaCosse et al., 2020; Rattan et al., 2018). Black, Latine, and Indigenous students receive significantly lower grades than white and Asian students in college STEM courses led by instructors who endorse entity beliefs about their students' intellectual abilities (Canning et al., 2019). Women in STEM similarly anticipate significantly worse experiences in courses taught by such instructors (LaCosse et al., 2020). The precise causes of these outcomes are unclear, though literature suggests that environments that promote the notion that fixed, high intelligence is required for success can prompt students from marginalized groups to question whether they possess the ability needed to achieve and belong in an academic community (Bian et al., 2018; Clark et al., 2021; Good et al., 2012; Rattan et al., 2018).

Students develop a sense of belonging in a particular academic domain when they perceive that they fit intellectually and socially in their disciplinary spaces (Johnson, 2012;

Lewis & Hodges, 2015; Stayhorn, 2018). An ample body of scholarship positions academic belonging as an important influence on students' engagement, achievement, and persistence (Freeman et al., 2007; Hausmann et al., 2007; Hurtado & Carter, 1997; Murphy & Zirkel, 2015; Strayhorn, 2019; Zirkel, 2004). While a sense of belonging is necessary for all students, the literature suggests it is especially salient for those with social identities that are underrepresented and marginalized in particular educational settings (Murphy & Zirkel, 2015; Sax et al., 2018; Steele et al., 2002). Such students are often more uncertain of their belonging than their peers and are more in tune with situational cues that validate or threaten the perceived legitimacy of their academic fit (Boucher & Murphy, 2017; Cheryan et al., 2009; Hughes et al., 2015; Lewis et al., 2017; Walton & Cohen, 2007). Black, Latine, and Indigenous students studying STEM at predominantly white institutions, for example, navigate perpetual threats to their belonging due to marginalization by their college or university (Dortch & Patel, 2017; Walton & Cohen, 2007). In college STEM environments, particularly those with disciplinary cultures of brilliance, entity beliefs may act as another threatening cue (Bian et al., 2018; Canning et al., 2019; Clark et al., 2021; Good et al., 2012; Rattan et al., 2018). Existing evidence documents that women and Black STEM students report a decline in their sense of belonging and intent to persist relative to their non-marginalized peers when they perceive that their STEM environment promotes entity-oriented views of intelligence or a culture of brilliance (Bian et al., 2018; Clark et al., 2021; Deiglmayer et al., 2019; Good et al., 2012; Rattan et al., 2018). The present study adds novel insight into how college students' *own* domain-specific intellectual ability beliefs change in relation to their perceptions of disciplinary-level cultures of brilliance and how such shifts influence academic belonging and persistence, particularly for students marginalized in a field (Bian et al., 2018).

Undergraduate physics courses traditionally employ a lecture-recitation format in which instructors convey established knowledge and procedures while students passively take notes and complete structured problems (NRC, 2013). This instructional format inhibits physics students from actively engaging in their own learning (NRC, 2013). Research supports that it also helps to fuel competitive classroom cultures that contribute to the marginalization of women, Black, Latine, and Indigenous students in physics spaces (NRC, 2013). In response to the shortcomings of the traditional lecture-recitation model, physics education researchers have increasingly developed and implemented interactive instructional approaches in college physics classrooms (NRC, 2013). These approaches seek to enhance students' cognitive and affective growth by employing collaborative engagement techniques that support scientific thinking, problem-solving, and metacognition capabilities (Freeman et al., 2014; Karim et al., 2018; NRC, 2013; Theobald et al., 2020).

Empirical evidence suggests that interactive instructional approaches benefit college physics students' academic performance, attitudes, and beliefs (Freeman et al., 2014). Over the past few decades, a number of physics education researchers have explored whether these approaches might serve as a tool for increasing the persistence of physics students with marginalized identities (Karim et al., 2018; Lorenzo et al., 2006; Pollock et al., 2007; Rodriguez et al., 2016). To date, most studies in this area focus on whether various interactive approaches narrow the "gap" in standardized conceptual assessment scores, exam grades, and course passing rates between marginalized and non-marginalized students (Brewe et al., 2010; Karim et al., 2018; Lorenzo et al., 2006; Maries et al., 2020; Pollock et al., 2007). Existing evaluations concerning the effectiveness of interactive physics pedagogies in decreasing these gaps in performance are mixed (Karim et al., 2018; Maries et al., 2020; Pollock et al., 2007). The

strengths of such approaches appear to depend largely on their implementation and classroom context (Theobald et al., 2020; Maries et al., 2020; Pollock et al., 2007). In recent years, scholars have pointed out that focusing solely on achievement comparisons when evaluating interactive instructional approaches promotes a deficit perspective that perpetuates the marginalization of women, Black, Latine, and Indigenous students in physics spaces (Traxler et al., 2016). To date, relatively few studies have focused on non-cognitive factors such as intellectual ability beliefs and belonging when studying interactive approaches in college physics classrooms (Good et al., 2019; Little et al., 2019). Such information is necessary for understanding how interactive physics classrooms can foster diversity, inclusion, equity, and justice in physics learning spaces by reframing the qualities promoted as necessary for success, belonging, and persistence.

Purpose of Study

The purpose of this longitudinal survey study was twofold. The first goal was to examine the contextual dynamics through which undergraduate physics majors' domain-specific ability beliefs shifted and changed over the course of three semesters. Specifically, I examined these dynamics for undergraduates enrolled in major-specific physics courses that incorporated an interactive experimental lab activity. The second goal was to explore the relationships between students' personal and environmental contexts, their physics ability beliefs, their academic sense of belonging, and their short-term persistence intentions over the same time period.

Research Question

On average, are there significant linear changes in a student's physics ability beliefs, sense of belonging, and intended persistence in physics over the course of three semesters? Do these changes depend on a student's gender, race, ethnicity, academic level, academic struggle, and perceptions that innate brilliance is required for success in the discipline?

Literature Review

This literature review synthesizes existing research in multiple areas pertinent to the present study. I begin by providing a theoretical and empirical overview of implicit ability beliefs. I then focus more specifically on work that examines the dynamic, domain-specific nature of college students' ability beliefs. Next, I concentrate on the role of field-specific ability beliefs in creating and perpetuating disparities in brilliance-focused disciplines. I then cover the concept of academic belonging, dissect differences in physics belonging based on gender, race, and ethnicity, and discuss the relationships between domain-specific ability beliefs, academic belonging, and persistence in college STEM settings. I end with an overview of interactive instructional approaches in college physics courses.

Implicit Ability Beliefs

In studying children's approaches to achievement and challenges in school settings, Dweck and colleagues generated a model that framed students' perceptions, goals, and actions as resulting from different implicit theories of intelligence (Dweck & Leggett, 1988). Today often referred to as implicit ability beliefs or mindsets, implicit theories of intelligence were named as such due to their often-unconscious influences on attitudes, perceptions, emotions, and behavior (Dweck & Leggett, 1988; Dweck, 2012). Individuals who ascribe to entity beliefs (also known as an entity theory or fixed mindset) view their intellectual ability as more or less innate and stable. Those who hold incremental beliefs (also known as an incremental theory or growth mindset) view their intellectual ability as capable of growth and change (Dweck & Leggett, 1988; Dweck, 2012). According to Dweck's model, implicit ability beliefs act as the basis of meaning systems that organize and guide one's actions in academic settings (Dweck & Yeager, 2019; Hong et al., 1999). Empirical evidence suggests that the meanings individuals and groups ascribe to things

such as effort, challenge, and failure vary according to their ability beliefs and that this variation can produce divergent behavioral responses (Blackwell et al., 2007; Hong et al., 1999; Miele et al., 2013; Nussbaum & Dweck, 2008; Robins & Pals, 2002). Students with entity beliefs are more likely to attribute success to inherent traits and talents (Robins & Pals, 2002). They tend to view effort as an indication of low ability, are less likely to develop learning-focused goals, and often employ ineffective, defensive strategies when faced with academic setbacks (Hong et al., 1999; Nussbaum & Dweck, 2008). On the other hand, students with incremental beliefs view effort and setbacks as key components of mastery and are more likely to develop effective learning strategies that promote persistence in the face of academic challenges (Hong et al., 1999; Robins & Pals, 2002).

Implicit Ability Beliefs & Student Outcomes

The divergent meaning systems generated by students' implicit ability beliefs can carry important consequences (Blackwell et al., 2007; Robins & Pals, 2002; Yeager et al., 2019). Multiple studies correlate incremental ability beliefs with factors such as greater self-esteem, self-efficacy (a belief in one's capacity to achieve a desired result), academic belonging, and STEM career intentions (Bandura, 1986; Degol et al., 2018; Good et al., 2012; Robins & Pals, 2002; van Aalderen-Smeets et al., 2019). Research also suggests positive links between incremental ability beliefs and academic achievement, though such findings are not universal across the literature (Aronson et al., 2002; Blackwell et al., 2007; Burgoyne et al., 2020; Kalender et al., 2022; Malespina et al., 2022; Sisk et al., 2018; Yeager et al., 2019). Several correlational studies found that middle and high school students with incremental ability beliefs performed significantly higher than those with entity beliefs both in courses and on standardized assessments (Blackwell et al., 2007; Claro et al., 2016; Romero et al., 2014; Schleicher, 2019).

Two recent empirical investigations similarly observed that college students with fixed disciplinary-specific ability beliefs obtained lower final grades in calculus-based introductory physics courses (Kalender et al., 2022; Malespina et al., 2022). Kalender et al. (2022) further determined that fixed notions of physics ability partially explained women's lower final physics grades in an introductory calculus-based physics, as women were more likely than men to hold fixed views about their physics abilities. Other scholars have experimentally explored how interventions meant to teach students to view their intellectual ability as malleable impact academic achievement, particularly for students with gender, racial, and ethnic identities negatively stereotyped in school settings (Aronson et al., 2002; Binning et al., 2020; Good et al., 2003; Yeager et al., 2019). Aronson et al. (2002) found that Black college students exposed to such an intervention had greater GPAs than those in a control group who did not receive an intervention. Good et al. (2003) determined that female 7th grade students who completed a growth-oriented intervention earned higher scores on standardized math and reading tests than their peers. Binning et al. (2020) exposed college students in an introductory biology and an introductory calculus-based physics course to a series of reflective writing and interactive classroom activities meant to help normalize academic struggle. Students who were exposed to the activities had greater attendance, course grades, 1-year persistence in college, and 2- to 4-year cumulative GPA than those who were not. The benefits of the activities on students' grades were particularly pronounced for women the physics course and for students of color the biology course (Binning et al., 2020). These and other findings suggest that for students with marginalized identities, malleable intellectual ability beliefs may help buffer against the negative effects of stereotype threat on academic achievement (Aronson et al., 2002; Binning et al., 2020; Claro et al., 2016; Good et al., 2003; Good et al., 2012). Interventions that promote incremental

ability beliefs also appear to improve grades for low-achieving students, though only when a student's classroom environment also emphasizes malleable views of intelligence (Yeager et al., 2019). At the same time, the benefits of interventions that promote incremental ability beliefs may not extend to all students (Burgoyne et al., 2020; Sisk et al., 2018). In an extensive meta-analysis of over 300 studies examining relationships between intellectual ability beliefs and academic achievement in students with a wide range of identities and backgrounds, Sisk et al. (2018) found a weak, non-significant effect of classroom interventions meant to promote incremental ability beliefs on academic achievement. In fact, evidence suggests that fixed ability beliefs can actually bolster the performance of students from favorably stereotyped groups (such as white men) as well as high-achieving students who do not encounter challenges in a particular evaluative situation (Dweck, 2012; Mendoza-Denton et al., 2008). Sisk et al. (2018) point out that mixed results from ability belief intervention may stem in part from the fact that such interventions do not necessarily universally impact students' actual beliefs about their intellectual abilities across a variety of contexts and domains.

Intraindividual Change in Ability Beliefs

While an individual's implicit intellectual ability beliefs were initially seen as fairly static, a growing body of evidence supports that such beliefs develop and shift over time through interactions with the environment (Dweck & Yeager, 2019; Dweck, 2012; Kinlaw & Kurtz-Costes, 2003; Little et al., 2019). To date, most research on shifts in ability beliefs focuses on K-12 groups, though empirical work also documents changes in college student populations (Dai & Cromley, 2014; Flanigan et al., 2017; Kinlaw & Kurtz-Costes, 2003; Limeri et al., 2020a; Malespina et al., 2022; Shively & Ryan, 2013). In college STEM settings, undergraduates commonly report an average increase in entity beliefs over the course of introductory classes

(Dai & Cromley, 2014; Flanigan et al., 2016; Marshman et al., 2018; Malespina et al., 2022; Shively & Ryan, 2013). An investigation of changes in college students' ability beliefs during a semester-long organic chemistry course observed that undergraduates who perceived continuous struggle in the course reported a greater increase in entity beliefs over time than those who either did not or who overcame struggle (Limeri et al., 2020a). Students who perceived continuous struggle also started the semester with greater entity beliefs than those who did not, suggesting a potentially reciprocal relationship between implicit ability beliefs and academic struggle (Limeri et al., 2020a). Malespina et al. (2022) determined that over the course of an introductory calculus-based college physics course, women became increasingly more likely than men to believe that a fixed, inherent intellectual ability was necessary to be successful in physics. Little et al.'s (2019) qualitative exploration of students' approaches to challenges in a college physics class demonstrated that a particular student could exhibit more fixed or growth beliefs and behaviors depending on the context of the challenge itself. For example, a single student might employ an incremental belief system when completing a low-stakes homework assignment and an entity belief system while taking a high-stakes exam. Much remains unknown about the contextual dynamics through which college students' ability beliefs change as they interact with their learning environments (Dweck, 2012; Limeri et al., 2020a; Little et al., 2019).

Domain-Specific Ability Beliefs

The vast majority of theoretical and empirical literature related to implicit ability beliefs examines individuals' conceptions of their general intellectual ability, without considering if and how such conceptions might vary across different academic domains. Newer research questions the logic of focusing on general intelligence alone and calls for the development of domain-specific scales that measure students' ability beliefs in various subject areas (Dai & Cromley,

2014; Kalender et al., 2022; Limeri et al., 2020b; Malespina et al., 2022; Shively & Ryan, 2013; van Aalderen-Smeets et al., 2019). Domain differentiation becomes more important as students advance through higher levels of education and are exposed to a wider range of disciplines (Gunderson et al., 2017; Limeri et al., 2020b). Studies that rely only on general intelligence survey items to understand how students' implicit ability beliefs relate to various outcomes run the risk of missing important inferences related to domain-specific ability beliefs (Limeri et al., 2020b; Shively et al., 2013; van Aalderen-Smeets et al., 2019). The present study addressed this concern by employing a scale that asked students to identify their physics ability beliefs rather than their general intellectual ability beliefs.

Field-Specific Ability Beliefs & Disciplinary Disparities

Leslie et al. (2015) coined the phrase "field-specific ability beliefs" to describe intellectual ability beliefs that prevail across entire disciplines and in turn shape their values, norms, and traditions (p. 262). Fields such as physics, math, and philosophy that elevate inherent, exceptional intellectual ability over effort and dedication contain disproportionately low numbers of women, Black, Latine, and Indigenous individuals (Leslie et al., 2015; Meyer et al., 2015; Storage et al., 2016). The detrimental effect of disciplinary cultures of brilliance on the representation of such groups stems from pervasive cultural stereotypes that stigmatize individuals with such identities as less innately intelligent (both generally and in specific areas such as science and math). Though not supported by scientific fact, these negative intelligence stereotypes continue to systematically marginalize and exclude stigmatized groups from disciplinary environments that elevate inherent giftedness as a requirement for success (Bian et al., 2018; Storage et al., 2016). Disciplinary cultures of brilliance correlate with bias and discrimination against individuals from stereotyped groups (Leslie et al., 2015; Storage et al.,

2016). In addition, environments that emphasize brilliance are more likely to activate stereotype threat in intellectually stigmatized individuals, or a preoccupation with a negative stereotype that reduces one's confidence and focus (Dar-Nimrod & Heine, 2006; Steele & Aronson, 1995). Experimental evidence suggests that women are more likely than men to feel anxious about their ability to belong and succeed in brilliance-focused environments, in part because they perceive that they do not align with the prototype of a brilliant person (Bian et al., 2018; Deiglmayer et al., 2019).

While conceptual overlap exists between fixed notions of intellectual ability and the assumption that innate brilliance is required for success in certain fields, empirical evidence suggests these two constructs are in fact distinct (Rattan et al., 2012). As a whole, individuals are more likely to believe that exceptional intellectual ability (as opposed to intellectual ability itself) cannot be acquired through hard work alone (Rattan et al., 2012). At the same time, it is possible that students' own implicit intellectual ability beliefs may shape their perceptions and behaviors in brilliance-focused fields. Multiple researchers have suggested that incremental ability beliefs might promote the persistence of marginalized students in such disciplines, but this relationship has not yet been empirically explored (Bian et al., 2018; van Aalderen-Smeets et al., 2018). My study addressed this gap by examining relationships between students' own domain-specific ability beliefs, their perceptions that brilliance is required for success in their field, and their sense of belonging and intended persistence in their major.

Academic Sense of Belonging

A sense of belonging, defined here as a subjective feeling of connection and legitimacy as a valued group member in a social setting, is fundamental to a person's overall well-being (Baumeister & Leary, 1995; Strayhorn, 2019). In academic contexts, students develop a sense of

belonging through sustained, positive interactions with key players in their educational environments, including their peers, instructors, school staff, and course curricula (Boucher & Murphy, 2017; Freeman et al., 2007; Hurtado & Carter, 1997; Strayhorn, 2019). A wealth of research supports that academic belonging is particularly important for the engagement, achievement, and persistence of students with identities that are underrepresented and marginalized in their educational environments (Freeman et al., 2007; Hausmann et al., 2007; Hurtado & Carter, 1997; Murphy & Zirkel, 2015; Sax et al., 2018; Strayhorn, 2019; Steele et al., 2002). Such students are more vulnerable to situational cues that threaten the legitimacy of their group membership (Cheryan et al., 2009; Boucher & Murphy, 2017; Hughes et al., 2015; Lewis et al., 2017; Walton & Cohen, 2007). Given the situational, relational nature of students' belongingness, it is valuable to examine this construct in the context of particular academic environments and domains.

In studying the academic sense of belonging of college STEM students, Lewis and Hodges (2015) recognized the necessity of examining not only students' perceived social belonging but also their level of ability belonging in their STEM discipline. Whereas social belonging pertains to feeling accepted and valued by other members of one's STEM learning environments, ability belonging refers to one's perceived intellectual competence and fit relative to others in an academic domain. An individual's level of ability belonging in a domain relates to their academic self-concept, or their perceived competence in a particular academic subject in relation to their peers' (Marsh, 1986; Sax, 1994; Sax, 2008; Sax et al., 2015). Women commonly self-report significantly lower perceived competence in quantitative-heavy disciplines such math and physics than men regardless of their objective academic success (Goetz et al., 2013; Sax, 1994; Sax et al., 2015). While gender gaps in perceived math ability frequently appear in K-12

settings, empirical evidence suggests that these gaps often intensify as individuals move through college STEM courses (Sax, 1994). High social and ability belonging together predict students' motivation and intent to persist in various STEM disciplines (Lewis & Hodges, 2015; Rainey et al., 2018). As such, it is important to take into account both social and ability belonging when examining students' overall sense of belonging in an academic domain. The following sections synthesize literature on the academic social and ability belonging of college students with gender, racial, and ethnic identities underrepresented in physics and related STEM fields.

Gender & Academic Sense of Belonging

Across educational levels women commonly report lower levels of social and ability belonging in their physics and mathematical learning environments (Lewis et al., 2016; Lewis et al., 2017; Sax, 1994; Sax et al., 2015; Seyranian et al., 2018). In a series of field studies on 3,000 postsecondary students, Lewis et al. (2017) found women expressed a lower overall sense of belonging in their discipline than men regardless of their academic performance. This lower sense of belonging correlated with a lower short- and long-term persistence for women, though sense of belonging did not relate to persistence for men (Lewis et al., 2017). Perez-Felkner et al. (2017) determined a similar connection between lower women's math ability belonging and lower persistence in secondary students interested in physics, math, engineering, and computer science.

Several studies have explored gender-specific changes in physics social and ability belonging during students' experiences in college physics and math courses. Seyranian et al. (2018) repeatedly surveyed 160 undergraduates during an introductory physics course and observed that women reported a lower social belonging in their course as well as a lower identification with physics. Banchefsky et al. (2019) collected data on students in physics and

calculus courses and discovered that women perceived a lower overall ability belonging in STEM even though they placed greater importance on succeeding academically in math and science. In line with prior literature, social and ability belonging both predicted students' intent to persist in their STEM field, though the relationship between social belonging and persistence was stronger for women (Banchefsky et al., 2019).

What accounts for pervasive gender disparities in social and ability belonging in physics and related disciplines and the heightened importance of belonging for the achievement and persistence of women in these fields? A review by Lewis et al. (2016) isolated negative intelligence stereotypes, disciplinary cultures of brilliance, classroom-level entity ability belief systems, a lack of role models and positive peer relationships, and exclusionary environments as contributors to women's lower sense of belonging in physics spaces. As previously discussed, negative stereotypes about women's lower innate abilities in math and science are prevalent in academic spaces. These stereotypes, paired with physics' disciplinary-wide culture of brilliance, can cause women to question whether they intellectually belong in the field (Bian et al., 2018; Leslie et al., 2015). Interviewing seven young women who expressed an interest in physics on a biannual basis over the course of five years, Archer et al. (2020) found that, despite their academic success, most did not view themselves as naturally "clever enough" to continue in the discipline (p. 15). Even the one young woman in their study who decided to major in physics in college did not view herself as an "effortlessly clever physicist" (p. 18). At the graduate level, Smith et al. (2013) determined that women in male-dominated STEM fields believe that they need to work harder to reach the same accomplishments as men. In addition, physics continues to be viewed both in and outside of academia as a masculine discipline and postsecondary physics programs remain predominantly male (Bjorkquist et al., 2019). This leads to a disproportionate

lack of female role models and peers, two factors known to reduce belonging for aspiring female physicists (Murphy et al., 2006; Rainy et al., 2018). Lastly, exclusionary environments, which range from unwelcome disciplinary cultures and microaggressions (brief derogatory messages), to overt sexism, harassment, and discrimination, keep female physicists from achieving and maintaining a sense of belonging in their classrooms and labs (Bjorkquist et al., 2019; Gonsalves et al., 2016; Settles et al., 2006). Together, these factors frequently lead women to question the extent to which they belong intellectually and socially in the field of physics (Lewis et al., 2016).

Race, Ethnicity, & Academic Sense of Belonging

Black, Latine, and Indigenous students also possess a lower sense of social and ability belonging in physics learning environments than their non-minoritized peers (Fries-Britts et al., 2010; McGee, 2016). Indeed, a 2020 report by the American Institute of Physics (AIP) identified sense of belonging as a core factor that supports or deters the academic success and persistence of undergraduate African American students in physics and astronomy. The report highlighted the lack of welcoming, inclusive classroom, lab, departmental, and disciplinary environments as a central cause of the ongoing underrepresentation of African Americans in the field of physics (AIP, 2020). These exclusionary environments arise in part from physics' roots of "white empiricism" which elevates white people as the only group capable of true scientific objectivity and thus the only group that truly belongs in scientific spaces (Prescod-Weinstein, 2020, p. 421). As a result of white empiricism and negative intelligence stereotypes, as well as other racist biases and structures, Black, Latine, and Indigenous students are forced to regularly justify their intellectual ability and right to exist in physics and other STEM disciplines (Fries-Britt & Holmes, 2012; Frier-Britt, Johnson, & Burt, 2013; MeGee, 2016). In physics departments at

predominantly white institutions, underrepresented students of color must also contend with marginalization by their college or university as a whole (Dortch & Patel, 2017; Fries-Britt et al., 2013; Walton & Cohen, 2007).

Positive faculty and peer interactions are important in supporting the postsecondary experiences and trajectories of Black, Latine, and Indigenous physics students (AIP, 2020, Fries-Britt, Younger, & Hall, 2010). At the same time, negative faculty and peer interactions are exceedingly common for racially and ethnically minoritized students in physics spaces (AIP, 2020; Fries-Britts et al., 2010; McGee, 2016). Negative interactions create hostile, isolating learning environments that reduce students' sense of belonging and deter them from persisting over time (AIP, 2020; Castellanos, 2018). Studies exploring the experiences of Black and Latine physics undergraduates reveal that such students face microaggressions , negative intelligence stereotypes, a lack of recognition for their work, and other forms of racial and ethnic hostility and discrimination from their instructors, mentors, and peers (AIP, 2020; Fries-Britt & Holmes, 2012; MeGee, 2016). In addition to reducing social and ability belonging, such interactions promote imposter syndrome, stereotype threat, and isolation (AIP, 2020). Importantly, while negative faculty and peer interactions are more prevalent at predominantly white institutions, physics departments at minority-serving institutions can and do transmit exclusionary messages as well, particularly as plenty of faculty members at these institutions are not themselves from underrepresented racial and ethnic groups (McGee, 2016).

Physics students with multiple marginalized identities possess experiences that influence their sense of belonging in unique ways (Johnson et al., 2017). Minoritized women commonly document heightened microaggressions and stereotype threat (Fries-Britt & Holmes, 2012; Johnson et al., 2017). Across STEM fields, Black, Latina, and Indigenous women often report a

very low sense of belonging in their disciplinary environments (Johnson, 2012; Rainy et al., 2018). Minoritized women commonly document heightened biases and negative intelligence stereotypes (Johnson et al., 2017). Given their small numbers in many STEM programs, underrepresented women of color also frequently describe intense isolation that comes from feeling both ignored and hyper-visible (Johnson et al., 2017; Ong, 2005; Rosa & Mensah, 2016).

Domain-Specific STEM Ability Beliefs, Sense of Belonging, & Persistence

Although incremental implicit ability beliefs and a strong sense of belonging both predict undergraduate STEM persistence, particularly for students with marginalized gender, racial, and ethnic identities, very few studies have empirically examined the relationship between these variables (Cook et al., 2017; Good et al., 2012; Goyer et al., 2021; Kricorian et al., 2020; Smith et al., 2013). In a longitudinal study of a college calculus course, Good et al. (2012) found women who perceived their classroom environment promoted an entity view of math ability experienced a marked decline in math social belonging and intended persistence over time, particularly in the presence of negative stereotypes about women's math ability. Women who perceived their classroom as promoting an incremental view of math ability maintained a greater level of math belonging and intended persistence, despite negative gender stereotypes (Good et al., 2012). Clark et al. (2021) determined that women studying in a range of STEM fields anticipated greater sexism and experienced a lower sense of belonging and commitment to persist when they perceived members of their STEM department to hold entity-oriented views of intelligence. Several other studies have asked women and/or Black students about their anticipated sense of social belonging in fields and programs that emphasize varying notions of intelligence. On average, women and Black students anticipate less belonging in academic

settings that promote innate brilliance and/or entity ability beliefs (Bian et al., 2018; Deiglmayr et al., 2019; Rattan et al., 2018; Smith et al., 2013).

These studies provide valuable insights, though most fail to examine the role of students' racial and ethnic identities in shaping such trends. In addition, the abovementioned studies do not focus on students' own domain-specific intellectual ability beliefs or level of ability belonging. The potential for a college student's domain-specific intellectual ability beliefs to shape their social belonging, ability belonging, and persistence in a field has been suggested, though to the best of my knowledge not previously tested (Boucher & Murphy, 2017; Murphy & Zirkel, 2015). It is possible that a student's domain-specific incremental ability beliefs could help to promote a sense of social and intellectual fit. Such a dynamic could reduce the influence of negative societal stereotypes as well as the impact of disciplinary cultures of brilliance on the persistence of STEM students from intellectually marginalized groups (Bian et al., 2018).

Interactive Instructional Approaches in College Physics Courses

Traditional modes of postsecondary physics instruction follow a lecture-based model that positions students as predominantly passive recipients of established knowledge (NRC, 2013). In such settings, physics instructors present concepts and examples while students take notes and attempt structured practice problems. Recitation and laboratory sessions that typically accompany traditional introductory physics courses tend to conform to a similarly prescribed format in which students tightly follow predetermined protocols to solve problems and carry out experiments (Etkina & Murthy, 2006; NRC, 2013; Wilcox & Lewandowski, 2016). Decades of empirical research document the limitations of this traditional lecture-recitation-laboratory format in fostering the development of students' quantitative reasoning, conceptual understanding, experimental skills, and positive attitudes toward physics (Etkina & Murthy,

2006; Hake, 1998; NRC, 2013; Redish et al., 1998; Wilcox & Lewndowski, 2016). Evidence also suggests that this course format inhibits the inclusion of students with marginalized identities by promoting classroom cultures of brilliance and competition that foster a weed-out mentality (Brewe et al., 2010; NRC, 2013; Seymour & Hunter, 2019; Theobald et al., 2020).

In response to the shortcomings of the traditional model, physics education researchers have developed and implemented numerous interactive instructional approaches in college physics classrooms (NRC, 2013). While they vary in structure, scope, and practice, these approaches seek to enhance students' cognitive and affective growth by supporting their scientific thinking, problem-solving, and metacognition capabilities (Freeman et al., 2014; Karim et al., 2018; NRC, 2013; Theobald et al., 2020). Common across interactive approaches is an appreciation for the social, embedded nature of learning; an acknowledgment that students' acquisition of knowledge and skills are inherently situated in the contexts, cultures, and histories of particular disciplinary settings (Finkelstein, 2005; Lave & Wegner, 1991). Interactive approaches tend to be collaborative in nature and encourage physics students to authentically engage with their instructors and peers to design and test models, explore concepts, laws, and theories, and carry out experiments (Brewe et al., 2010; Etkina & Murthy, 2006; Freeman et al., 2014; NRC, 2013). As students engage in these interactive learning endeavors, they receive timely, scaffolded instructor and/or peer feedback that guides and supports them in achieving learning goals (Karim et al., 2018). Examples of such approaches include Peer Instruction (PI), which incorporates electronic clicker questions and small-group discussions into lectures (Mazur, 1997), Modelling Instruction (MI), in which students create models to explore and represent concepts (Brewe et al., 2010), and SCALE-UP, which restructures standard lecture halls into rooms with small tables where students participate in collaborative learning activities

related to the topic at hand (Beicher & Saul, 2003). Another established interactive approach, the Investigative Science Learning Environment (ISLE), focuses heavily on exposing physics students to the process of learning science through *doing* science (Etkina & Murthy, 2006). This specific approach provides students with scaffolded opportunities to collaboratively construct and test hypotheses, analyze data, and generate conclusions on topics relevant to the physics course at hand (Etkina & Murthy, 2006). A central goal of the ISLE is to "empower" students to think and reason through problems like experimental physicists and in doing so learn to effectively persevere through academic challenges using strategic trial-and-error (Etkina et al., 2021, p. 10).

A wealth of physics education research focuses on characterizing student cognitive and affective outcomes in interactive physics courses, particularly in relation to traditional courses formats (Freeman et al., 2014; Karim et al., 2018; Maries et al., 2020; Rodriguez et al., 2016). College students participating in physics courses that incorporate interactive approaches often perform better on standardized physics assessments such as the Force Concept Inventory (FCI) and the Conceptual Survey of Electricity and Magnetism (CSEM) than those in traditional lecture-based courses (Brewe et al., 2010; Karim et al., 2018; Maries et al., 2020; Rodriguez et al., 2016). A meta-analysis of 225 studies comparing exam scores and passing rates between interactive and traditional lecture-based college STEM courses determined that incorporating active learning techniques increased student exam scores by around 6% (Freeman et al., 2014). College students in traditional lecture-based STEM courses were moreover 1.5 times more likely to fail than those in active learning STEM courses (Freeman et al., 2014). Physics students in courses that employ ISLE and Modeling Instruction approaches self-report a significant growth

in positive attitudes and expert-like beliefs over the course of the semester (Madsen et al., 2013; Rodriguez et al., 2016; Wilcox & Lewandowski).

Marginalized Student Outcomes in Interactive College Physics Courses

Given the documented benefits of interactive instructional approaches on physics students' academic success, attitudes, and beliefs, physics education researchers have explored whether interactive learning techniques can serve as a tool for increasing the performance and persistence of physics students with marginalized identities. To date, most work focuses on whether interactive approaches narrow the "achievement gap" between men and women in introductory college physics courses on standardized assessments such as the FCI and CSEM (Brewe et al., 2010; Karim et al., 2018; Lorenzo et al., 2006; Maries et al., 2020; Pollock et al., 2007). Men often obtain higher scores on these assessments than women (Docktor & Heller, 2008; Henderson et al., 2017; Madsen et al., 2013; McCullough, 2018; Tai & Sadler, 2001). The reasons behind this achievement disparity are debated, though factors such as lower exposure to formal and informal physics learning experiences among women, stereotype threat, and the masculine nature of assessment questions are common explanations (Traxler et al., 2016). Existing evidence on the potential of interactive pedagogical approaches to reduce this performance gap is mixed. Lorenzo et al. (2006) found that incorporating these approaches in a calculus-based introductory college physics course reduced the pre-semester gender gap on standardized conceptual assessments. Other researchers have determined that, while students in interactive physics courses outperform those in traditional lecture-based courses on conceptual assessments, the gender gap in such courses persists or even intensifies, suggesting that men may disproportionately benefit from interactive instructional approaches (Brewe et al., 2010; Karim et al., 2018; Maries et al., 2020). Comparisons of gaps in exam scores and passing rates between

interactive and traditional lecture-based courses are more promising (Ballen et al., 2017; Brewe et al., 2010; Miyake et al., 2010; Theobald et al., 2020). Compiling data from across STEM disciplines, Theobald et al. (2020) identified that sustained active learning instructional techniques significantly reduced the disparity in exam scores and passing rates between college students with marginalized and non-marginalized racial and ethnic identities. Evaluations of specific interactive approaches such as ISLE and SCALE-UP similarly show significantly greater exam scores and lower failure rates for physics students with marginalized gender, racial, and ethnic identities (Beichner, 2008; Brahmia, 2008; Etkina et al., 1999). Rodriguez et al. (2016) observed that women who participated in introductory physics courses that incorporated MI and/or ISLE techniques both outperformed and were more likely to persist in their upper-level college physics courses than men.

While interactive instructional approaches thus carry potential to improve the performance and persistence of college physics students with marginalized gender, racial, and ethnic identities, their benefits are not universally observed. Indeed, it is becoming increasingly apparent in the physics education research community that the strengths of these approaches depend largely on their implementation and classroom context (Theobald et al., 2020; Maries et al., 2020; Pollock et al., 2007). Activities that involve collaborative peer learning can increase instances of peer exclusion and stereotype-driven stress and anxiety among marginalized physics students (Maries et al., 2020; Pollock et al., 2007). In addition, even in interactive instructional settings, instructors can heavily emphasize finding the correct answer over reasoning through a problem (Pollock et al., 2007). Recommendations for interactive implementation practices that promote inclusion and equity in physics learning include deliberate attention to peer group dynamics and regular, scaffolded feedback that teaches students to view their physics abilities as

malleable and effectively navigate academic challenges (Karim et al., 2018; Maries et al., 2020; Pollock et al., 2007; Theobald et al., 2020). In recent years, scholars have rightfully pointed out that focusing solely on achievement comparisons when evaluating interactive instructional approaches promotes a deficit perspective that perpetuates the marginalization of female, Black, Latine, and Indigenous students in physics spaces (Traxler et al., 2016). When empirically examining the educational outcomes of such approaches, it is important to not only consider students' academic achievement measures, but also how various aspects of their course experiences influence their perceptions and beliefs about their ability, belonging, and approach to facing academic challenges in physics (NRC, 2013). To date, relatively few studies have focused explicitly on these and other non-cognitive factors when studying interactive instructional approaches in the college physics classroom (Good et al., 2019; Little et al., 2019). Little et al. (2019) interviewed five college students about their approaches to academic challenges following a year-long transformed introductory physics course sequence for life science majors. In qualitatively analyzing students' responses, they determined that a single student often described more fixed or malleable beliefs and behaviors depending on the contextual nature of the challenge itself. The present study provides important insight into the contextual dynamics through which college STEM students' domain-specific intellectual ability beliefs shift and change during a physics course that incorporates an interactive instructional approach, as well as the impact of these changes on students' perceptions and behavior (Little et al., 2019).

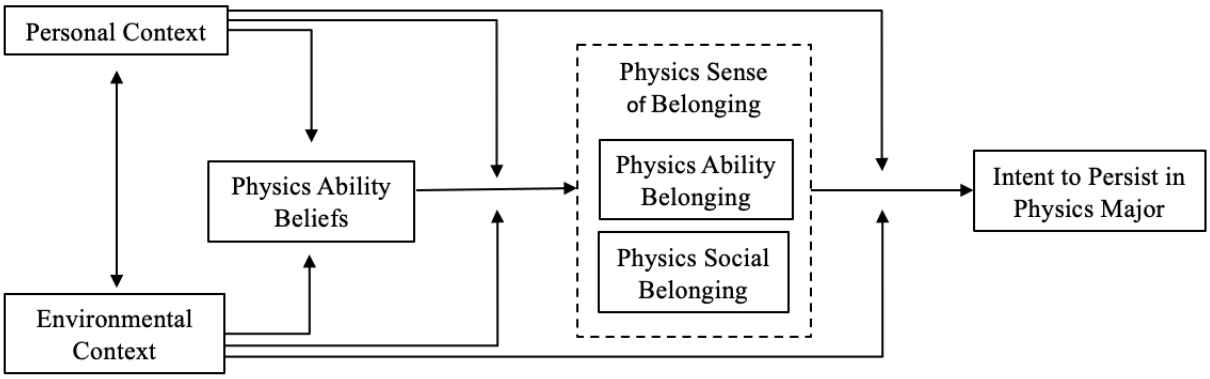
Conceptual Framework

This study relies on a framework that combines concepts from three theoretical perspectives detailed in the literature review above: implicit theories of intelligence (Dweck & Leggett, 1988; Dweck & Yeager, 2019; Murphy & Dweck, 2010), the field-specific ability

beliefs hypothesis (Leslie et al., 2015), and Lewis & Hodges' (2015) model of academic belonging (Figure 2.1). This framework depicts the hypothesized relationship between a college student's personal and environmental contexts, their physics-specific implicit ability beliefs, their sense of belonging in physics, and their intent to persist in a physics major. In the present study, *personal context* includes a student's gender, race, ethnicity, academic level, GPA, perceptions of academic struggle in a course, and field-specific ability beliefs (defined as the extent to which a student believes that innate brilliance is required for success in physics). *Environmental context* includes the intellectual ability and field-specific ability beliefs promoted in a physics disciplinary environment. Contextual features of a postsecondary physics environment interact with a student's personal context through their impacts on the student's self-perceptions and field-specific ability beliefs. As participants in their classroom and disciplinary settings, students also potentially influence their environmental context. In my framework, personal and environmental factors shape a student's physics ability beliefs over a semester (Limeri et al., 2020a; Little et al., 2019). Contextual components also influence the longitudinal relationship between a student's implicit physics ability beliefs and their physics social and ability belonging, as well as the relationship between a student's physics belonging and intent to persist in a physics major (Bian et al., 2018; Good et al., 2012; Lewis et al., 2017; Lewis & Hodges, 2015; Walton & Cohen, 2007).

Figure 2.1

Conceptual Framework for Relationships Between a Student's Personal and Environmental Contexts, Physics Ability Beliefs, Physics Ability and Social Belonging, and Intent to Persist in a Physics Major



Methods

A quantitative approach was utilized for this study. Quantitative research is ideal for characterizing the relationships between variables of interest (Creswell & Creswell, 2018). This methods section outlines the specific quantitative research design, setting, participants, instruments, and variables. It then details data analysis procedures and discusses ethical considerations.

Research Design

This quantitative study utilized a correlational, longitudinal survey design to examine changes in undergraduate physics majors' physics ability beliefs, ability and social belonging, and short-term persistence intentions over the course of three semesters while enrolled in major-specific college physics courses that incorporated an experimental lab activity (Creswell & Creswell, 2018). Collecting self-reported data electronically using established, validated survey scales allowed me to gather valuable information on the beliefs and perceptions of students in an efficient, cost-effective manner. While the non-experimental nature of this study prevented

causal conclusions, an experimental design was not feasible due to logistical constraints. The relatively small number of undergraduate physics majors and the widespread implementation of experimental lab activities in major-specific physics courses precluded the establishment of a control group.

This study took a critical approach to quantitative inquiry (Gillborn, Warmington, & Demac, 2018). This approach challenges the notion that quantitative analyses reveal an objective, neutral, and value-free reality and employs such analyses to expose and address inequities perpetuated by oppressive societal forces (Gillborn et al., 2018). When designing and implementing the study, I followed Castillo and Gillborn's (2022) recommendations for researchers seeking to apply a critical quantitative approach. First, I rejected the deficit-based lens common in physics education research and instead examined how students' perceptions of their disciplinary environments related to their beliefs, self-perceptions, and intentions (Traxler et al., 2016). Second, I drew upon literature centered on the experiences of students with traditionally marginalized social identities in physics spaces to both frame the study and to compile survey items (Castillo & Gillborn, 2022).

Third, I carefully reflected on the strengths and limitations of the social identity categories included in my study and recognized that such categories describe social constructions rather than natural groupings (Castillo & Gillborn, 2022). Quantitative studies of undergraduate physics programs often refrain from including students' race and ethnicity due to the low number of Black, Latine, and Indigenous students in such programs (Traxler et al., 2016). By leaving out race and ethnicity, researchers fail to examine the ways in which racism present in physics learning environments shapes the well-being, beliefs, perceptions, and academic and professional trajectories of physics students of color (Castillo & Gillborn, 2022). Adopting a longitudinal

study design supported a better understanding of the beliefs, perceptions, and experiences of students with marginalized racial and ethnic identities, as participants completed a survey at multiple time points, which promoted a level of contextual insight not possible through cross-sectional data collection. The low number of Black, Latine, and Indigenous physics students at Southeastern University limited my capacity to quantitatively examine the beliefs and perceptions of students with specific marginalized racial and ethnic identities (or students with intersecting marginalized identities). I included a covariate in my models that combined white and Asian students into one group and Black and Latine students into another group. I recognize the limitations that this grouping method provides, as white, Asian, Black, and Latine students have both unique and heterogenous experiences. By adopting this grouping system, I do not mean to imply that the experiences of students with specific racial and ethnic identities are not important, nor that white and Asian students in physics act as a normative default. Instead, I employed this grouping system to examine how the beliefs, perceptions, and experiences of physics students with traditionally marginalized racial and ethnic identities potentially differ from their non-marginalized peers due to the oppressive dynamics in physics learning environments.

Lastly, I included a positionality statement, provided context for my study, and transparently discussed the limitations of results. In doing so, I addressed the critical quantitative principle that “data cannot speak for itself” (Castillo & Gillborn, 2022, p. 1). By explicitly situating my methods and findings, I recognized the subjectivity inherent to quantitative research and allowed the reader to make informed interpretations and decisions from my conclusions (Castillo & Gillborn, 2022).

Research Site

This study took place at a large, predominantly white, public land-grant institution in the southeast (referred to in the study as Southeastern University). The academic institution has many STEM degree programs, with 61% of the undergraduate student population enrolled in a STEM major. The Department of Physics at Southeastern University contains 59 faculty, 130 graduate students, and 137 undergraduate students. Approximately 20% of physics undergraduates identify as women. Of those women, 74% are white, 11% are Asian, 11% are Latine, and 4% are Black. Men make up 80% of undergraduates in the major. Seventy-seven percent of these men are white, 13% are Asian, 5% are Latine, 3% are Black, and less than 1% are Indigenous. Faculty in the Department of Physics at Southeastern University engage in research in numerous subfields, including astrophysics, nuclear physics, biophysics, condensed matter physics, optical physics, and physics education research.

Interactive Instructional Approach: Experimental Lab Activity Program

In 2013, a faculty member in the Department of Physics developed a collection of experimental lab activities to provide undergraduate physics majors and minors with the opportunity to conduct short, inquiry-based experiments in the department's shared research facility as part of their physics courses. Each fall and spring semester since its inception, 3-5 physics courses have incorporated an experimental lab activity as an official course component. Specific experiments are designed and modified each term by course instructors in collaboration with the lab activity director and a graduate teaching assistant. Examples of existing experimental lab activities include carbon dating of Brazil nuts, observation of chaotic motion, and measuring the absorption spectrum of molecules of different sizes and modeling this behavior as a quantum-mechanical particle in a box. The activities are meant to authentically

expose undergraduates to the process of experimental physics and the trial-and-error nature of science. Undergraduates work in small groups of 2-4 to develop hypotheses and collect and analyze data, though they each write up and submit their findings independently. Instructors and TAs grade student write-ups using intentional growth and process-oriented feedback. Prior to the development of the experimental lab activities, the undergraduate physics curriculum at Southeastern University offered traditional cookie-cutter labs for students during their first three semesters of college, and no inquiry-based course or lab work until their senior year capstone course. Based on internal program evaluations, the activities appear to support undergraduate physics students' self-reported confidence and understanding of experimental physics.

While experimental lab activities were initially restricted to advanced physics courses at Southeastern University, in Fall 2021, the program was expanded to include introductory major-specific physics courses. As such, most undergraduates majoring or minoring in physics at this institution are enrolled in a physics course each semester that incorporates such an activity.

Participants

The target population in this study included undergraduates at Southeastern University who enrolled in a major-specific physics course incorporating an experimental lab activity during the Fall 2021, Spring 2022, and Fall 2022 semesters (14 courses in total). Given the relatively small size of the undergraduate physics program, a total population sampling design was employed in which all undergraduate physics majors in the target population were included in the sampling frame and invited to participate in the study (N ~ 200). Many, but not all undergraduates in the sampling frame were enrolled in a relevant physics course during all three semesters of the study. Survey response rates varied within and across each term, though the average response rate across all iterations was 52% (Table 2.1). A total of 125 undergraduates

completed at least one survey over the course of the three semesters, resulting in 417 values at the time level. Seventy students completed a survey at 3 or more time points and 35 at 5 or more time points.

Table 2.1

Survey Response Rates

Semester	Beginning	Middle	End
Fall 2021	65 (58%)	64 (57%)	31 (27%)
Spring 2022	63 (50%)	72 (57%)	39 (30%)
Fall 2022	40 (60%)	46 (70%)	39 (59%)

Table 2.2 illustrates the gender, race, ethnicity, academic level, and major of undergraduate participants. In line with the overall demographics of undergraduates in the Physics Department, 80% of respondents were men and 76.8% were white. Four percent of respondents were Black, 11.2% were Latine, and 8% were Asian. No respondents were Indigenous. Around 35% of respondents were underclassmen, and 65% upperclassmen. Most respondents were physics majors (84.4%), though 16 were majoring in other STEM disciplines such as engineering or math and 3 were majoring in a non-STEM area. In almost all instances, respondents in other majors were minoring in physics. While both physics and non-physics majors were included in models for research question 1a, only physics majors were included for research questions 1b, 1c, and 1d, as these questions asked students about their belonging and intended persistence in the physics major specifically.

Table 2.2

Demographic and Academic Breakdown of Respondents

Variable	Coding & Frequency
Gender	Women (0): 25 (20%) Men (1): 100 (80%)
Race/ethnicity	Black (1): 5 (4%) Latine (1): 14 (11.2%) Indigenous (1): 0 (0%) Asian (0): 10 (8%) White (0): 96 (76.8%)
Academic level	Freshman (0): 14 (11.5%) Sophomore (1): 28 (23%) Junior (2): 37 (30.3%) Senior (3): 42 (34.4%)
Major	Physics: 103 (84.4%) Other STEM: 16 (13.1%) Non-STEM: 3 (2.5%)

Instruments & Variables

My study incorporated multiple established instruments, some slightly modified to account for my domain-specific, longitudinal focus. I obtained participant demographic and academic background variables (gender, race, ethnicity, academic level, and major) from the university's office of registration and records using participants' student identification number. Students provide their gender, race, and ethnicity when they apply to the university. Several years ago, the registration and records office added a way for students to easily update their gender pronouns in the course management system and provided a non-binary option. No participants in the present study identified as non-binary in the official university system. None-the-less, there is still the possibility that my manner of obtaining students' demographic information missed those who did not update their gender identity in the official university

system. For all analyses, gender was coded as an indicator variable (women = 0, men = 1). Due to the low number of participants with non-white racial and ethnic identities, race and ethnicity was coded as an indicator variable with white and Asian students as 0 and Black and Latine students as 1 (see the Research Design section above for a discussion of this coding system). The following subsections describe each survey instrument and the corresponding variable measured. Table 2.3 provides a summary of all instruments and variables included in the study. Complete survey scales appear in Appendix A.

Table 2.3

Variables and Their Corresponding Instruments

Variable	Variable Type	Instrument
Physics Ability Beliefs (Student)	[a]*Con:* 6-point Likert-type scale	Physics Ability Beliefs Scale (van Aalderen-Smeets et al., 2019)
Physics Ability Belonging	*Con:* 6-point Likert-type scale	Ability Uncertainty Scale (Lewis & Hodges, 2015)
Physics Social Belonging	*Con:* 6-point Likert-type scale	Physics Sense of Belonging Scale (Good et al., 2012)
Intent to Persist in Physics Major	*Con:* 6-point Likert-type scale	Intent to Persist Scale (Lewis & Hodges, 2015)
Perceived Academic Struggle	*Cat:* Dummy-coded (0 = "did not struggle"; 1 = "overcame struggle"; 2 = "continued struggle")	Academic Struggle Items (Limeri et al., 2020a)
Field-Specific Ability Beliefs	*Con:* 6-point Likert-type scale	Field-Specific Ability Beliefs Scale (Leslie et al., 2015)
Gender	*Cat:* Dummy-coded (0 = women; 1 = men)	Obtained from institutional research office
Race and Ethnicity	*Cat:* Dummy-coded (0 = white and Asian; 1 = Black and Latine)	Obtained from institutional research office
Academic Level	*Cat:* Dummy-coded (0 = freshmen; 1 = sophomore; 2 = junior; 3 = senior)	Obtained from institutional research office

[a]Con = Continuous; Cat = Categorical

Physics Ability Beliefs Scale

The Physics Ability Beliefs Scale uses a 6-point Likert-type scale (1 = *strongly agree* to 6 = *strongly disagree*) to measure one's belief in their capacity to change their ability and aptitude in physics with time and effort. This scale diverges from Dweck's (2000) widely used Implicit Theories of Intelligence Scale not only in its domain specificity (Dweck's scale measures students' general intelligence beliefs), but in its use of the term *ability* rather than *intelligence*. A recent study of undergraduate STEM students determined that students define *intelligence* in different ways, a finding that reduces the validity of studies that rely on Dweck's scale to study mindset in this population (Limeri et al., 2020b). Some students see *intelligence* as knowledge, whereas others view it as ability (Limeri et al., 2020b). Replacing *intelligence* with *ability* promotes lower measurement error and greater construct validity without sacrificing content validity, as Dweck's conception of intelligence aligns closer to the *ability* definition (Dweck, 2000). I modified this 7-item scale from the previously validated Implicit STEM Ability Beliefs Scale (van Aalderen-Smeets et al., 2019). The scale shows good reliability ($\alpha > 0.84$). My modification of the scale added even greater domain specificity by replacing the term STEM with physics in each item, creating questions such as, "To be honest, I don't think I can really change my physics aptitude." Prior research suggests that undergraduate STEM students possess different implicit ability beliefs within specific STEM fields, so such greater specificity was necessary (Limeri et al., 2020b).

Field-Specific Ability Beliefs Scale

The Field-Specific Ability Beliefs Scale uses a 6-point Likert-type scale (1 = *strongly agree* to 6 = *strongly disagree*) to examine perceptions about the level of innate intelligence and aptitude required for success in a particular discipline (Leslie et al., 2015). The scale consists of

4 items such as, “If you want to succeed in [discipline], hard work alone just won’t cut it; you need to have an innate gift or talent.” Leslie et al. (2015) found items to display a high internal consistency (α = .90).

Ability Uncertainty Scale

The Ability Uncertainty Scale uses a 6-point Likert-type scale (1 = *strongly agree* to 6 = *strongly disagree*) to measure the degree to which college students worry that they do not possess the aptitude or ability needed to belong and succeed in their undergraduate major (Lewis & Hodges, 2015). The 12-item scale includes items such as, “I’m not certain I “fit in” intellectually in my major.” Lewis and Hodges (2015) established the construct validity of the Ability Uncertainty Scale and determined that all items load strongly onto a single factor (ability uncertainty, the reverse of which equates to a student’s level of ability belonging). The scale also demonstrates good reliability (α = .90).

Physics Sense of Belonging Scale

The Physics Sense of Belonging Scale was modified from Good et al.’s (2012) Math Sense of Belonging Scale. Whereas the Ability Uncertainty Scale measures a student’s perceived level of ability belonging, this scale measures a student’s social belonging in their academic spaces. This 30-item validated scale is divided into five subscales to assess the extent to which students feel like accepted members of their math community. My study utilizes the Membership (α = .91) subscale, which includes 14-items measured using a 6-point Likert-type scale (1 = *strongly agree* to 6 = *strongly disagree*). I modified Good et al.’s (2012) scale by replacing “math” with “physics” in each item, creating questions such as, “I feel that I belong to the physics community.”

Intent to Persist Scale

The Intent to Persist Scale is a 4-item 6-point Likert-type (1 = *strongly agree* to 6 = *strongly disagree*) scale to measure college students' intentions to remain in their current academic major during their undergraduate studies (Lewis & Hodges, 2015). The scale includes questions such as, "It is likely that I will remain in my major next academic year." The Intent to Persist Scale only examines persistence in the short term and does not ask students about their post-college intentions. The scale demonstrates good reliability (α = .84).

Academic Struggle Items

Limeri et al. (2020a) created two items to measure students perceived academic struggle in a course during a semester. Both items use a *yes/no* response format. The first asks students, "Did you encounter struggle in [course name] this semester?" Participants who respond "yes" are then asked, "Were you able to overcome the struggle that you encountered?" The authors evaluated the content validity of these two items by having an initial group of participants qualitatively elaborate on the accuracy of their conclusions. Academic struggle items were dummy coded into a variable with "did not struggle" as the reference group.

Data Collection Procedures

Before the start of each semester, I communicated with course instructors, the experimental lab activity director, and the teaching assistant to share links to the electronic surveys and consent forms and coordinate the timing of survey distribution throughout the term. In the first week of the semester, I visited each physics course in-person to introduce the study and answer questions from students. Instructors then provided students with survey links and instructions via their course management system. Students who voluntarily consented to participate in the study were directed to a beginning-of-semester survey. This survey consisted of

33 items containing the following scales described in the previous section: The Physics Ability Beliefs Scale, the Field-Specific Ability Beliefs Scale, the Ability Uncertainty Scale, the Physics Sense of Belonging Scale, and the Intent to Persist Scale. After participants received feedback on their experimental lab activity write-up, I directed them to complete a mid-semester survey. This shorter survey asked only the seven items from the Physics Ability Beliefs Scale. At the end of each term, I instructed participants to complete an end-of-semester survey, which included 30 items containing the following scales: The Physics Ability Beliefs Scale, the Ability Uncertainty Scale, and the Physics Sense of Belonging Scale, the Intent to Persist Scale, and the two Academic Struggle items. Following the end of the semester, I used participating students' identification numbers to request the following information from Southeastern University's office of institutional research: gender, race/ethnicity, undergraduate academic level, and major.

In the Spring 2022 semester, students who completed all three surveys over the course of a term were given a $10 electronic gift card. In the Fall 2022 semester, the university's internal review board permitted instructors to incorporate the surveys as a homework grade, though students voluntarily consented for me to use their survey data in the study.

Data Analysis Procedures

I used SAS Version 9.4 M7 and STATA/IC 16.0 to complete data analyses. After merging participants' survey responses with their demographic and academic background information into a single dataset, I carefully examined all data to identify errors and inconsistencies and to locate and remove any partially completed survey responses (Groves et al., 2009). My analysis technique (multilevel modeling) allowed for unbalanced outcome data, so including both students who only completed the surveys during a single semester (and thus have

a total of 3 data points) along with those who completed the surveys during multiple semesters (and thus have a total of 6-9 data points) was acceptable (Raudenbush & Bryk, 2002).

Instrument Validity & Reliability

I performed confirmatory factor analysis (CFA) to assess the construct validity of each scale (Kline, 2016). Before running a CFA for each scale, I averaged each participant's responses to each item across all time points. To evaluate global model fit, I examined chi-square goodness of fit, root mean square error of approximation, comparative fit index, and squared root mean square residual. To evaluate local model fit, I ensured all standardized parameter loadings were above 0.4 and examined residual correlations between individual items. To assess the reliability of my instruments, I calculated within-person and between-person reliability estimates (Cranford et al., 2006; Scott et al., 2020). These estimates reflect an instrument's reliability to detect within-person fluctuations and between-person differences (Scott et al., 2020).

Multilevel Modeling

To analyze the dynamics of students' physics ability beliefs, ability, and social belonging, and persistence intentions over the course of three semesters, I used multilevel modeling. Multilevel modeling was an ideal analysis tool, as it accounted for the longitudinal, hierarchical structure of my dataset. In the current study, student change/variability is depicted using a 2-level hierarchical model (Raudenbush & Bryk, 2002). At Level 1, each student's variability (change in physics ability beliefs over time, for example) is represented by an intercept and slope that become outcome variables in a Level 2 model. These Level 2 outcomes can depend on student-level characteristics (such as gender and race/ethnicity). Multilevel modeling permitted an examination of variance in a dependent variable at each level. It allowed for an analysis of how temporal- and student-level factors contribute to interindividual differences in intraindividual

change. In addition, multilevel modeling generated a separate regression line for each student, taking into account the extent to which individuals started out and changed differently over time (Raudenbush & Bryk, 2002).

As multilevel models assume linearity, normality, and homoscedasticity, I began by evaluating these assumptions using my dataset. I also ran post-hoc power analysis to look for potential multicollinearity in predictors. Before running my models with predictors, I first tested an unconditional model for each outcome variable to establish sufficient variability at each level for continued analysis (see B1, B4, B7, and B10). As students' field-specific ability beliefs did not show significant within-student variation over time (and the scale was only included in the beginning-of-semester survey), each participant's average field-specific ability belief value was included as a Level 2 predictor in multilevel models. Several predictors were grand mean centered (field-specific physics ability beliefs, physics ability beliefs in 1b, 1c, and 1d, and ability and social belonging (1d)) to make their interpretations more meaningful. The following subsections summarize the multilevel model that corresponds to each part of my research questions (see Appendix B for a visual and description of each equation).

Research Question 1a. *On average, is there significant linear change in a student's physics ability beliefs over time? Does this change depend on a student's gender, race, ethnicity, academic level, perceived academic struggle in a course, and field-specific ability beliefs?*

Equation (B3) dissects the dynamics by which a student's physics ability beliefs change over the course of three semesters. My analyses focused primarily on γ_{10} (the average within-student relationship between time and physics ability beliefs), γ_{30} (the average within-student relationship between academic struggle and physics ability beliefs), and γ_{40} (the average within-student relationship between time, perceived academic struggle, and physics ability beliefs). I

also examined the average effects of students' gender, race, ethnicity, and field-specific ability beliefs on the above-mentioned relationships. In each circumstance, I tested if the coefficient is significantly different from zero. I also calculated the proportion of within- and between-student variation in physics ability beliefs accounted for by the full model (B3).

Research Questions 1b & 1c. *On average, is there significant linear change in a student's ability belonging/social belonging over time? Does this change depend on a student's physics ability beliefs, gender, race, ethnicity, academic level, and field-specific ability beliefs?*

I ran separate models for physics ability belonging and physics social belonging outcomes, although I used a similar model structure for each (B6 and B9). In these analyses, I focused on γ_{10} (the average within-student relationships between time and ability/social belonging), γ_{30} (the average within-student relationships physics ability beliefs and ability/social belonging), and γ_{40} (the average within-student relationships between time, physics ability beliefs, and ability/social belonging). I also examined the average effects of students' gender, race, ethnicity, and field-specific ability beliefs on the above-mentioned relationships. In each circumstance, I tested if the coefficient was significantly different from zero. I also calculated the proportion of within- and between-student variation in social and ability belonging accounted for by the full model (B6 and B9).

Research Question 1d. *On average, is there a significant linear relationship between a student's physics ability beliefs, physics ability belonging, physics social belonging, and intent to persist in a physics major over time? Does this relationship depend on a student's gender, race, ethnicity, academic level, and field-specific ability beliefs?*

In equation (B12), a student's intended persistence in their physics major acts as an outcome variable, with physics ability beliefs, ability belonging, and social belonging serving as

predictors. I focused on γ_{10} (the average within-student relationship between time and intended persistence), γ_{30} (the average within-student relationship between physics ability beliefs and intended persistence), γ_{40} (the average within-student relationship between ability belonging and intended persistence), and γ_{50} (the average within-student relationship between time, physics ability belonging, physics ability beliefs, and intended persistence). I also examined the average effects of students' gender, race, ethnicity, and field-specific ability beliefs on the above-mentioned relationships. In each circumstance, I tested if the coefficient was significantly different from zero. I also calculated the proportion of within- and between-student variation in social and ability belonging accounted for by the full model (B12).

Ethical Issues

The Internal Review Board (IRB) at my study institution helped to ensure that I ethically collected and analyzed data. The primary ethical considerations of this study involved ensuring the confidentiality and security of student and instructor data. I maintained participant confidentiality in several ways. First, surveys were distributed via an anonymous link. Student names and email addresses were at no point included in my study, and official identification numbers were retained in the dataset. Instead, each student participant was assigned a number (1,2,3,4, etc.). An encrypted, password-protected file was created that codes the number assigned to each participant to their student ID. This file allowed me to pair demographic and academic background information with survey responses and to match responses gathered across the semester to specific individuals.

Positionality Statement

I identify as a white, middle-class, queer, cisgender woman. I obtained a bachelor's and a master's degree in a biology field, the latter of which came from a large research-intensive institution similar in size, structure, and demographic make-up to the institutions in the present study. I thus have personal experience navigating postsecondary scientific spaces as a woman and am in certain ways an insider to my population of interest. In addition, I am a trained higher education practitioner and researcher who is extremely invested in increasing diversity, equity, inclusion, and justice across STEM fields. I advise undergraduates in the biological sciences at Southeastern University and through conversations with my advisees, I witness instances of exclusion and inequity in postsecondary STEM education on a regular basis. At the same time, I do not have personal experience as a student in the discipline of physics. As a white, middle-class individual from a largely college-educated family, I possess extensive privileges due to my race, class, and familial education background. I am in these ways an outsider to this study's population. My dual position as an insider and an outsider is helpful in providing me with direct experiences with issues of diversity, equity, inclusion, and justice in STEM and with a certain degree of legitimacy and trustworthiness among my study population as a woman in STEM. It is also a bit dangerous in that my own identity as a science person (as well as a white, educationally and economically privileged person) may prevent me from fully seeing certain power structures at play.

Results

In this section, I first provide the construct validity and reliability estimates for my survey scales. I next present findings for each component of my research question, which examined

contextual changes in students' physics ability beliefs, sense of belonging, and intended persistence in physics over the course of the three semesters.

Validity & Reliability

I used CFA with the robust weighted least squared estimator (WLSMV) to evaluate the construct validity of each of the five survey scales. The robust weighted least squared estimator was necessary as the distribution of item responses was often skewed, a common trait of Likert-type questions (Kline, 2016). Given the heterogeneity of existing literature, I began by analyzing whether the seven items of the Physics Ability Beliefs Sale were best represented as one or two ('entity' and 'incremental') correlated latent factors (van Aaldernen-Smeets et al, 2018; Limeri et al., 2020b). A two-factor model produced a better global fit between the model and the observed data (RMSEA = 0.039, CFI = 0.980, SRMR = 0.112). All parameter loadings were well above the 0.4 cutoff, and residual analysis did not point to any issues. As such, I averaged participants' responses to the four incremental items to obtain a score that represented the extent to which students perceived their physics abilities as malleable at a given time point. This score was then used as the physics ability belief variable in the multilevel models described below.

I next confirmed the factor structure of the other four scales. One of the four items in the Field-Specific Ability Belief Scale loaded comparatively poorly (0.44) onto the latent factor and as such was removed from further analyses. Four of twelve items on the Ability Belonging Scale loaded similarly poorly onto the latent ability belonging factor and were also removed, which resulted in an acceptable local and global fit for this scale (RMSEA = 0.062, CFI = 0.950, SRMR = 0.083). The four items on the Social Belonging Scale loaded strongly onto the social belonging latent variable (RMSEA = 0.00, CFI = 1.00, SRMR = 0.015). One item on the 'Intent to Persist' scale loaded comparatively poorly onto the intended persistence latent variable and was thus

removed. After confirming factor structures, I averaged participants' responses to the remaining items within each scale to obtain a field-specific ability belief, ability belonging, social belonging, and intended persistence score for each student at each time point measured for use in multilevel modeling.

All scales displayed high within-person and between-person reliability with the exception of the Field-Specific Ability Belief Scale, which showed high between-person, but not within-person reliability ($R_{BP} = 0.87$; $R_{WP} = 0.48$). Further analyses revealed that one item from the scale in particular showed low within-person reliability. After removing this item, the Field-Specific Ability Belief Scale showed high within- and between-person reliability (Table 2.4). Removed survey items are italicized in Appendix A.

Table 2.4

Within- and Between-Person Reliability Estimates

	R_{WP} (Within-person reliability)	R_{BP} (Between-person reliability)
Physics ability beliefs scale	0.78	0.96
Ability belonging scale	0.80	0.97
Social belonging scale	0.88	0.98
Field-specific ability beliefs scale	0.75	0.93
Intent to persist scale	0.78	0.95

Multilevel Models

All multilevel models met assumptions of linearity and normality and homoscedasticity of residuals at Level 1. In addition, multicollinearity was not present among predictors. The subsections below summarize the findings for each component of my research question.

Research Question 1a

The first part of my research question focused on whether there was significant, linear within-student change in a student's physics ability beliefs over time. It then examined the extent to which this change depended on a student's gender, race, ethnicity, academic level, perceived academic struggle in a course, and perceptions that innate brilliance is required for success in physics. In multilevel modeling, it is important to begin with a preliminary model (formally known as a fully unconditional or null model) to establish that there is sufficient variability in an outcome at Level 1 (within students) and Level 2 (between students) to justify continued analysis. In the present analysis, the unconditional model determined the amount of variability in physics ability beliefs at Level 1 and Level 2 in the absence of any predictors and estimated the mean value of physics ability beliefs across all time points (Level 1) and students (Level 2) (B1; Raudenbush & Bryk, 2002). Results of this model revealed that 58% of variability in physics ability beliefs was between students ($\tau_{00} = 0.28$, $z = 6.04$, $p < 0.0001$) and 42% was within students ($\sigma^2 = 0.20$, $z = 11.93$, $p < 0.0001$). Such findings indicated that there was enough within- and between-student variability in physics ability beliefs to warrant further analysis. The mean value of physics ability beliefs across all time points and students (γ_{00}) was 5.14. This signified that, on average, students agreed that their physics abilities were malleable with effort and time.

I then tested a model that investigated whether students' physics ability beliefs changed over the course of the three semesters (B2). On average, there was a slight but significant decrease in the malleability of students' physics ability beliefs over time ($\gamma_{10} = -0.06$, $t = -4.34$, $p < 0.0001$). At the same time, there was significant interindividual variability in this rate of change ($\tau_{11} = 0.01$, $z = 2.80$, $p = 0.003$). Linear time accounted for 20% of within-student variability in physics ability beliefs. Adding the remainder of Level 1 and Level 2 predictors to

the model (B3) revealed that the change in a student's physics ability beliefs over time depended on their perceived level of academic struggle in a physics course (γ_{30} = -0.09, t = -2.45, p = 0.02). Specifically, students who experienced ongoing academic struggle in a physics course reported less malleable beliefs about their physics abilities over time than those who either overcame or who never struggled. Testing simple slopes showed that physics ability beliefs did not initially differ between students who did and did not continuously struggle in a physics course, but that these differences grew over time (-0.95±0.30, t = -3.12, p = 0.002).

Students' physics ability beliefs also differed based on the extent to which they perceived innate intelligence as required for success in physics as a discipline. On average, students slightly disagreed that innate brilliance is required to succeed in physics (2.94). Those who perceived that achieving success in physics requires a certain innate aptitude tended to report less malleable beliefs about their own physics abilities (γ_{03} = -0.20, t = -2.47, p = 0.02). Students' field-specific ability beliefs did not shape the rate of change in their physics ability beliefs. There were no differences in average physics ability beliefs or rates of change over time based on students' academic level, gender, race, or ethnicity (Table 2.5). The full model accounted for 41% of between-student and 26% of within-student variability in physics ability beliefs.

Table 2.5

Unstandardized Coefficients (And Standard Errors) of Multilevel Model of Physics Ability Beliefs Containing All Level 1 And Level 2 Predictors (Level 1 = 265; Level 2 = 67)

Fixed Effects	Coefficient (SE)
Physics ability beliefs, β_0	
Intercept, γ_{00}	4.90*** (0.31)
Gender, γ_{01}	0.29 (0.20)
Race/ethnicity, γ_{02}	0.07 (0.22)
Field-specific ability beliefs, γ_{03}	-0.20* (0.08)
Time slope, β_1	
Intercept, γ_{10}	0.09 (0.06)
Gender, γ_{11}	-0.06 (0.04)
Race/Ethnicity, γ_{12}	0.008 (0.04)
Field-specific ability beliefs, γ_{13}	-0.006 (0.02)
Academic level slope, β_2	
Intercept, γ_{20}	-0.02 (0.06)
Academic struggle slope, β_3	
Intercept, γ_{30}	0.24 (0.19)
Time X Academic struggle slope, β_4	
Intercept, γ_{40}	-0.09* (0.04)
Random Effects	
Physics ability beliefs, τ_{00}	0.165* (0.08)
Time slope variation, τ_{11}	0.002 (0.002)
Within-student variation, σ^2	0.147*** (0.02)
$R^2_{between}$	0.41
R^2_{within}	0.26

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Research Question 1b

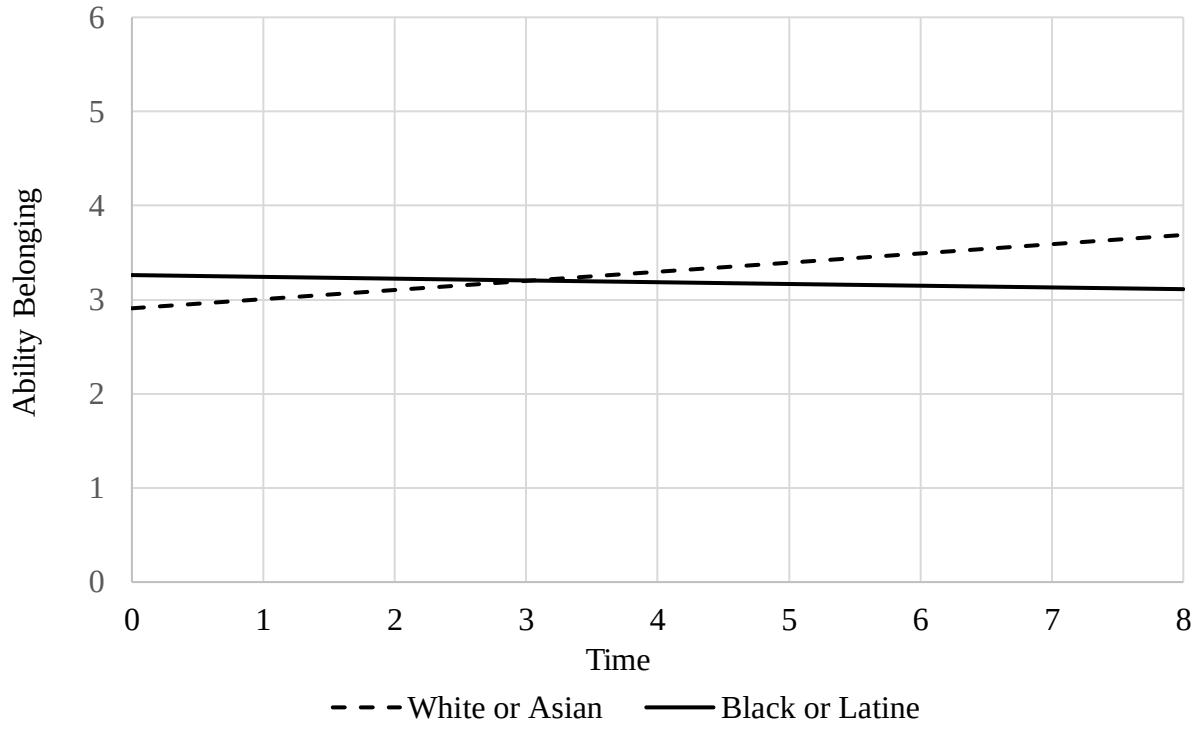
The second part of my research question considered whether there was significant linear change in a physics student's sense of ability belonging over time and tested if this change depended on gender, race, ethnicity, academic level, physics ability beliefs, and perceptions that

innate brilliance is required for success in physics. Results of the unconditional model (B4) revealed that 66% of variability in ability belonging was between students (τ_{00} = 0.73, z = 5.30, p<0.0001) and 33% was within students (σ^2 = 0.37, z = 8.32, p<0.0001). This supported that there was sufficient within- and between-student variability in ability belonging to justify further analyses. The mean value of ability belonging across all time points and physics students (γ_{00}) was 3.70 (between *slightly disagree* and *slightly agree*). In other words, students on average slightly disagreed to slightly agreed that they had the abilities needed to belong in the physics major.

On average, students' ability belonging did not change significantly over time (B5; γ_{10} = 0.03, t = 1.48, p = 0.142), though there was marginally significant interindividual variability in the rate of change (τ_{11} = 0.01, z = 1.67, p = 0.048). Linear time accounted for 17% of within-student variability in ability belonging. Adding the remainder of Level 1 and Level 2 predictors (B6) showed that changes in a student's ability belonging over time depended on their field-specific ability beliefs (γ_{13} = -0.05, t = -2.59, p = 0.02). Students who perceived high, innate intelligence as required for success in physics reported a lower ability belonging over time. Black and Latine, physics students also on average experienced a decline in ability belonging over time (γ_{12} = -0.12, t = -2.38, p = 0.02; Figure 2.2). Testing significance of contrasts indicated that Black and Latine students conveyed the greatest level of ability belonging at the start of the study. White and Asian students conveyed an increased sense of ability belonging over time (0.78±0.33, t = 2.14, p = 0.03; Figure 2.2).

Figure 2.2

Interaction Between Time, Race and Ethnicity, and Physics Ability Belonging

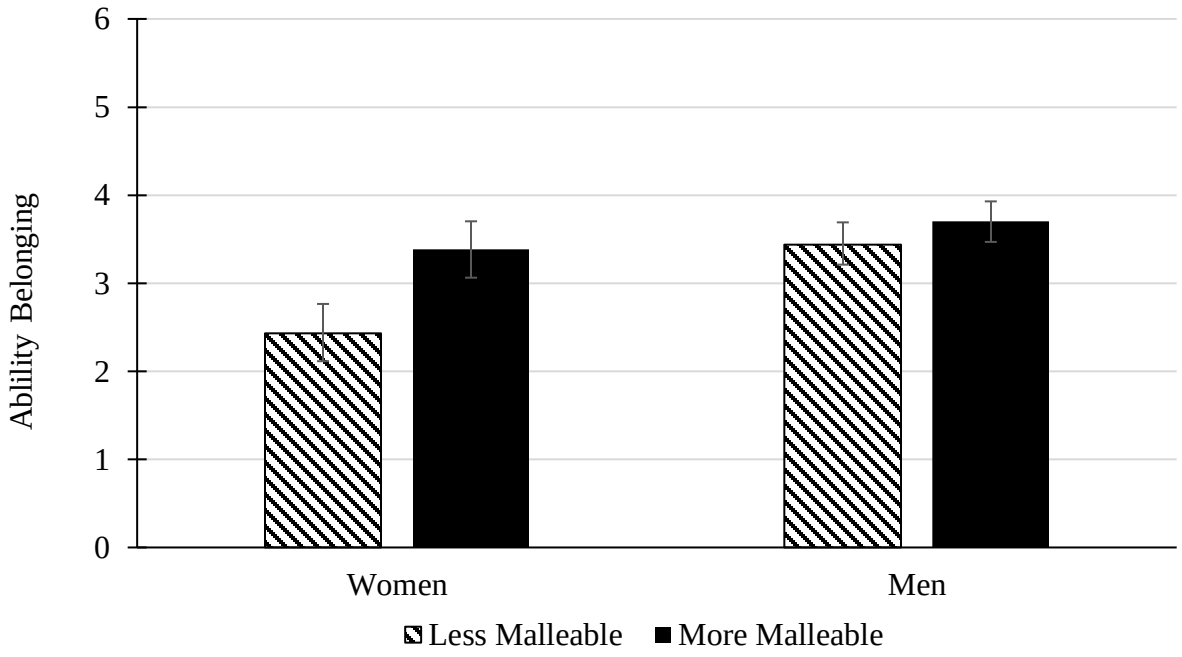


While the change in students' ability belonging over time did not depend on their physics ability beliefs, a significant within-student relationship existed between physics ability beliefs and ability belonging, such that when a student expressed more malleable beliefs about their physics abilities, they tended to report a great ability belonging ($\gamma_{30} = 0.69$, $t = 2.70$, $p = 0.008$). The relationship between a student's physics ability beliefs and ability belonging depended on their gender ($\gamma_{31} = -0.50$, $t = -2.06$, $p = 0.04$; Figure 2.3). Specifically, ability belonging differed significantly between women with more and less malleable physics ability beliefs (0.47 ± 0.18, $t = 2.70$, $p = 0.008$), though the same trend was not apparent for men (0.13 ± 0.11, $t = 1.22$, $p = 0.23$). In addition, men with less malleable ability beliefs had significantly higher ability belonging than women with less malleable ability beliefs (1.01 ± 0.32, $t = 3.15$, $p = 0.002$), though these differences in ability belonging disappeared for men and women with more malleable physics

ability beliefs (0.32±0.32, t = 1.00, p = 0.32). Across all students and time points, men had a higher average ability belonging in the physics major than women (γ_{01} = 0.66, t = 2.45, p = 0.02).

Figure 2.3

Interaction Between Gender, Physics Ability Beliefs, and Physics Ability Belonging



There was no difference in ability belonging based on students' academic level. The full model accounted for 20% of between-student and 25% of with-in student variability in ability belonging (Table 2.6).

Table 2.6

Unstandardized Coefficients (And Standard Errors) of Multilevel Model of Physics Belonging Containing All Level 1 And Level 2 Predictors (Level 1 = 219; Level 2 = 90)

Fixed Effects	Ability Belonging Coefficient (SE)	Social Belonging Coefficient (SE)
Belonging, β_0		
Intercept, γ_{00}	2.91*** (0.27)	3.88*** (0.26)
Gender, γ_{01}	0.66* (0.27)	0.48* (0.23)
Race/ethnicity, γ_{02}	0.35 (0.34)	-0.32 (0.30)
Field-specific ability beliefs, γ_{03}	0.29 (0.24)	0.34 (0.27)
Gender X Field-specific ability beliefs, γ_{04}	-0.47 (0.25)	-0.48 (0.27)
Race/ethnicity X Field-specific ability beliefs, γ_{05}	0.21 (0.26)	-0.79** (0.27)
Time slope, β_1		
Intercept, γ_{10}	0.10* (0.04)	0.05* (0.02)
Gender, γ_{11}	-0.05 (0.04)	
Race/ethnicity, γ_{12}	-0.12* (0.05)	
Field-specific ability beliefs, γ_{13}	-0.05* (0.02)	
Academic level slope, β_2		
Intercept, γ_{20}	0.004 (0.09)	0.01 (0.09)
Physics ability beliefs slope, β_3		
Intercept, γ_{30}	0.69** (0.26)	0.69* (0.28)
Gender, γ_{31}	-0.50* (0.24)	-0.48 (0.27)
Race/ethnicity, γ_{32}	-0.18 (0.28)	-0.78* (0.31)
Time X Physics ability beliefs slope, β_4		
Intercept, γ_{40}	0.03 (0.03)	0.05 (0.03)
Random Effects		
Belonging, τ_{00}	0.582*** (0.12)	0.607*** (0.13)
Within-student variation, σ^2	0.279*** (0.04)	0.369*** (0.05)
$R^2_{between}$	.20	0.25
R^2_{within}	.25	0.14

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Research Question 1c

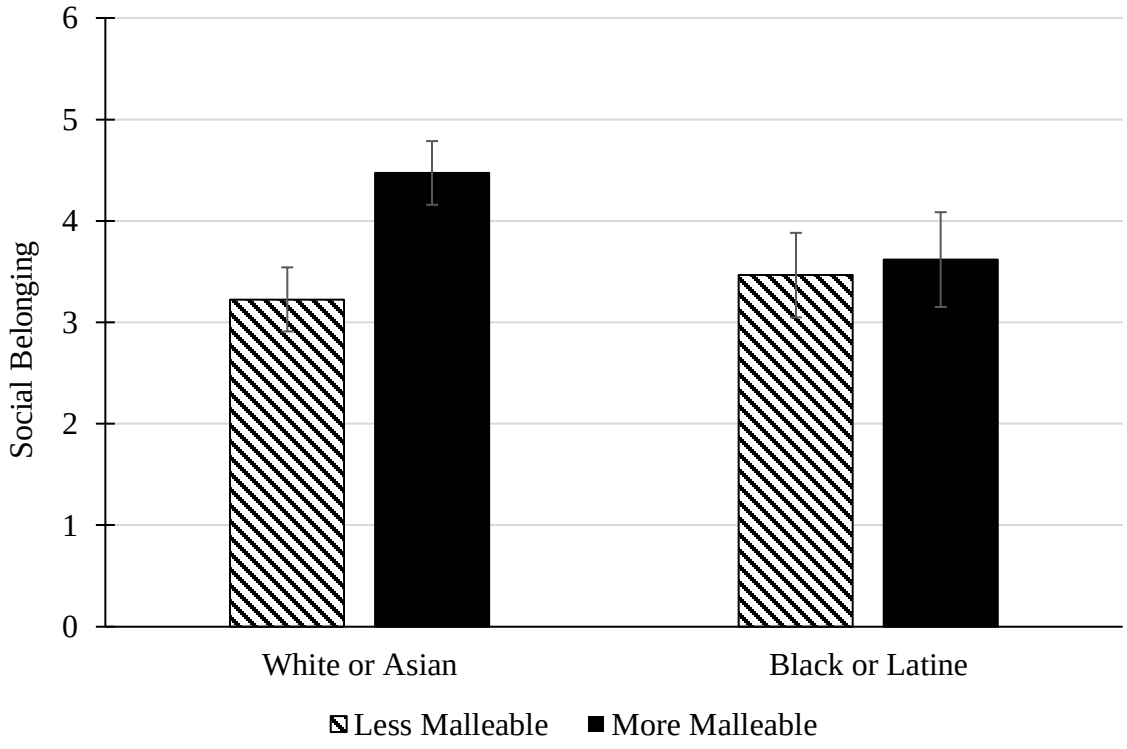
The third part of my research question examined if there was a significant linear change in a physics student's sense of social belonging over time, and whether this change depended on a student's gender, race, ethnicity, academic level, physics ability beliefs, and perceptions that innate brilliance is required for success in physics. The unconditional model (B7) revealed that 65% of variability in social belonging was between students ($\tau_{00} = 0.80$, $z = 5.22$, $p<0.0001$) and 35% was within students ($\sigma^2 = 0.43$, $z = 8.33$, $p<0.0001$). As such, there was sufficient within- and between-student variability in social belonging for further analyses. The mean value of social belonging across all time points and physics students (γ_{00}) was 4.34 (between *slightly agree* and *agree*). In other words, students on average slightly agreed that they felt like a member of their physics community.

Students' social belonging in the physics major did not change significantly over time (B8; $\gamma_{10} = 0.03$, $t = 1.34$, $p = 0.18$), nor was there significant interindividual variability in the rate of change ($\tau_{11} = 0.004$, $z = 1.07$, $p = 0.14$). Linear time accounted for only 9% of within-student variability in social belonging. Given the lack of change and variability in social belonging over time, interactions between time and Level 2 predictors were not included in the full model. Adding Level 1 and Level 2 predictors showed that, on average, when students reported more malleable beliefs about their physics abilities, they also expressed a greater social belonging in the physics major ($\gamma_{30} = 0.69$, $t = 2.46$, $p = 0.02$). At the same time, this trend was not uniform across students with different races and ethnicities. As depicted in Figure 2.4, white and Asian students with more malleable physics ability beliefs reported significantly higher social belonging than those with less malleable physics ability beliefs (0.62 ± 0.18, $t = 3.55$, $p = 0.0005$), though social belonging did not differ for Black and Latine students with more or less malleable

physics ability beliefs (0.08±0.25, t = 0.31, p = 0.76). Black and Latine students who perceived high, innate intelligence as required for success in physics did report a significantly lower average level of social belonging than both Black and Latine students who did not perceive as such and White and Asian students with a range of field-specific ability beliefs (γ_{05} = -0.79, t = -2.86, p = 0.005). In addition, men reported a higher average sense of social belonging in the major than women (γ_{01} = 0.48, t = 2.06, p = 0.04). There were no differences in average social belonging based on students' academic level (Table 2.6). The full model accounted for 25% of between-student and 14% of with-in student variability in social belonging.

Figure 2.4

Interaction Between Race and Ethnicity, Physics Ability Beliefs, and Physics Social Belonging



Research Question 1d

The fourth and final part of my research question investigated if there was a significant linear relationship between a student's physics ability beliefs, ability belonging, social belonging, and intent to persist in a physics major over time. It also examined whether this relationship depended on a student's gender, race, ethnicity, academic level, and perceptions that innate brilliance is required for success in physics. Results of the unconditional model (B10) revealed that 83% of variability in persistence intentions was between students ($\tau_{00} = 0.79$, $z = 5.64$, $p<0.0001$) and 17% was within students ($\sigma^2 = 0.16$, $z = 6.96$, $p<0.0001$). Findings indicated that there was sufficient within- and between-student variability in persistence intentions to justify further analyses. The mean value of intended persistence across all time points and students (γ_{00}) was 4.94 (just under *agree*). This signifies that on average, students agreed that they intended to persist in the physics major over time.

Students' persistence intentions did not change significantly over time (B11; $\gamma_{10} = -0.005$, $t = -0.22$, $p = 0.83$), nor was there significant interindividual variability in the rate of change ($\tau_{11} = 0.005$, $z = 0.90$, $p = 0.18$). Linear time accounted for 10% of within-student variability in persistence intentions. Adding Level 1 predictors (B12) showed that, on average, a positive within-student relationship existed between ability belonging and intended persistence ($\gamma_{40} = 0.20$, $t = 3.31$, $p = 0.001$). A significant within-student relationship did not exist between social belonging or physics ability beliefs and intended persistence (Table 2.7). Adding Level 2 predictors to the model (B13) revealed that students who perceived success in physics as requiring innate intelligence conveyed lower persistence intentions ($\gamma_{03} = -0.21$, $t = -2.20$, $p = 0.03$). In addition, there was a small yet significant interaction between gender, social belonging, and persistence intentions, such that men with high social belonging reported particularly high

persistence intentions ($\gamma_{42} = 0.26$, $t = 2.16$, $p = 0.03$). There were no significant differences in average persistence intentions based on students' race and ethnicity, academic level, or physics ability beliefs. Given the lack of change and variability in social belonging over time, interactions between Level 1 and Level 2 predictors and time were not included in the full model. The full model accounted for 28% of between-student and 12% of with-in student variability in persistence intentions (Table 2.7).

To examine whether ability belonging mediated the relationship between a student's physics ability beliefs and intended persistence, I conducted a mediation analysis (Baron & Kenny, 1986). Following Baron & Kenny (1986) using uncentered data, in the absence of other predictors students with more malleable beliefs about their physics abilities reported greater persistence intentions (Step 1) and ability belonging (Step 2). The association between physics ability beliefs and intended persistence was significantly reduced when ability belonging was added (Step 3, Sobel test = 2.73, $p = 0.006$). This indicated that ability belonging significantly mediated the relationship between physics ability beliefs and intended persistence in the physics major.

Table 2.7

Unstandardized Coefficients (And Standard Errors) of Multilevel Models of Intended Persistence (Level 1 = 168; Level 2 = 87)

Fixed Effects	Coefficient (SE) Level 1 Only	Coefficient (SE) Level 1 + Level 2
Persistence, β_0		
Intercept, γ_{00}	4.78*** (0.26)	4.78*** (0.26)
Gender, γ_{01}		0.20 (0.22)
Race/Ethnicity, γ_{02}		0.49 (0.27)
Field-specific ability beliefs, γ_{03}		-0.24* (0.09)
Time slope, β_1		
Intercept, γ_{10}	0.003 (0.02)	0.01 (0.02)
Academic level slope, β_2		
Intercept, γ_{20}	0.006 (0.08)	-0.03 (0.08)
Physics ability beliefs slope, β_3		
Intercept, γ_{30}	0.14 (0.08)	-0.07 (0.23)
Gender, γ_{31}		0.19 (0.24)
Race/ethnicity, γ_{32}		-0.04 (0.22)
Ability belonging slope, β_4		
Intercept, γ_{40}	0.20** (0.05)	0.22 (0.14)
Gender, γ_{41}		-0.03 (0.15)
Race/ethnicity, γ_{42}		0.03 (0.17)
Social belonging slope, β_5		
Intercept, γ_{50}	0.05 (0.05)	-0.10 (0.10)
Gender, γ_{41}		0.26* (0.12)
Race/ethnicity, γ_{42}		-0.21 (0.17)
Random Effects		
Persistence, τ_{00}	0.6269***	0.568***
Within-student variation, σ^2	0.1449***	0.141
$R^2_{between}$	0.21	0.28
R^2_{within}	0.11	0.12

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Discussion

This study contributes needed insight into the longitudinal dynamics of the physics ability beliefs, field-specific ability beliefs, sense of belonging, and persistence intentions of undergraduate physics majors enrolled in physics courses that incorporated an interactive instructional approach. Findings add novel connections between these factors and illuminate ways in which dynamics overlap and diverge for students with various gender, racial, and ethnic identities. The results from this study also offer important implications for undergraduate physics programs and instructors.

In agreement with recent empirical work, students' own physics ability beliefs were best represented not as a continuum (entity to incremental), but as two distinct yet covarying, dynamic constructs (entity and incremental) (Kalender et al., 2022; Limeri et al., 2020a; Malespina et al., 2022). Overall, participants agreed that their physics abilities were capable of growth and change with effort. At the same time, the malleability of students' ability beliefs declined over the course of the three semesters across all academic levels, even in the presence of an interactive instructional approach. Research documents that college students often convey less malleable beliefs about their intellectual abilities in STEM subjects over time, though to date such changes have mainly been studied in introductory STEM course contexts (Dai & Cromley, 2014; Flanigan et al., 2016; Limeri et al., 2020a; Marshman et al., 2018; Malespina et al., 2022; Shively & Ryan, 2013). Dissection of this longitudinal trend revealed that undergraduates who experienced ongoing academic struggle in a physics course reported a decline in their incremental physics ability beliefs over time compared to those who either never struggled or who overcame struggle. A substantial body of literature supports a positive connection between incremental ability beliefs and academic performance, though most existing work focuses on the

benefits of incremental ability beliefs on performance, rather than on the influence of academic performance on ability beliefs (Blackwell et al., 2007; Claro et al., 2016; Kalender et al., 2022; Malespina et al., 2022; Romero et al., 2014; Schleicher, 2019). The present study corroborates work by Limeri et al. (2020a), who suggested a reciprocal relationship between domain-specific ability beliefs and academic struggle in which both factors influence each other over time. Though unlike findings from Limeri et al. (2020a), physics students who experienced continued academic struggle did not start out with less malleable physics ability beliefs than their peers. This divergent result could stem in part from the fact that Limeri et al. (2020a) examined the chemistry ability beliefs of undergraduates in a variety of STEM majors who most likely brought a greater range of beliefs about chemistry abilities. The present study examined the domain-specific ability beliefs of undergraduates enrolled in courses meant for students majoring in said domain. Such students possibly entered college with more consistent domain-specific ability beliefs, as they decided to focus their undergraduate studies in the subject.

Participants' physics ability beliefs also varied based on their field-specific ability beliefs. As a whole, students were less certain that effort is more important than innate, high intelligence for success in physics than they were in the malleability of their own physics abilities (Rattan et al., 2012). At the same time, students who perceived innate, high intelligence as a prerequisite for success in physics reported less malleable beliefs about their own physics abilities. In other words, ascribing to the commonly held belief that inherent brilliance is required to thrive in physics influences the dynamics of one's beliefs about their own abilities in the discipline. Such a connection between these two distinct yet overlapping constructs (field-specific brilliance beliefs and domain-specific incremental ability beliefs) has been posited but largely unexplored in the literature (Bian et al., 2018; Kalender et al., 2022; Malespina et al., 2022; van Aalderen-

Smeets et al., 2018). This finding contributes important empirical evidence that disciplinary-level cultures of brilliance can inhibit students from viewing their abilities as malleable with time and effort (Bian et al., 2018; Malespina et al., 2022).

Students' physics ability beliefs and field-specific ability beliefs did not vary significantly based on their gender, race, ethnicity, or academic level. This contrasts with results from several recent studies, which determined that women in college physics courses conveyed increasingly fixed beliefs about their physics abilities over time compared to men, a finding attributed to oppressive stereotypes that position women as less capable in science and math than men (Kalender et al., 2022; Malespina et al., 2022; Marshman et al., 2018). Once again, this differing finding could arise in part from the fact that the present study focused on undergraduates enrolled in courses meant for physics majors, whereas other studies surveyed students in algebra- and calculus-based physics courses intended for students majoring in a variety of STEM fields. It seems plausible that women, Black, and Latine students who elect to major or minor in physics have more malleable beliefs about their physics abilities than those who take a physics course as a requirement for a different STEM major. Nonetheless, it is promising that students with traditionally marginalized gender, racial, and ethnic identities did not report different individual- or disciplinary-level physics ability beliefs than their non-marginalized peers. Such a result suggests that women, Black, and Latine physics majors at Southeastern University who enrolled in courses that incorporated an experimental lab activity were equally as likely as men, white, and Asian undergraduates in the program to view their physics abilities as malleable.

Overall, participants were not particularly confident about their ability or social belonging in the physics major. In line with existing literature, women on average reported lower

perceived ability and social belonging in the physics major than men (Banchefsky et al., 2019; Bjorkquist et al., 2019; Lewis et al., 2016; Lewis et al., 2017; Sax, 1994; Sax et al., 2015; Seyranian et al., 2018). In addition, while Black and Latine students did not initially express a lower sense of ability belonging than their white and Asian peers, such a trend appeared over time. The exact causes of these disparities could not be entirely isolated by the present study, though a wealth of empirical work documents that women, Black, Latine, and Indigenous students commonly feel that they do not belong in physics and related STEM fields due to white, masculine cultures and exclusionary, discriminatory, and isolating conditions (AIP, 2020; Fries-Britt & Holmes, 2012; Gonsalves et al., 2016; Lewis et al., 2016; MeGee, 2016; Ong, 2005; Prescod-Weinstein, 2020' Settles et al., 2006). In addition, collaborative, interactive activities in college physics courses can spur greater peer exclusion and stereotype-driven stress for marginalized students (Maries et al., 2020; Pollock et al., 2007). Results of the present study emphasize that oppressive dynamics can lead women, Black, and Latine students to experience a lower sense of belonging in a physics major than their male, white, and Asian peers even after accounting for the effects of individual and disciplinary-level beliefs about intelligence.

This study contributes novel connections between students' own physics ability beliefs and their ability and social belonging in a physics major. On average, students reported greater ability and social belonging when they expressed more malleable beliefs about their physics abilities and lower belonging when they perceived innate, high intelligence as required for success in the discipline. The relationship between physics ability beliefs and ability belonging was more pronounced for women than for men, such that women with less malleable beliefs about their physics abilities reported the lowest level of ability belonging. Differences in ability belonging largely disappeared between women and men with more malleable physics ability

beliefs. Prior work has established that women experience a lower sense of belonging in a STEM field when they perceive that others in their discipline or learning environment promote entity ability beliefs or innate brilliance as required for success (Bian et al., 2018; Clark et al., 2021; Deiglmayr et al., 2019; Good et al., 2012; Rattan et al., 2018; Smith et al., 2013). Perceptions that a learning environment promotes incremental ability beliefs, on the other hand, can increase a woman's sense of belonging in STEM, even in the presence of negative stereotypes about women's STEM abilities (Good et al., 2012). My findings add to this work by indicating that women are significantly less likely to perceive that they belong intellectually in physics when they believe that their *own* physics abilities are not malleable. While the present study did not explicitly measure students' stereotypes about women's STEM abilities, it is possible that believing one's physics abilities are malleable with time and effort reduces the impact of negative intelligence stereotypes on women's ability belonging in physics.

The positive relationship between incremental physics ability beliefs and social belonging in the physics major was far more apparent for white and Asian students than for Black and Latine students. Given the lack of racial and ethnicity diversity in the physics program at Southeastern University and the prevalence of hostility, exclusion, and discrimination against Black, Latine, and Indigenous individuals in physics spaces, there are many factors restricting the social belonging of marginalized students of color in physics (AIP, 2020; Fries-Britts et al., 2010; Hyater-Adams et al., 2018; McGee, 2016). It is thus not surprising that incremental physics ability beliefs alone have a lesser impact on the social belonging of Black and Latine students, who likely contend with numerous threats to their social belonging in their postsecondary physics spaces. At the same time, Black and Latine students who perceived high, innate intelligence as required for success in physics reported particularly low levels of social

belonging in the major. This finding suggests Black and Latine students experience lower levels of social belonging in physics when they endorse the common notion that innate brilliance is needed to achieve disciplinary success. Existing literature documents that disciplinary cultures of brilliance often correspond to lower disciplinary belonging for women, who due to oppressive stereotypes worry that they do not align with the prototypical brilliant person (Bian et al., 2018; Deiglmayer et al., 2019). Although the present study cannot infer causal relationships, my results substantiate that the sense of belonging of Black and Latine physics students, who are also subjected to negative intelligence stereotypes, is similarly inhibited by disciplinary cultures of brilliance.

A high level of ability belonging corresponded to greater persistence intentions across all students and semesters. Ability belonging, moreover, mediated the relationship between incremental physics ability beliefs and intended persistence. While empirical work has recorded positive relationships between domain-specific incremental ability beliefs and persistence (Clark et al., 2021; Good et al., 2012; Kricorian et al., 2020; van Aalderen-Smeets et al., 2018) and ability belonging and persistence (Banchefsky et al., 2019; Lewis & Hodges, 2015; Lewis et al., 2017; Rainey et al., 2018), the present study establishes an important connection between these three constructs. The positive relationships between incremental physics ability beliefs, ability belonging, and intended persistence did not vary based on students' gender, race, ethnicity, or academic level, which indicates that these two factors benefit the persistence of all physics students. At the same time, as previously discussed, incremental physics ability beliefs had an outsized positive impact on the ability belonging of women. This suggests that malleable physics ability beliefs can support the persistence of women in physics through their role in increasing women's ability belonging in the discipline.

While a greater social belonging did not as a whole correspond to higher persistence intentions over the three semesters, there was a significant interaction effect, such that men with high levels of social belonging reported the greatest persistence intentions. This contrasts with past work, which determined the relationship between social belonging and persistence in STEM to be stronger for women than for men (Banchefsky et al., 2019; Good et al., 2012). While past research surveyed students in introductory college calculus and physics courses majoring in a variety of disciplines, the present study surveyed physics majors across a range of academic levels. Given that women on average reported lower social belonging in the major than men, it is likely that the social dynamics of the physics major are more welcoming and available for men than for women. As such, women are forced to rely more heavily on other factors (such as ability belonging) to persist. This does not mean that social belonging is not important for women in physics, but that the current masculine dynamics of physics spaces may deter women from relying on social belonging as a persistence strategy as strongly as men.

Students who ascribed to the belief that innate, high intelligence is required for success in physics conveyed lower persistence intentions in the major, a finding that did not vary by gender, race, or ethnicity. Literature documents that fields that emphasize innate brilliance contain fewer women, Black, Latine, and Indigenous individuals (Leslie et al., 2015; Meyer et al., 2015; Storage et al., 2016). My results indicate that believing innate brilliance is needed to thrive in a discipline is detrimental to the persistence of individuals with a range of social identities. As detailed above, students who perceived innate, high levels of intelligence as required for success in physics also reported less malleable physics ability beliefs and lower ability and social belonging. In addition, Black and Latine students who ascribed to this notion conveyed particularly low levels of social belonging in physics. Together, these findings substantiate that

dismantling physics' stereotypical culture of brilliance is necessary for fostering postsecondary physics learning environments in which students with a diversity of social identities can grow, belong, and persist.

Directions for Future Research

This study included multiple limitations and opportunities for further inquiry. First, while the demographics of survey respondents closely matched the demographics of the undergraduate physics major at Southeastern University, white and male participants greatly outnumbered women, Black, and Latine participants and there were no Indigenous participants. Given the relatively low number of participants with marginalized gender, race, and ethnic identities, I was not able to inferentially analyze the dynamics of Black and Latine participants individually. In addition, it is possible that analyses underrepresented the strength of certain dynamics. I was also not able to address the intersectional nature of marginalization through interaction effects given the comparatively low number of women and people of color in the sample. On top of this, the physics major at Southeastern University is itself rather small, which led to smaller sample sizes than one would obtain in a larger undergraduate program. Ongoing data collection will partially ameliorate these limitations through the addition of more study participants, though expanding the study to multiple institutions could also aid in this matter. Results from this study also potentially underestimated the relationship between academic struggle and physics ability beliefs, as students who experienced ongoing academic struggle were undoubtedly more likely to withdraw from a physics course and thus not continue to participate in the study over time. Second, my study employed a correlational design and as such could not assert causal conclusions about the relationship between various factors. Third, there exists a paucity of context-specific survey measures that discern the mechanisms underlying individuals' domain-

specific ability beliefs over time. Since the start of this study, another research team (Kalender et al., 2022) published a physics mindset survey that overlaps substantially with both the Physics Ability Beliefs Scale and Field-Specific Physics Ability Beliefs Scale. Future work should continue to evaluate and modify domain-specific measurements to ensure that they are best capturing physics ability beliefs. Fourth, multilevel modeling does not take into account the potential influence of measurement error, nor does it examine complex relationships between latent and observed variables. The sample size of the present study did not allow for multilevel structural equation modeling, though such a technique would address this limitation. Fifth, the present study surveyed physics majors enrolled in courses that incorporated an interactive instructional approach, but it did not discern how specific components of the approach influenced students' beliefs, perceptions, and intentions. Lastly, for practical purposes I focused only on relationships among several factors previously posited as influential on physics students' ability beliefs, academic belonging, and short-term persistence. I could not capture all variables that influenced the dynamics of these outcomes over time. Much room exists to explore and examine additional factors that shape the students' physics ability beliefs over time.

Practical Implications

Physics is traditionally regarded as an intellectually difficult field that necessitates a high, innate intelligence as a prerequisite for success and disciplinary membership (Cheryan et al., 2017; Gonsalves & Danielsson, 2020; Law, 2020; Leslie et al., 2015). The present study substantiates that this culture of brilliance is harmful to undergraduate physics majors with a range of social identities, even those who fit the mold of the prototypical brilliant person. Disciplinary-level brilliance beliefs corresponded to students having less malleable beliefs about their own physics abilities and lower academic belonging and persistence intentions. In other

words, physics' culture of brilliance acts as a source of exclusion that deters students from thriving and remaining in the discipline over time. The interactive instructional approach in itself was not sufficient for disrupting the notion that innate, high intelligence is required for success in physics. It is extremely important that programs and instructors proactively address and disrupt physics' culture of brilliance and replace it with one that frames sustained, strategic effort as paramount for thriving in the field. Such a disruption first requires administrators and instructors to intentionally reflect on their own beliefs about the role that innate, high intelligence plays in the field, as such beliefs undoubtably influence the culture that they build and maintain in their disciplinary spaces. Instructors might then incorporate lessons into interactive physics courses about the academic and professional journeys of historical and current physicists to illustrate that the actual process of learning and doing STEM requires collaborative dedication and perseverance over innate giftedness. Physics programs could also host seminar speakers that expose students to the range of skills, approaches, and applications valued by professional physicists. In addition, programs and instructors should actively involve students in fostering programmatic and classroom norms that elevate effort over innate, high intelligence.

On top of dismantling a culture of brilliance in physics learning spaces, instructors and TAs should implement practices that aid students in perceiving their own abilities in the discipline as capable of growth and change, particularly when they are faced with academic challenges. Binning et al. (2020) a classroom activity with documented efficacy in increasing the malleability of students' ability beliefs in college physics contexts. Alongside such student-focused activities, instructors play an important role in establishing and reinforcing norms that foster classroom cultures of learning, challenge-seeking, and growth as opposed to competition for high grades (Yeager et al., 2019; Zeeb, Ostertag, & Renkl, 2020). Examination and grading

techniques that prioritize students' process over the final answer are also beneficial for emphasizing the iterative nature of learning and doing physics (Dweck, 2012; Miller, Kestin, & Miller, 2022; Zeeb et al., 2020). Resources exist for instructors to require students to critically reflect on their feelings and ability beliefs following summative assessments and to make a concrete plan for improvement (FLAMEnet, 2023). Instructors and TAs should work to normalize the trial-and-error process of learning and doing physics by offering low-stakes opportunities such as the experimental lab activities that allow students to fail without penalty.

My findings stress that women, Black, and Latine physics majors face threats to their sense of ability and social belonging in interactive physics courses above and beyond physics ability beliefs and cultures of brilliance. While tending to these factors are important, increasing diversity, inclusion, equity, and justice in undergraduate physics spaces requires understanding and addressing the multitude of interpersonal, cultural, and structural factors that inhibit the academic belonging and persistence of students with marginalized social identities. For example, literature documents that women and marginalized students of color in STEM are often hesitant to actively participate in interactive instructional activities due to the increased self-doubt peer exclusion that comes from interacting with peers in white, masculinized learning spaces (Bando et al., 2019; Eddy et al., 2015; Ernest et al., 2019; Reinholz et al. 2022; Setren et al., 2021). Instructors and TAs should structure such activities so that students with marginalized social identities are not singled out or left out of actively engaging in the learning process (Doucette & Singh, 2022). Undergraduate physics programs should also implement lessons and activities that support students and instructors with a diversity of social identities and backgrounds in developing an awareness, understanding, and commitment to ameliorate inequities in the discipline (Byrd, 2022; Byrd, 2023; Arielle-Evans et al., 2019; Dalton & Hudging, 2020; Decker

& Daane, 2017; Lock & Hazari, 2016; Watts et al., 2011). By critically interrogating and reworking the power dynamics of postsecondary physics learning environments, students with a range of social identities will be able to be perceived as competent, valued, and legitimate disciplinary members (Johnson, 2020).

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CHAPTER 3

EXAMINING THE SHORT-TERM DYNAMICS OF COLLEGE PHYSICS MAJORS' DISCIPLINARY ABILITY BELIEFS AND IDENTITY DEVELOPMENT

The number of bachelor's degrees awarded to women, Black, Latine, and Indigenous individuals in science, technology, math, and engineering (STEM) disciplines has increased in the United States over the last two decades (NSF, 2021). At the same time, the representation of individuals with these gender, racial, and ethnic identities varies considerably by STEM field (NSF, 2021). Of all STEM baccalaureate areas, physics consistently remains one of the least diverse (NSF, 2021; NRC, 2013). In 2020 women earned 24% and Black, Latine, and Indigenous individuals just 3.4%, 12.4%, and 3% of physics bachelor's degrees respectively (APS, 2023). Although the percentage of Latine students in physics increased somewhat since 1999, the percentage of physics bachelor's degrees awarded to Black students declined during this time (Mervis, 2022). Bachelor's programs in physics can lead to well-paying STEM careers in a range of sectors such as renewable energy and information technology (NRC, 2013). Addressing factors that perpetuate the underrepresentation of women, Black, Latine, and Indigenous students in physics bachelor's degree programs is necessary for both making the discipline of physics more diverse, inclusive, equitable, and just and for broadening access to high-paying STEM professions (NRC, 2013).

At the undergraduate level, physics programs traditionally rely on a lecture-recitation course format in which students passively take notes and complete structured problem sets and high-stakes exams (NRC, 2013). Physics education research suggests that this instructional format helps to fuel individualistic classroom cultures in which students compete to showcase their intellectual abilities (Mervis, 2011; NRC, 2013). The notion that college courses should be

delivered in a way that *weeds out* students who do not possess the ability to "make it" in a discipline is prevalent in STEM fields beyond physics (Seymour & Hunter, 2019). Research documents that weed-out course cultures are damaging to the learning and engagement of STEM students with a range of social identities and backgrounds (NRC, 2013; Mervis, 2011). Such courses are particularly detrimental to the persistence of women, Black, Latine, and Indigenous college students who due to oppressive societal stereotypes are unjustly positioned as less innate intellectually talented than their male, White, and Asian peers (Bian et al., 2018; Leslie et al., 2015; Seymour & Hunter 2019; Storage et al., 2016; Thompson, 2019). Negative intelligence stereotypes can spur elevated instances of bias, exclusion, and self-doubt, particularly in environments that promote competition and frame high innate intellectual ability as necessary for success and belonging (Bian et al., 2018; Rattan et al., 2018). These oppressive dynamics are further intensified by disciplinary-wide associations with innate brilliance that exist in STEM fields such as physics (Gonsalves & Danielsson, 2020; Leslie et al., 2015).

College STEM instructors who promote a weed-out mentality reinforce the notion that success in STEM requires an inherently high level of intelligence (Leslie et al., 2015). Research documents that as undergraduates engage in college STEM courses, they commonly report increasingly fixed beliefs about their intellectual ability in specific STEM subjects (Dai & Cromley, 2014; Flanigan et al., 2017; Limeri et al., 2020a; Malespina et al., 2022; Marshman et al., 2018; Shively & Ryan, 2013). Students with fixed ability beliefs (known also as entity beliefs or a fixed mindset) view their intelligence as largely inherent and unchanging (Dweck, 2012). In contrast, those with malleable ability beliefs (also known as incremental beliefs or a growth mindset) view their intelligence as capable of change with strategic effort and experience. In undergraduate STEM contexts, students with entity beliefs about their intellectual ability in a

particular subject experience less confidence, lower academic performance and belonging, and greater attrition in their STEM courses and majors than those with incremental beliefs (Dai & Cromley, 2014; Kalender et al., 2022; Malespina et al., 2022; Shively & Ryan, 2013). Multiple studies have isolated factors that contribute to changes in undergraduates' ability beliefs during college STEM courses, though empirical work focuses largely on student-level variables such as motivation and academic struggle (Flanigan et al., 2017; Limeri et al., 2020a; Little et al., 2019; Kalender et al., 2022; Malespina et al., 2022). A need exists for scholarship that examines how college STEM students' domain-specific intellectual ability beliefs vary and change in relation to aspects of their STEM learning environments.

Empirical work suggests that the intellectual ability beliefs explicitly and implicitly communicated in college STEM settings have an outsized impact on college students whose gender, racial, and ethnic identities are marginalized by negative intelligence stereotypes (Canning et al., 2019; Good et al., 2012; LaCosse et al., 2020). Marginalized students have significantly worse academic experiences and outcomes than their peers in college STEM courses led by instructors who endorse entity beliefs about their students' intellectual abilities (Canning et al., 2019; LaCosse et al., 2020). The exact causes of these disparities are unclear, though literature suggests that environments that convey that high innate intelligence is required for success can prompt students from marginalized groups to question whether they possess the ability needed to achieve, belong in, and identify with a particular domain (Archer et al., 2020a; Archer et al., 2020b; Bian et al., 2018; Clark et al., 2021; Good et al., 2012; Rattan et al., 2018).

Physics Identity Development

Disciplinary identity development is an important component of students' persistence in physics over time (Hazari et al., 2010; Potvin & Hazari, 2013). Physics education researchers

commonly conceptualize physics identity as being recognized by the self and others as a "physics person," an "exemplary physics student," or a "physicist" (Hazari et al., 2020, p. 1593; Hazari et al., 2010, p. 989; Potvin & Hazari, 2013). A wealth of literature isolates factors that shape the physics identity development of students with various gender, racial, and ethnic identities at different academic levels and in different contexts (Hazari et al., 2010; Hazari et al., 2020; Hyater-Adams et al., 2019; Kalender et al., 2019a; Kalender et al., 2019b; Li & Singh, 2021; Potvin & Hazari, 2013; Ong, 2005). In a recent survey study, Hazari et al. (2020) discerned three factors that directly influenced the discipline-specific identity development of undergraduate women physics majors: competence/performance (which for simplicity's sake I refer to as competence), recognition, and a sense of belonging. *Competence* represented the women's perceptions of their knowledge, skills, and abilities in physics relative to their peers. *Recognition* pertained to perceptions of explicit and implicit recognition from instructors and peers as an exemplary physics student. *Sense of belonging* involved the students' perceived social fit within their physics community (Hazari et al., 2020; Strayhorn, 2019). A fourth factor, *interest* in physics, indirectly influenced the women's physics identity through its positive relationship with both competence and recognition (Hazari et al., 2020). While past research documents that an interest in physics strongly influences students' decision to pursue physics as a major and a career, this construct appears less influential on the disciplinary identity development of students once they enter an undergraduate physics program (Hazari et al., 2020; Hazari et al., 2010).

Empirical work documents that the factors that contribute to physics identity development are not uniformly accessible to students with various gender, racial, and ethnic identities (Hazari et al., 2020; Nespor, 1994). In white male-dominated fields such as physics and

math, women, Black, Latine, and Indigenous individuals tend to report a lower perceived competence than their male, white, and Asian peers regardless of their actual academic performance (Goetz et al., 2013; Kalender et al, 2019a; Sax, 1994; Sax et al., 2015). In addition, students with these marginalized social identities often receive less positive recognition from both their instructors and their peers (Doucette & Singh, 2020; Kalender et al., 2019a; Li & Singh, 2021). On top of this, women, Black, Latine, and Indigenous physics students frequently possess a lower sense of belonging in both K-12 and postsecondary physics spaces (Banchefsky et al., 2019; Fries-Britts et al., 2010; Lewis et al., 2016; Lewis et al., 2017; Rainey et al., 2018; Seyranian et al., 2018). These trends emphasize that *who* can achieve competence, recognition, and belonging and hence develop a disciplinary identity in physics is strongly tied to the interpersonal, cultural, and structural features of physics learning environments (Avraamidou, 2022; Gonsalves & Danielsson, 2020; Johnson, 2020). The present study contributes novel insight into how one such environmental feature: the beliefs that instructors explicitly and implicitly convey about students' intellectual abilities in physics, influence the competence, recognition, social belonging, and hence physics identity development of undergraduate physics majors with various gender, racial, and ethnic identities.

Interactive Instructional Approaches in College Physics Courses

In an effort to improve the learning environment of undergraduate physics courses, physics instructors have increasingly developed and implemented interactive instructional approaches in college physics classrooms (NRC, 2013). While they vary in scope, such approaches seek to enhance students' cognitive and affective growth by employing collaborative engagement techniques that support their scientific thinking, problem solving, and metacognition capabilities (Freeman et al., 2014; Karim et al., 2018; NRC, 2013; Theobald et al., 2020).

Empirical work shows that interactive instructional approaches can benefit college physics students' academic performance, attitudes, and beliefs (Freeman et al., 2014). A number of physics education researchers have examined such approaches as a tool for increasing the persistence of physics students with marginalized gender, racial, and ethnic identities (Karim et al., 2018; Lorenzo et al., 2006; Pollock et al., 2007; Rodriguez et al., 2016). Evidence suggests that while interactive instructional approaches carry the potential to improve the performance and persistence of college physics students with marginalized gender, racial, and ethnic identities, these benefits are not uniformly observed. Unsurprisingly, the strengths of such approaches depend largely on their implementation and classroom context (Theobald et al., 2020; Maries et al., 2020; Pollock et al., 2007). Collaborative peer learning activity can actually increase instances of stereotype-driven stress and anxiety among marginalized physics students (Maries et al., 2020; Pollock et al., 2007). When examining interactive instructional approaches, it is thus important to investigate how various aspects of marginalized students' course experiences influence their beliefs and perceptions about their abilities and place in physics (NRC, 2013). To date, relatively few studies have focused on such dynamics when studying interactive approaches in college physics classrooms (Good et al., 2019; Little et al., 2019). Greater empirical insight is essential for understanding how interactive physics classroom environments can better foster the engagement, well-being, disciplinary identification, and persistence of undergraduates with a diversity of social identities and backgrounds.

Purpose of Study

The purpose of this time-series survey study was twofold. The first goal was to examine the contextual dynamics through undergraduate physics majors' domain-specific ability beliefs and perceived recognition from instructors and peers shifted and changed on a weekly basis over

the course of a semester. Specifically, I examined these dynamics for students enrolled in an introductory or advanced major-specific college physics course that incorporated an interactive experimental lab activity. The second goal was to explore the relationships between students' personal and environmental contexts, their physics ability beliefs, their perceived recognition, their ability and social belonging, their physics identity, and their short-term persistence over a semester.

Research Questions

1. On average, are there significant linear changes in a student's physics ability beliefs and perceived recognition over the course of a semester? Do these changes depend on a student's gender, race, ethnicity, course level, perceived academic struggle, type of academic task encountered during a week, and perceived instructor ability beliefs?
2. On average, are there significant linear relationships between a student's physics ability beliefs, perceived recognition, sense of ability and social belonging in physics, physics identity, and an intent to persist in a physics major? Do these relationships depend on a student's gender, race, ethnicity, course level, and perceived instructor ability beliefs?

Literature Review

This literature review synthesizes existing research in multiple areas pertinent to the present study. I begin by providing a theoretical and empirical overview of implicit ability beliefs. Next, I focus more specifically on work that examines the dynamic, domain-specific nature of college students' ability beliefs and explores the impacts of environmental-level ability beliefs. I then cover the construct and components of physics identity and outline observed differences in physics identity development based on gender, race, and ethnicity. I end by

discussing the relationships between domain-specific ability beliefs, disciplinary identity development, and persistence in college STEM settings.

Implicit Ability Beliefs

Dweck and colleagues constructed a framework that positioned students' perceptions, goals, and actions as resulting from different implicit theories of intelligence (Dweck & Leggett, 1988). Today often referred to as implicit ability beliefs or mindsets, implicit theories of intelligence were named as such due to their often-unconscious influences on affect and behavior (Dweck & Leggett, 1988; Dweck, 2012). Individuals with entity beliefs (also known as an entity theory or fixed mindset) view their intellectual ability as more or less innate and stable. Those with incremental beliefs (also known as an incremental theory or growth mindset) view their intellectual ability as capable of growth and change (Dweck & Leggett, 1988; Dweck, 2012). Dweck's framework positions implicit ability beliefs as the basis of meaning systems that guide students' behavior in academic settings (Dweck & Yeager, 2019; Hong et al., 1999). Empirical work suggests that the meanings individuals and groups ascribe to effort, challenge, and failure vary according to their ability beliefs and that this variation can produce divergent behavioral responses (Blackwell et al., 2007; Hong et al., 1999; Miele et al., 2013; Nussbaum & Dweck, 2008; Robins & Pals, 2002). Students with entity beliefs are more likely to attribute success to inherent traits and talents (Robins & Pals, 2002). They tend to view effort as an indication of low ability, are less likely to develop learning-focused goals, and often employ ineffective, defensive strategies when faced with academic setbacks (Hong et al., 1999; Nussbaum & Dweck, 2008). Students with incremental beliefs, on the other hand, view effort and setbacks as key components of mastery and are more likely to develop effective learning strategies that promote persistence in the face of academic challenges (Hong et al., 1999; Robins & Pals, 2002).

Implicit Ability Beliefs & Student Outcomes

The divergent meaning systems generated by students' implicit ability beliefs can carry important consequences (Blackwell et al., 2007; Robins & Pals, 2002; Yeager et al., 2019). Multiple studies correlate incremental ability beliefs with factors such as greater self-esteem, self-efficacy (a belief in one's capacity to achieve a desired result), academic belonging, and STEM career intentions (Bandura, 1986; Degol et al., 2018; Good et al., 2012; Robins & Pals, 2002; van Aalderen-Smeets et al., 2019). Research also suggests positive links between incremental ability beliefs and academic achievement, though such findings are not universal across the literature (Aronson et al., 2002; Blackwell et al., 2007; Burgoyne et al., 2020; Kalender et al., 2022; Malespina et al., 2022; Sisk et al., 2018; Yeager et al., 2019). Several correlational studies have found that middle and high school students with incremental ability beliefs perform significantly higher than those with entity beliefs both in courses and on standardized assessments (Blackwell et al., 2007; Claro et al., 2016; Romero et al., 2014; Schleicher, 2019). Two recent empirical investigations similarly observed that college students with fixed disciplinary-specific ability beliefs obtained lower final grades in calculus-based introductory physics courses (Kalender et al., 2022; Malespina et al., 2022). Kalender et al. (2022) further determined that fixed notions of physics ability partially explained women's lower final physics course grades, as women were more likely than men to hold fixed views about their physics abilities. Other scholars have experimentally explored how interventions meant to teach students to view their intellectual ability as malleable impact academic achievement, particularly for students with gender, racial, and ethnic identities negatively stereotyped in school settings (Aronson et al., 2002; Good et al., 2003; Yeager et al., 2019). Aronson et al. (2002) found that Black college students exposed to such an intervention had greater GPAs than those in a control

group who did not receive an intervention. Good et al. (2003) determined that female 7th grade students who completed a growth-oriented intervention earned higher scores on standardized math and reading tests than their peers. Binning et al. (2020) exposed college students in an introductory biology and an introductory calculus-based physics course to a series of reflective writing and interactive classroom activities meant to help normalize academic struggle. Students who were exposed to the activities had greater attendance, course grades, 1-year persistence in college, and 2- to 4-year cumulative GPA than those who were not. The benefits of the activities on students' grades were particularly pronounced for women the physics course and for students of color the biology course (Binning et al., 2020). These and other findings suggest that for students with marginalized social identities, malleable intellectual ability beliefs may help buffer against the negative effects of stereotype threat on academic achievement (Aronson et al., 2002; Claro et al., 206; Good et al., 2003; Good et al., 2012). Interventions that promote incremental ability beliefs also appear to improve grades for low-achieving students, though only when a student's classroom environment also emphasizes malleable views of intelligence (Yeager et al., 2019). At the same time, the benefits of interventions that promote incremental ability beliefs may not extend to all students (Burgoyne et al., 2020; Sisk et al., 2018). In an extensive meta-analysis of over 300 studies examining relationships between intellectual ability beliefs and academic achievement in students with a wide range of identities and backgrounds, Sisk et al. (2018) found a weak, non-significant effect of classroom interventions meant to promote incremental ability beliefs on academic achievement. In fact, evidence suggests that fixed ability beliefs can actually bolster the performance of students from favorably stereotyped groups (such as white men) as well as high-achieving students who do not encounter challenges in a particular evaluative situation (Dweck, 2012; Mendoza-Denton et al., 2008). Sisk et al. (2018) point out

that mixed results from ability belief intervention may stem in part from the fact that such interventions do not necessarily universally impact students' actual beliefs about their intellectual abilities across a variety of contexts and domains.

Domain-Specific Ability Beliefs

Most existing work examines conceptions of general intellectual ability, without accounting for how such conceptions might vary for an individual across different academic domains. Newer research questions the logic of focusing on general intelligence alone and calls for the development of domain-specific scales that measure students' ability beliefs in various subject areas (Kalender et al., 2022; Limeri et al., 2020b; Malespina et al., 2022; Shively & Ryan, 2013; van Aalderen-Smeets et al., 2019). Domain differentiation becomes more important as students advance through higher levels of education and are exposed to a wider range of disciplines (Gunderson et al., 2017; Limeri et al., 2020b). Studies that rely only on general intelligence survey items to understand how students' implicit ability beliefs relate to various outcomes run the risk of missing important inferences related to domain-specific ability beliefs (Limeri et al., 2020b; Shively et al., 2013; van Aalderen-Smeets et al., 2019). The present study addressed this concern by employing a scale that asks students to identify their physics ability beliefs rather than their general intellectual ability beliefs.

Intraindividual Change in Ability Beliefs

Individuals' implicit intellectual ability beliefs have long been viewed as fairly stable, though a growing body of evidence supports that such beliefs develop and shift over time through interactions with the environment (Dweck & Yeager, 2019; Dweck, 2012; Kinlaw & Kurtz-Costes, 2003). To date, most research on shifts in ability beliefs focuses on K-12 groups, though empirical work also documents changes in college student populations (Dai & Cromley,

2014; Flanigan et al., 2017; Kinlaw & Kurtz-Costes, 2003; Limeri et al., 2020a; Malespina et al., 2022; Shively & Ryan, 2013). In college STEM settings, undergraduates commonly report an average increase in entity beliefs over the course of introductory classes (Dai & Cromley, 2014; Flanigan et al., 2017; Marshman et al., 2018; Shively & Ryan, 2013). An investigation of changes in college students' ability beliefs at four points during a semester-long organic chemistry course observed that undergraduates who perceived continuous struggle in the course reported a greater increase in entity beliefs over time than those who either did not or overcame struggle (Limeri et al., 2020a). Students who perceived continuous struggle also started the semester with greater entity beliefs than those who did not, suggesting a potentially reciprocal relationship between implicit ability beliefs and academic struggle (Limeri et al., 2020a). Malespina et al. (2022) determined that over the course of an introductory calculus-based college physics course, women became increasingly more likely than men to believe that a fixed, inherent physics ability was necessary to be successful in the discipline. Little et al.'s (2019) qualitative exploration of students' approaches to challenges in a college physics class demonstrated that a particular student could exhibit more fixed or growth beliefs and behaviors depending on the context of the challenge itself. Much remains unknown about the contextual dynamics through which college students' ability beliefs change as they interact with their learning environments (Dweck, 2012; Limeri et al., 2020a; Little et al., 2019). My study contributed to this knowledge gap by analyzing the dynamics of college physics students' domain-specific ability beliefs on a weekly basis throughout a semester.

Environmental-Level Ability Beliefs

While implicit ability beliefs are commonly studied at the level of the individual, environments, organizations, and entire disciplines can endorse certain notions of intelligence

and in doing so embed certain ability beliefs into their core cultures (Canning et al., 2020; Dweck and Yeager, 2019). In the context of educational and workplace environments, such cultures take the form of shared symbols, values, and norms that pertain to the nature of factors such as intellectual ability, effort, and achievement (Canning et al., 2020; Murphy & Dweck, 2010). Murphy & Dweck (2010) examined the role of environmental-level ability beliefs in shaping the self-presentation and self-perceptions of college students in various campus contexts. Using a randomized experimental design, they determined that students emphasized their intelligence when applying to a campus organization that promoted entity beliefs and their motivation when applying to an organization that elevated incremental beliefs. Association with an entity or incremental organization led students to rate such beliefs as more important for their self-concept (Murphy & Dweck, 2010). Implicit ability beliefs and their corresponding meaning systems thus not only operate at higher levels than the individual, but environmental ability beliefs have important impacts on the beliefs and behaviors of current and prospective group members (Canning et al., 2019; Dweck & Yeager, 2019).

Postsecondary course instructors play an important role in conveying intellectual ability beliefs in college STEM environments (Canning et al., 2019; LaCosse et al., 2020; Muenks et al., 2020; Rattan et al., 2012). Students in STEM classes taught by instructors who endorse entity beliefs report lower course interest, engagement, belonging, and performance than students in STEM classes taught by instructors with incremental beliefs (LaCosse et al., 2020; Muenks et al., 2020; Rattan et. 2012). Women in STEM courses anticipate significantly worse course experiences from entity belief instructors than men (LaCosse et al., 2020). While students as a whole tend to perform poorer in STEM classes taught by faculty who espouse entity as opposed to incremental beliefs, Black, Latine, and Indigenous students receive significantly lower grades

than White and Asian students in such courses (Canning et al., 2019). While the precise causes of these disparate outcomes are unclear, negative biases and stereotypes about the innate intellectual abilities of women, Black, Latine, and Indigenous individuals likely contribute to these outcomes (Canning et al., 2019). The present study explored a potential mechanism of these findings by measuring how college STEM students' own intellectual ability beliefs, sense of belonging, perceived recognition, and disciplinary identity varied and changed in relation to their perceived instructors' ability beliefs over the course of a semester.

Physics Identity: A Domain-Specific Science Identity

In recent decades, science identity has emerged as a central psychological component of students' engagement and persistence in various scientific fields (Carlone & Johnson, 2007; Chemers et al., 2011; Eddy & Brownell, 2016; Estrada et al., 2011). Science education researchers commonly root their investigations of this construct in Gee's (2000) definition of identity as "being recognized as a certain kind of person in a given context" (p. 99). Gee's (2000) conceptualization of identity positions individuals as having multiple identities, each with varying levels of relevance and salience in different contexts (Stets & Burke, 2000; Roccas & Brewer, 2002; Vignoles et al., 2011). He frames these identities as being less connected to a person's "internal states" and more to their "performances in society," and emphasizes recognition from others rather than recognition from the self as central to one's identity development (Gee, 2000; p. 99). Theoretical extensions of Gee's work revisit this dichotomy and point out that external recognition as a "certain kind of person" is unlikely to influence one's identity if it is not also accompanied by a self-recognition as such (Potvin & Hazari, 2013). Current studies of science identity focus on how students both recognize themselves and are recognized by other individuals in their environment as a *kind of person* deemed legitimate in a

particular science discipline (Avraamidou, 2022; Carlone & Johnson, 2007). Both internal and external processes of identity recognition are inherently shaped by individual, interpersonal, institutional, and sociocultural forces (Burke & Stets, 2009; Gee, 2000; Stets & Burke, 2000; Syed et al., 2011; Vignoles et al., 2011). Importantly, while empirical work suggests that an individual's domain-specific science identity is fairly stable in a given context and time period, the identification process itself is best thought of a trajectory, one that shifts and changes over time and space as individuals interact with their environment (Hazari et al., 2020; Potvin & Hazari, 2013; Wenger, 1998). In investigating the development of students' disciplinary science identity, it is thus useful to examine both the micro-level, situated dynamics in which processes of identity recognition occur as well as macro-level reflexive narrations of identity negotiation (Hazari et al., 2020; Potvin & Hazari, 2013). The present study took the former approach.

Studying the narrated experiences of 15 postsecondary women of color who were majoring in scientific disciplines over a span of six years, Carlone and Johnson (2007) isolated three interacting dimensions that together promoted a strong science identity - competence, performance, and recognition. The women of color gained competence as they developed a solid foundation in scientific content knowledge through science experiences both in and out of the classroom. Performance allowed for demonstration of their competence at scientific events such as seminars and poster sessions. Recognition involved being explicitly and implicitly acknowledged by oneself and others in one's field as a "science person" (p. 1190). Conceptual frameworks specific to physics identity development draw from Carlone and Johnson's (2007) model to examine how secondary and postsecondary students come to see themselves as a "physics person," an "exemplary physics student," and a "physicist" (Hazari et al., 2010, p. 989; Hazari et al., 2020, p. 1593; Potvin & Hazari, 2013). Hazari et al. (2010) analyzed survey data

from over 3,000 college students majoring in a range of STEM and non-STEM disciplines to quantitatively isolate factors important for predicting undergraduates' identification with and intention to work in physics. In addition to Carlone and Johnson's (2007) three identity dimensions, the authors determined that an interest in physics was an important predictor of the college students' self-reported level identification as a physics person (Hazari. et al., 2010). Hazari et al. (2010) utilized their findings to develop a conceptual model of physics identity development. Their model collapses students' competence and performance in physics into a single factor (competence/performance) that represents one's perceptions of their knowledge and skills in physics relative to others. This competence/performance factor aligns more closely with the notion of academic self-concept, or perceptions of one's competence and potential in a subject, than a student's actual level of academic performance (Goetz et al., 2013; Sax, 1994; Sax et al., 2015). The present study used students' level of ability belonging, or self-reported intellectual competence and fit relative to their peers, to measure their perceived competence/performance in physics (Lewis & Hodges, 2015).

Hazari et al. (2010) determined that students' self-reported levels of physics interest, competence/performance, and perceived recognition together predicted to their identification as a physics person, which in turn strongly predicted their physics career intentions (Hazari et al., 2010). Subsequent empirical work has focused on further illuminating what meaningful student recognition from others entails in the classroom (Hazari & Cass, 2018; Wang & Hazari, 2018). Meaningful recognition from instructors can be explicit, such as highlighting students' successes, and implicit, such as assigning students with roles and responsibilities in class that convey confidence in their competence in the subject (Hazari et al., 2015; Wang & Hazari, 2018). Through a qualitative investigation of high school physics classes, Hazari & Cass (2018)

observed that effective teacher recognition entailed setting high yet obtainable expectations, devoting time and resources to foster student understanding, affirming students' capabilities, and utilizing interactive instructional approaches.

Hazari et al.'s (2010) conceptual model of physics identity development is rooted in the experiences and perceptions of college students with a diversity of social identities majoring in a wide range of disciplines. Several scholars have subsequently applied and revised this model to examine factors that influence the physics identity development of college students majoring in engineering, physics, and related STEM disciplines (Hazari et al., 2020; Kalender et al. 2019a, Kalender et al., 2019b). The following sections synthesize findings from these investigations with a focus on those that look specifically at the physics identity development of college students with gender, racial, and ethnic identities marginalized in postsecondary physics spaces.

Gender & Physics Identity

Given the documented role that a strong physics identity plays in promoting students' persistence in the discipline, multiple researchers have explored the dynamics through which women develop a physics identity in their educational environments (Avraamidou, 2022; Gonsalves et al., 2016; Gonsalves et al., 2020; Hazari & et al., 2017; Hazari et al., 2020; Kalender, 2019a; Kalender, 2019b). Surveying over 500 students in an introductory calculus-based physics course, Kalender et al. (2019a) determined that women self-reported significantly lower levels of physics interest, competence, and recognition from peers and instructors than men. Women's lack of recognition from others significantly in turn related to their lower levels of perceived competence, interest, and identity in physics, a finding that has been echoed by similar studies (Godwin et al., 2016; Kalender et al., 2019a; Lock et al., 2019).

In a survey study of the disciplinary identity development of introductory and advanced undergraduate women majoring in physics, Hazari et al. (2020) found that women physics majors' competence/performance covaried significantly with the extent to which they felt recognized both externally and internally as an "exemplary physics student" (p. 1593). Perceived competence/performance and recognition together influenced the women's self-perceptions as an exemplary physics student and as a physicist. In addition, a sense of social belonging in physics, or a subjective feeling of connection and legitimacy as a valued member of a physics community, covaried with the women's self-reported competence/performance and recognition (Hazari et al., 2020). For upper-level women undergraduates in the study, a sense of social belonging in physics also correlated with a strong physics identity (Baumeister & Leary, 1995; Hazari et al., 2020). Interest in physics was not a direct predictor of the women's physics identity, which the authors surmised stemmed from their sample consisting only of undergraduate physics majors who likely uniformly possessed strong interests in the field (Hazari et al., 2020). The variable nature of the components and dynamics of physics identity highlighted above emphasize the highly context-dependent nature of physics identity development (Hazari et al., 2020).

Perceived recognition from others as a legitimate physics person is important dimension of disciplinary identity development for students of all genders, though empirical work demonstrates that it has an outsized impact on the physics identity development of women throughout their educational journey (Hazari et al., 2017; Kalender et al., 2019b). As mentioned above, women in physics commonly report lower levels of positive recognition from others and are also less likely to recognize themselves as a physics person (Doucette & Singh, 2020; Kalender et al., 2019a; Li & Singh, 2021). This recurrent result reflects the reality that *who* can

achieve recognition in physics is constrained by the cultural, structural, and historical dynamics of the field (Avraamidou, 2022; Gonsalves & Danielsson, 2020). Though it is often framed as being gender neutral, physics as a discipline was constructed by and for white, cisgender men (Archer et al., 2020a; Traxler et al., 2016). Differential recognition of physics students by gender exists as a means to reproduce disciplinary norms that positions white masculinity as a standard for legitimate membership in a physics community (Avraamidou, 2022; Gonsalves et al., 2014). Proactively broadening who and what is worthy of recognition in physics is thus an essential component of supporting the disciplinary identity development and hence persistence of women in the field (Avraamidou, 2022; Gonsalves et al., 2014; Gonsalves et al., 2020).

In addition to receiving less recognition, women commonly experience lower social and ability belonging (or perceived competence relative to others) in their physics learning environments than men (Banchefsky et al., 2019; Lewis et al., 2016; Lewis et al., 2017; Rainey et al., 2018; Seyranian et al., 2018). Empirical work documents that women on average report a decrease in domain-specific social and ability belonging over the course of introductory college physics and calculus classes (Banchefsky et al., 2019; Seyranian et al., 2018). Masculine disciplinary stereotypes, emphasis on innate brilliance, entity belief environments, a lack of women role models and peers, and exclusionary environments all contribute to women's lower sense of belonging in physics spaces (Bjorkquist et al., 2019; Gonsalves et al., 2016; Lewis et al., 2016; Settles et al., 2006). A lower sense of social and ability belonging correlates with lower short- and long-term persistence for women in the discipline (Banchefsky et al., 2019; Perez-Felkner et al., 2017).

Race, Ethnicity, & Physics Identity

An extensive two-year mixed methods investigation into factors that support and inhibit the representation of Black students in physics and astronomy across multiple educational levels isolated physics identity and a sense of belonging as key components of persistence (AIP, 2020). Compared to gender, less research has examined the dynamics through which physics students with marginalized racial and ethnic identities develop and navigate their disciplinary identities. Discussions of increasing the representation of Black, Latine, and Indigenous individuals in STEM fields such as physics historically assumed a deficit perspective and focused on how marginalized students could assimilate into disciplinary settings rather than how such settings could change to be more inclusive and equitable (Carter et al., 2019; McGee, 2020). Recent scholarship challenges this deficit perspective by highlighting the ways in which various aspects of physics disciplinary settings perpetually marginalize Black, Latine, and Indigenous individuals (AIP, 2020; Aikenhead & Ogawa, 2007; Carter et al., 2019; Hyater-Adams et al., 2018; Traxler et al., 2016). Conceptualization of who can identify as a physics person remains highly influenced by physics' roots of "white empiricism" which elevates white people as the only group capable of true scientific objectivity (Prescod-Weinstein, 2020, p. 421). In a narrative inquiry of the disciplinary identity development of Black physics undergraduates, graduate students, and professionals, Hyater-Adams et al. (2019) discovered that participants often felt conflicted about seeing themselves as physicists, as the discipline's prototypical norms and values did not entirely align with their own professional interests and goals. In addition, stereotypical associations closely tie notions of a physics person with high levels of innate intelligence, which promotes the exclusion of groups unjustly subjected to negative intelligence stereotypes (Leslie et al., 2015). At the same time, physics' cultural veil of objectivity and

neutrality makes it more difficult for current and aspiring physicists to acknowledge and address the ways in which individual and institutional racism limits who can gain recognition (both external and internal) as a physics person (AIP, 2020; Avraamidou, 2022).

As it does for women in physics, positive recognition from the self and others as a physics person repeatedly stands out as a key component of physics identity development for Black, Latine, and Indigenous individuals (AIP, 2020; Carter et al., 2019; Fries-Britt, Younger, & Hall, 2010; Hyater-Adams et al., 2019; Rodriguez et al. 2019). At the same time, negative faculty and peer interactions are exceedingly common for racially and ethnically marginalized students in postsecondary physics spaces, particularly those at predominantly white institutions (PWIs) (AIP, 2020; Fries-Britts et al., 2010; Fries-Britt, Johnson, & Burt, 2013; McGee, 2016). Negative interactions create hostile, isolating learning environments that deter minoritized students from seeing themselves as physicist and persisting in the field over time (AIP, 2020; Castellanos, 2018). Studies exploring the experiences of Black and Latine physics undergraduates reveal that such students commonly face microaggressions (brief and/or subtle derogatory messages), negative intelligence stereotypes, a lack of recognition for their work, and other forms of racial and ethnic hostility and discrimination from their instructors, mentors, and peers (AIP, 2020; Fries-Britt & Holmes, 2012; Hyater-Adams et al., 2018; McGee, 2016). Importantly, while negative faculty and peer interactions are more prevalent at PWIs, physics departments at minority-serving institutions can and do transmit exclusionary messages as well, particularly as plenty of faculty members at these institutions are not themselves members of underrepresented racial and ethnic groups (McGee, 2016).

In addition, Black, Latine, and Indigenous students also often possess a lower sense of social and ability belonging in physics learning environments than their non-minoritized peers

(Fries-Britts et al., 2010; McGee, 2016). As a result of white empiricism and negative intelligence stereotypes, as well as other racial biases and structures, Black, Latine, and Indigenous students are forced to regularly justify their intellectual ability and right to exist in physics and other STEM disciplines (Fries-Britt & Holmes, 2012; MeGee, 2016). In physics departments at predominantly white institutions, underrepresented students of color face marginalization and exclusion by their college or university as a whole (Walton & Cohen, 2007).

Black, Latine, and Indigenous women in physics are forced to contend with marginalization based on both their gender and their race and/or ethnicity. Minoritized women commonly document heightened biases and negative intelligence stereotypes (Fries-Britt & Holmes, 2012; Johnson et al., 2017). Given their small numbers in many STEM programs, underrepresented women of color also frequently describe intense isolation that comes from feeling both ignored and hyper-visible (Johnson et al., 2017). In an ethnographic study that followed 10 Black, Latine, and Indigenous women majoring in physics during and after their college experience, Ong (2005) observed that, regardless of their level of academic success, the women physicists of color remained perennially aware of how others in their physics community perceived them. Throughout their experience in college and beyond, the women or color were hyperalert to cues that threatened their perceived competence and legitimacy as a physicist. To manage conflicts between their gender, racial, ethnic, and physicist identities, some women of color in Ong's study attempted to "separate their gendered and racial selves from their scientist selves" to conform as much as possible to the "ordinary" physicist (p. 600). Other women of color intentionally displayed gender, racial, and ethnic identities and doing so "rejected the ordinary scientist image in favor of a new ideal that consolidates seemingly conflicting gender, racial/ethnic, and scientist identities" (p. 600). This later tactic was not always well-received by

established members of the physics community and sometimes led to further exclusion and negative recognition (Ong, 2005).

Avraamidou (2022) points out that studies of physics identity development often fail to acknowledge the ways in which internal and external processes of recognition as a physics person, an exemplary physics student, and a physicist are inherently tied to issues of racism and sexism in physics itself. Research documents that Black, Latine, and Indigenous women in physics commonly experience high amounts of racism and sexism in the form of microaggressions and exclusion from their peers, instructors, and colleagues (Avraamidou, 2022; Fries-Britt & Holmes, 2012; Ko & Kachchaf, 2014; Rosa & Mensah, 2016). For many women of color, acknowledgement from family and community as a competent physicist offers a positive source of recognition and identity development (Avraamidou, 2022; Fries-Britt & Holmes, 2012). At the same time, explicit and implicit recognition from established members of the physics community remains key for both disciplinary identity development and persistence (Avraamidou, 2022). In a qualitative, longitudinal analysis exploring the "politics of recognition" in physics settings, Avraamidou (2022) determined that, particularly for women of color, recognition as a physics person is far more dynamic and variable than it is often represented in the literature (p. 58). Perceived external and internal recognition as a physics person can vary considerably over time as individuals interact with others in and outside of their physics learning spaces (Avraamidou, 2022). When examining students' physics identity development, it is thus important to examine the contextual, micro-level dynamics in which their perceived recognition as a physics person, an exemplary physicist student, and a physicist varies and changes over time, though such insight is largely lacking from quantitative studies (Avraamidou, 2022). The present study addressed this gap in the literature by capturing college physics students' perceived

recognition along with contextual information about their classroom experiences on a weekly basis throughout a semester.

Domain-Specific STEM Ability Beliefs, Identity, & Persistence

Although domain-specific implicit ability beliefs and disciplinary identity both impact undergraduates' STEM persistence, to the best of my knowledge only one study has explicitly examined the relationship between these variables (Cook et al., 2017; Good et al., 2012; Goyer et al., 2021; Hazari et al., 2020; Kalender et al., 2019b; Kricorian et al., 2020; Li & Singh, 2021; Seyranian et al., 2018; Smith et al., 2013). Cribbs et al. (2021) surveyed first-year undergraduates about their anxiety, ability beliefs, self-efficacy, and disciplinary identification in mathematics. College students who expressed malleable beliefs about their math ability reported a significantly stronger math identity than those who expressed fixed math ability beliefs (Cribbs et al., 2021). Established relationships also exist between intellectual ability beliefs and two factors known to directly influence disciplinary identity development, specifically competence and sense of belonging. Scholars have documented a significant positive relationship between incremental ability beliefs and women's perceived competence in math (Degol et al., 2018; Heyder et al., 2021; Hill et al., 2017). In a longitudinal study of a college calculus course, Good et al. (2012) found women who perceived their classroom environment as promoting an entity view of math ability experienced a marked decline in math social belonging and intended persistence over time, particularly in the presence of negative stereotypes about women's math ability. Women who perceived their classroom as promoting an incremental view of math ability maintained a greater level of math belonging and intended persistence, despite negative gender stereotypes (Good et al., 2012). A few other studies have asked women and/or Black students about their anticipated sense of social belonging in fields and programs that emphasize varying

notions of intelligence. On average, women and Black students anticipate less belonging in academic settings that promote innate brilliance and/or entity ability beliefs (Bian et al., 2018; Deiglmayr et al., 2019; Rattan et al., 2018; Smith et al., 2013).

The studies outlined above provide valuable insights, though most fail to include students' racial and ethnic identities as a variable. In addition, Cribbs et al.'s (2021) study did not break down results by students' gender. A need exists for empirical work that investigates how students' competence, recognition, belonging, and identity are shaped by their individual and classroom-level domain-specific ability beliefs. It is possible that a student's incremental ability beliefs could help to promote a sense of social and intellectual fit, particularly in a classroom environment that also emphasizes malleable notions of intelligence. In addition, a student's beliefs about their physics abilities might relate to the extent that they see themselves as a physicist, while a classroom environment that promotes malleable notions of intelligence might also foster greater recognition of students, particularly those with traditionally marginalized social identities. The present study contributes empirical understanding into the dynamics of college students' individual and classroom-level ability beliefs and disciplinary identity development over time.

Conceptual Framework

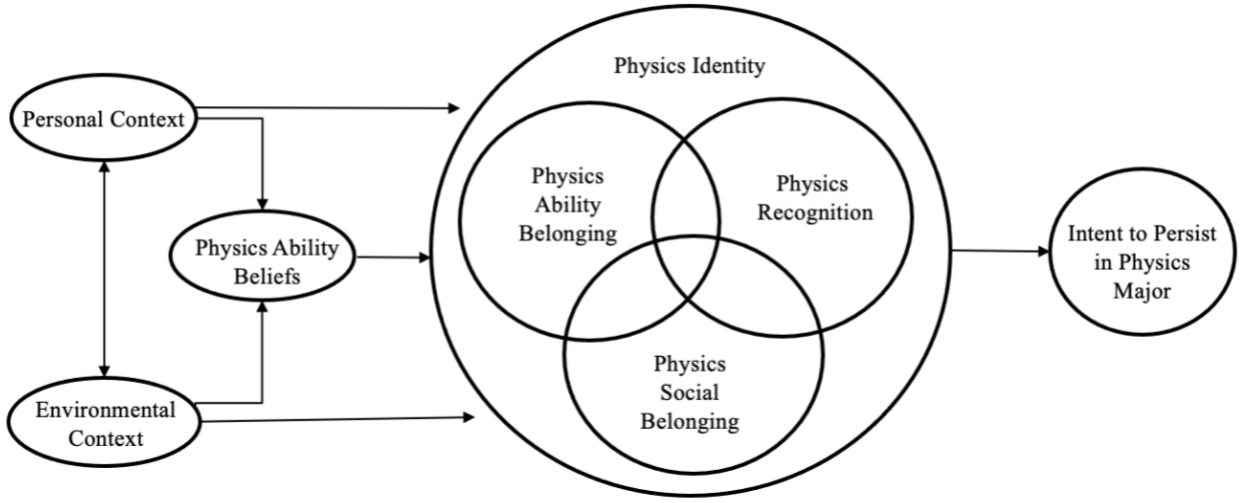
This study relied on a framework that combines concepts from three theoretical perspectives detailed in the literature review above: implicit theories of intelligence (Dweck & Leggett, 1988; Dweck & Yeager, 2019; Murphy & Dweck, 2010), Lewis & Hodges' (2015) model of academic belonging, and Hazari et al.'s (2020) model of physics identity development (see visual in Figure 3.1). This framework depicts the hypothesized relationship between a college student's personal and environmental contexts, their physics-specific implicit ability

beliefs, their perceived recognition from instructors and peers as an exemplary physics student, their sense of academic belonging in physics, their physics identity, and their intent to persist in a physics major. In the present study, *personal context* includes a student's gender, race, ethnicity, course level, and perceptions of academic struggle in a course. *Environmental context* includes a student's perception of their instructor's implicit beliefs about the malleability of students' physics abilities as well as other aspects of their physics course, such as the type of academic tasks encountered and the degree of interactive engagement. While not explicitly measured in this study, environmental context also includes the extent to which instructors and peers foster an inclusive learning environment for students with marginalized identities by discouraging bias, discrimination, microaggressions, and the endorsement of oppressive stereotypes about who can succeed, belong, and identify with physics. Contextual features of a postsecondary physics environment interact with a student's personal context through their impacts on the student's self-perceptions and field-specific ability beliefs. As participants in their classroom and disciplinary settings, students also potentially influence their environmental context. In my framework, personal and environmental factors shape a student's physics ability beliefs, perceived recognition, and social/ability belonging over the course of a semester (Limeri et al., 2020a; Little et al., 2019). Perceived recognition and social/ability belonging in turn shape a student's physics identity and intent to persist in their physics major over time (Bian et al., 2018; Good et al., 2012; Lewis et al., 2017; Lewis & Hodges, 2015; Walton & Cohen, 2007). As elaborated in my literature review, a student's level of ability belonging (a component of Lewis and Hodges' (2015) model of academic belonging) overlaps considerably with the conceptualization of perceived physics competence that appears in models of physics identity

and as such is used as a proxy for this dimension of physics identity in my study (Hazari et al., 2020).

Figure 3.1

Conceptual Framework for Relationships Between a Student's Personal and Environmental Contexts, Physics Ability Beliefs, Physics Ability and Social Belonging, Physics Recognition, Physics Identity, and Intent to Persist in a Physics Major



Methods

A quantitative approach was utilized for this study. Quantitative research is ideal for characterizing the relationships between variables of interest (Creswell & Creswell, 2018). This methods section begins by outlining the specific quantitative research design, setting, participants, instruments, and variables. It then details data analysis procedures and discusses ethical considerations.

Research Design

This quantitative study utilized a correlational, time-series survey design to examine changes in undergraduate physics major's physics ability beliefs, perceived recognition, academic belonging, physics identity, and short-term persistence intentions over the course of a

semester. Participants included physics majors enrolled in introductory or advanced major-specific college physics courses at a large, public, research-intensive, predominantly White university in the Southeastern United States that incorporated an interactive instructional approach (Creswell & Creswell, 2018). Collecting self-reported data electronically using established, validated survey scales allowed me to gather valuable information on the beliefs and perceptions of students and instructors in an efficient, cost-effective manner. While the non-experimental nature of this study prevented causal conclusions, an experimental design was not feasible due to logistical constraints. The relatively small number of undergraduate physics majors and the widespread implementation of the interactive instructional approach in major-specific physics courses precluded the establishment of a "control" group.

This study took a critical approach to quantitative inquiry (Gillborn, Warmington, & Demac, 2018). This approach challenges the notion that quantitative analyses reveal an objective, neutral, and value-free reality and employs such analyses to expose and address inequities perpetuated by oppressive societal forces (Gillborn et al., 2018). When designing and implementing the study, I followed Castillo and Gillborn's (2022) recommendations for researchers seeking to apply a critical quantitative approach. First, I rejected the deficit-based lens common in physics education research and instead examined how students' perceptions of their disciplinary environments related to their beliefs, self-perceptions, and intentions (Traxler et al., 2016). Second, I drew upon literature centered on the experiences of students with traditionally marginalized social identities in physics spaces to both frame the study and to compile survey items (Castillo & Gillborn, 2022).

Third, I carefully reflected on the strengths and limitations of the social identity categories included in my study and recognized that such categories describe social constructions

rather than natural groupings (Castillo & Gillborn, 2022). Quantitative studies of undergraduate physics programs often refrain from including students' race and ethnicity due to the low number of Black, Latine, and Indigenous students in such programs (Traxler et al., 2016). By leaving out race and ethnicity, researchers fail to examine the ways in which racism present in physics learning environments shapes the well-being, beliefs, perceptions, and academic and professional trajectories of physics students of color (Castillo & Gillborn, 2022). Adopting a time-series study design supported a better understanding of the beliefs, perceptions, and experiences of students with marginalized racial and ethnic identities, as participants completed a survey at multiple time points, which promoted a level of contextual insight not possible through cross-sectional data collection. The low number of Black, Latine, and Indigenous physics students at Southeastern University limited my capacity to quantitatively examine the beliefs and perceptions of students with specific marginalized racial and ethnic identities (or students with intersecting marginalized identities). I included a covariate in my models that combined white and Asian students into one group and Black and Latine students into another group. I recognize the limitations that this grouping method provides, as white, Asian, Black, and Latine students have both unique and heterogenous experiences. By adopting this grouping system, I do not mean to imply that the experiences of students with specific racial and ethnic identities are not important, nor that white and Asian students in physics act as a normative default. Instead, I employed this grouping system to examine how the beliefs, perceptions, and experiences of physics students with traditionally marginalized racial and ethnic identities potentially differ from their non-marginalized peers due to the oppressive dynamics in physics learning environments.

Lastly, I included a positionality statement, provided context for my study, and transparently discussed the limitations of results. In doing so, I addressed the critical quantitative

principle that “data cannot speak for itself” (Castillo & Gillborn, 2022, p. 1). By explicitly situating my methods and findings, I recognized the subjectivity inherent to quantitative research and allowed the reader to make informed interpretations and decisions from my conclusions (Castillo & Gillborn, 2022).

Research Site

This study took place at a large, predominantly white, public land-grant institution in the southeast (referred to in the study as Southeastern University). The academic institution has many STEM degree programs, with 61% of the undergraduate student population enrolled in a STEM major. The Department of Physics at Southeastern University contains 59 faculty, 130 graduate students, and 137 undergraduate students. Approximately 20% of physics undergraduates identify as women. Of those women, 74% are white, 11% are Asian, 11% are Latine, and 4% are Black. Men make up 80% of undergraduates in the major. Seventy-seven percent of these men are white, 13% are Asian, 5% are Latine, 3% are Black, and less than 1% are Indigenous. Faculty in the Department of Physics at Southeastern University engage in research in numerous subfields, including astrophysics, nuclear physics, biophysics, condensed matter physics, optical physics, and physics education research.

Interactive Instructional Approach: Experimental Lab Activity Program

In 2013, a faculty member in the Department of Physics developed a collection of experimental lab activities to provide undergraduate physics majors and minors with the opportunity to conduct short, inquiry-based experiments in the department’s shared research facility as part of their physics courses. Each fall and spring semester since its inception, 3-5 physics courses have incorporated an experimental lab activity as an official course component. Specific experiments are designed and modified each term by course instructors in collaboration

with the lab activity director and a graduate teaching assistant. Examples of existing experimental lab activities include carbon dating of Brazil nuts, observation of chaotic motion, and measuring the absorption spectrum of molecules of different sizes and modeling this behavior as a quantum-mechanical particle in a box. The activities are meant to authentically expose undergraduates to the process of experimental physics and the trial-and-error nature of science. Undergraduates work in small groups of 2-4 to develop hypotheses and collect and analyze data, though they each write up and submit their findings independently. Instructors and TAs grade student write-ups using intentional growth and process-oriented feedback. Prior to the development of the experimental lab activities, the undergraduate physics curriculum at Southeastern University offered traditional cookie-cutter labs for students during their first three semesters of college, and no inquiry-based course or lab work until their senior year capstone course. Based on internal program evaluations, the activities appear to support undergraduate physics students in their self-reported confidence and understanding in experimental physics.

While experimental lab activities were initially restricted to advanced physics courses at Southeastern University, in Fall 2021, the program was expanded to also include introductory major-specific physics courses. As such, most undergraduates majoring or minoring in physics at this institution are enrolled in a physics course each semester that incorporates such an activity.

Participants

Participants in this study included undergraduate physics majors at Southeastern University who enrolled in an introductory or advanced major-specific course that incorporated an experimental lab activity during the Fall 2022 semester (59 students in total). Of those invited to participate, 54 (93%) completed at least one survey over the course of the semester. Twenty-

eight participants completed at least 10 surveys and 46 completed at least 3, resulting in 466 total survey responses.

Table 3.1 illustrates the gender, race, ethnicity, academic level, and undergraduate major of participants in the introductory and advanced physics course. In total, 30% of participants were women, 2% were Black, 15% were Latine, 11% were Asian, and 72% were white. Forty-eight percent of participants were underclassmen and 52% upperclassmen. All but one participant was a physics major (this one participant was majoring in another STEM discipline).

Table 3.1

Demographic and Academic Breakdown of Respondents

Variable	Coding & Frequency	
	Introductory course (1)	Advanced Course (0)
Gender	Women (0): 9 Men (1): 21	Women (0): 7 Men (1): 16
Race/ethnicity	Black (1): 0 Latine (1): 4 Indigenous (1): 0 Asian (0): 3 White (0): 23	Black (1): 1 Latine (1): 4 Indigenous (1): 0 Asian (0): 3 White (0): 16
Academic level	Freshman: 17 Sophomore: 9 Junior: 4	Junior: 7 Senior: 17
Major	Physics: 29 Other STEM: 1	Physics: 24 Other STEM: 0

Instruments & Variables

My study incorporated multiple established instruments, some slightly modified to account for my domain-specific, time-series focus. I obtained participant demographic and

academic background variables (gender, race, ethnicity, academic level, and major) from the university's office of registration and records using participants' student identification number. Students provide their gender, race, and ethnicity when they apply to the university. Several years ago, the registration and records office added a way for students to easily update their gender pronouns in the course management system and provided a non-binary option. No participants in the present study identified as non-binary in the official university system. None-the-less, there is still the possibility that my manner of obtaining students' demographic information missed those who did not update their gender identity in the official university system. For all analyses, gender was coded as an indicator variable (women = 0, men = 1). Due to the low number of participants with non-white racial and ethnic identities, race and ethnicity was coded as an indicator variable with white and Asian students as 0 and Black and Latine students as 1. I recognize the limitations that this coding method provides, as both white, Asian, Black, and Latine students each have unique and heterogenous experiences. By adopting this coding system, I do not mean to imply that the experiences of students with specific racial and ethnic identities are not important, nor that white and Asian students in physics act as a normative default. Instead, I employed this coding system to examine how the beliefs, perceptions, and experiences of physics students with traditionally marginalized racial and ethnic identities potentially differ from their non-marginalized peers due to the oppressive dynamics in physics learning environments. The following subsections describe each survey instrument and the corresponding variable measured. Table 3.2 provides a summary of all instruments and variables included in the study. Complete survey scales appear in Appendix C.

Table 3.2

Variables and Their Corresponding Instruments

Variable	Variable Type	Instrument
Physics Ability Beliefs (Student)	[a]*Con:* 6-point Likert-type scale	Physics Ability Beliefs Scale (van Aalderen-Smeets et al., 2019)
Physics Ability Beliefs (Instructor Perception)	*Con:* 6-point Likert-type scale	Physics Ability Beliefs Scale (van Aalderen-Smeets et al., 2019)
Physics Ability Belonging	*Con:* 6-point Likert-type scale	Ability Uncertainty Scale (Lewis & Hodges, 2015)
Physics Social Belonging	*Con:* 6-point Likert-type scale	Physics Sense of Belonging Scale (Good et al., 2012)
Intent to Persist in Physics Major	*Con:* 6-point Likert-type scale	Intent to Persist Scale (Lewis & Hodges, 2015)
Perceived Academic Struggle	*Cat:* Dummy-coded (0 = "did not struggle"; 1 = "overcame struggle"; 2 = "continued struggle")	Academic Struggle Items (Limeri et al., 2020a)
Physics Recognition	*Con:* 5-point Likert-type scale	Physics Recognition Scale (Hazari et al., 2020)
Physics Identity	*Con:* 5-point Likert-type scale	Physics Identity Scale (Hazari et al., 2020)
Type of Academic Task	*Cat:* Dummy-coded (exam = 0/1; activity = 0/1, etc.)	Categories determined in collaboration with physics course instructors
Academic Level	*Cat:* Dummy-coded (0 = freshmen; 1 = upper-level)	Obtained from institutional research offices
Cumulative GPA	*Con:* 0 – 4.0	Obtained from institutional research offices

[a]Con = Continuous; Cat = Categorical

Physics Ability Beliefs Scale

The Physics Ability Beliefs Scale uses a 6-point Likert-type scale (1 = *strongly agree* to 6 = *strongly disagree*) to measure one's belief in their capacity to change their ability and aptitude in physics with time and effort. This scale diverges from Dweck's (2000) widely used Implicit Theories of Intelligence Scale not only in its domain specificity (Dweck's scale measures students' general intelligence beliefs), but in its use of the term "ability" rather than "intelligence". A recent study of undergraduate STEM students determined that students define "intelligence" in different ways, a finding that reduces the validity of studies that rely on Dweck's scale to study mindset in this population (Limeri et al., 2020b). Some students see "intelligence" as "knowledge", whereas others view it as "ability" (Limeri et al., 2020b). Replacing "intelligence" with "ability" promotes lower measurement error and greater construct validity without sacrificing content validity, as Dweck's conception of intelligence aligns closer to the "ability" definition (Dweck, 2000). I modified this 7-item scale from the previously validated Implicit STEM Ability Beliefs Scale (van Aalderen-Smeets et al., 2019). van Aalderen-Smeets et al. (2019) established the construct validity and dimensionality of the Implicit STEM Ability Beliefs Scale and determined that all 7 items load strongly onto a single factor (implicit STEM ability beliefs). The scale also shows good reliability ($\alpha > 0.84$). My modification of the scale adds even greater domain specificity by replacing the term "STEM" with "physics" in each item, creating questions such as, "To be honest, I don't think I can really change my physics aptitude." Prior research suggests that undergraduate STEM students possess different implicit ability beliefs within specific STEM fields, so such greater specificity is necessary (Limeri et al., 2020b). I also created a version that measures students' perceptions of their instructor's beliefs about their physics ability. I changed the wording in each of the 7 items from the first person to

the third person, creating questions such as, “To be honest, I don’t think students can really change their physics aptitude.”

Ability Uncertainty Scale

The Ability Uncertainty Scale uses a 6-point Likert-type scale (1 = *strongly agree* to 6 = *strongly disagree*) to measure the degree to which college students worry that they do not possess the aptitude, ability, or competence needed to belong and succeed in their undergraduate major (Lewis & Hodges, 2015). The 12-item scale includes items such as, “I’m not certain I “fit in” intellectually in my major.” Lewis and Hodges (2015) established the construct validity of the Ability Uncertainty Scale and determined that all items load strongly onto a single factor (ability uncertainty, which reverse-coded equates to a student’s level of ability belonging). The scale also demonstrates good reliability (α = 0.90).

Physics Sense of Belonging Scale

The Physics Sense of Belonging Scale was modified from Good et al.’s (2012) Math Sense of Belonging Scale. Whereas the Ability Uncertainty Scale measures a student’s perceived level of ability belonging, this scale measures a student’s social belonging in their academic spaces. This 30-item validated scale is divided into five subscales to assess the extent to which students feel like accepted members of their math community. My study utilizes the Membership (α = 0.91) subscale, which makes up 4 items measured using a 6-point Likert-type scale (1 = *strongly agree* to 6 = *strongly disagree*). I modified Good et al.’s (2012) scale by replacing “math” with “physics” in each item, creating questions such as, “I feel that I belong to the physics community.”

Physics Recognition Scale

The Physics Recognition Scale is a 2-item 5-point Likert-type (1 = *not at all* to 5 = *very much so*) scale to capture the degree to which undergraduate physics majors believe that their instructors and peers see them as an exemplary physics student (Hazari et al., 2020). In developing the scale, Hazari et al. (2020) established content validity by administering a pilot iteration with college students and presenting the items to both science education researchers and physicists associated with the Conferences for Undergraduate Women in Physics (CUWiP). The items demonstrate strong construct validity and reliability (α = 0.85).

Physics Identity Scale

The Physics Identity Scale is a 2-item 5-point Likert-type (1 = *not at all* to 5 = *very much so*) scale to measure undergraduate physics majors' self-perceptions as an exemplary physics student and a physicist (Hazari et al., 2020). In developing the scale, Hazari et al. (2020) established content validity by administering a pilot iteration with college students and presenting the items to both science education researchers and physicists associated with the Conferences for Undergraduate Women in Physics (CUWiP). The items demonstrate strong construct validity and reliability (α = 0.80).

Intent to Persist Scale

The Intent to Persist Scale is a 4-item 6-point Likert-type (1 = *strongly agree* to 6 = *strongly disagree*) scale to measure college students' intentions to remain in their current academic major during their undergraduate studies (Lewis & Hodges, 2015). The scale includes questions such as, "It is likely that I will remain in my major next academic year." The Intent to Persist Scale only examines persistence in the short term and does not ask students about their post-college intentions. The scale demonstrates good reliability (α = 0.84).

Academic Struggle Items

Limeri et al. (2020a) created two items to measure students' perceived academic struggle. Both items use a *yes/no* response format. The first asks students, "Did you encounter struggle in [course name] this semester?" Participants who respond "yes" are then asked, "Were you able to overcome the struggle that you encountered?" The authors evaluated the content validity of these two items by having an initial group of participants qualitatively elaborate on the accuracy of their conclusions. Academic struggle items are dummy coded into a variable with "did not struggle" as the reference group. While Limeri et al. (2020a) only asked this question at the end of the semester, I modified the first item so that it could be asked on a weekly basis. Asking students to identify their perceived performance throughout the semester provided insight into their lived academic experiences within a particular course.

Data Collection Procedures

Prior to the start of the semester, I communicated with course instructors and the experimental lab activity director and teaching assistant to share links to the electronic surveys and consent forms and coordinate survey distribution throughout the term. With permission of the university's internal review board, instructors incorporated the surveys as a homework grade, though students voluntarily consented for me to then use their survey data in the study. In the first week of the semester, I visited each physics course in-person to introduce the study and answer questions from students. Instructors then provided students with survey links and instructions via their course management system. In the second week of the semester, students completed an initial survey. This survey consisted of 31 items containing the following scales described in the previous section: The Physics Ability Beliefs Scale (student version version), the Ability Uncertainty Scale, the Physics Recognition Scale, the Physics Identity Scale, the Physics

Sense of Belonging Scale, and the Intent to Persist Scale. At the start of the initial survey, students were asked to enter their student identification number and physics course section, which was used to obtain demographic and academic information from the universities' offices of registration and records and to connect subsequent survey iterations to specific individuals and course sections. On Friday of 12 subsequent weeks during the semester, participants were prompted to complete a shorter 12-item Qualtrics survey that contained the following scales: the Physics Ability Beliefs Scale (student version), the Physics Recognition Scale, and the Academic Struggle Items. One survey item also asked students to identify the type(s) of academic tasks that they encountered in their physics course during the week. At the midpoint and end of the semester, students once again took a longer survey that included scales asked in the initial survey as well as the perceived instructor version of the Physics Ability Belief Scale, the Academic Struggle items, and the Academic Task Type items.

Data Analysis Procedures

I used SAS Version 9.4 M7 and STATA/IC 16.1 to complete all data analyses. After merging participants' survey responses and academic information into a single dataset, I carefully examined all data to identify errors and inconsistencies and to locate and remove any partially completed surveys from my dataset (Groves et al., 2009). Next, I evaluated unit and item non-response in the dataset. I calculated survey response rates, which included the proportions of students in my sample who completed all or some of my survey iterations as well as the proportion of such students in each class section. My analysis technique (multilevel modeling) allows for unbalanced outcome data, so including participants who did not complete all survey iterations was acceptable (Raudenbush & Bryk, 2002).

Instrument Validity & Reliability

I performed confirmatory factor analysis (CFA) to assess the construct validity of each scale (Kline, 2016). Prior to running a CFA for each scale, I averaged each participant's responses to each item across all time points. To evaluate global model fit, I examined chi-square goodness of fit, root mean square error of approximation, comparative fit index, and squared root mean square residual. To evaluate local model fit, I ensured that all standardized parameter loadings were above 0.4 and examined residual correlations between individual items. To assess the reliability of my instruments, I calculated within-person and between-person reliability estimates (Cranford et al., 2006; Scott et al., 2020). These estimates reflect an instrument's reliability to detect within-person fluctuations and between-person differences (Scott et al., 2020).

Multilevel Modeling

To analyze the dynamics of students' physics ability beliefs, perceived recognition, academic belonging, physics identity, and persistence intentions over the course of the semester, I used multilevel modeling. Multilevel modeling was an ideal analysis tool, as it accounted for the time-series, hierarchical structure of my dataset. In the current study, student change/variability is depicted using a 2-level hierarchical model (Raudenbush & Bryk, 2002). At Level 1, each student's variability (change in physics ability beliefs over time, for example) is represented by an intercept and slope that become outcome variables in a Level 2 model. These Level 2 outcomes can depend on student-level characteristics (such as gender and race/ethnicity). Multilevel modeling permitted an examination of variance in a dependent variable at each level, and allowed for an analysis of how temporal-, and student-level factors contribute to interindividual differences in intraindividual change. In addition, multilevel modeling generated

a separate regression line for each student, taking into account the extent to which individuals started out and changed differently over time (Raudenbush & Bryk, 2002).

As multilevel models possess assumptions of linearity, normality, and homoscedasticity, I began by evaluating these assumptions using my dataset. I also ran a post-hoc power analysis, to look for potential multicollinearity in my independent variables, and complete basic descriptive analyses (means, standard errors, and frequencies) on all variables. Prior to running my models with predictors, I first tested an unconditional model for each of my outcome variables to establish that there was sufficient variability at each level for continued analysis. As students' perceptions of their instructor's physics ability beliefs were only measured at several time points, each participant's average value was included as a Level 2 predictor in multilevel models. The following subsections summarize the multilevel model that corresponds to each part of my research questions (see Appendix D for a visual and description of each equation).

Research Question 1a. *On average, is there significant linear change in a student's physics ability beliefs? Does this change depend on a student's gender, race, ethnicity, course level, perceived academic struggle, type of academic task encountered during the week, and perceived instructor ability beliefs?*

Equation (D2) represents the hypothesized dynamics by which a student's incremental physics ability beliefs vary and change over the course of a semester. I focused on γ_{10} (the average within-student relationship between time and physics ability beliefs), γ_{20} (the average within-student relationship between academic struggle and physics ability beliefs), γ_{30} (the average within-student relationship between time, academic struggle, and physics ability beliefs), and γ_{40} through γ_{60} (the average within-student relationships between exams, in-class activities, experimental lab activities, and physics ability beliefs). I also examined the average effects of

students' gender, race/ethnicity, course level, and average perceived instructor physics ability beliefs on the above-mentioned relationships. Students' average perceived instructor physics ability beliefs were grand mean centered to make their interpretations more meaningful. In each circumstance, I tested if the coefficient was significantly different from zero. I also examined whether there was significant within-student and between-student variation in incremental physics ability beliefs after accounting for my included predictors.

Research Question 1b. *On average, is there significant linear change in a student's perceived recognition? Does this change depend on a student's gender, race, ethnicity, course level, physics ability beliefs, perceived academic struggle, type of academic task encountered during the week, and perceived instructor ability beliefs?*

Equation (D4) represents the hypothesized dynamics by which a student's perceived physics recognition varies over the course of a semester. I focused on γ_{10} (the average within-student relationship between time and recognition), γ_{20} (the average within-student relationship physics ability beliefs and perceived recognition), γ_{30} (the average within-student relationship between perceived academic struggle and perceived recognition), γ_{40} (the average within-student relationship between time, physics ability beliefs, and perceived recognition), γ_{50} (the average within-student relationship between time, perceived academic struggle, and perceived recognition), γ_{60} (the average within-student relationship between perceived academic struggle, physics ability beliefs, and perceived recognition), and γ_{70} through γ_{90} (the average within-student relationships between exams, in-class activities, experimental lab activities, and perceived recognition). I also examined the average effects of students' gender, race/ethnicity, course level, and averaged perceived instructor physics ability beliefs on the above-mentioned relationships. Several independent variables were group mean centered (physics ability beliefs) or grand mean

centered (average perceived instructor ability beliefs) to exam context effects and make their interpretations more meaningful. In each circumstance, I tested if the coefficient was significantly different from zero. I also examined whether there was significant within-student and between-student variation in physics recognition after accounting for my included predictors.

Research Question 2a. *On average, are there significant linear relationships between a student's physics ability beliefs, perceived recognition, and physics belonging (ability and social) over time? Do these relationships depend on a student's gender, race, ethnicity, course level, and perceived instructor ability beliefs?*

Equation (D6) represents the hypothesized dynamics by which a student's ability and social belonging varies over the course of a semester. I focused on γ_{10} (the average within-student relationship between time and belonging), γ_{20} (the average within-student relationship between perceived recognition and belonging), γ_{30} (the average within-student relationship between physics ability beliefs and belonging), and γ_{40} (the average within-student relationship between physics ability beliefs, perceived recognition, and belonging). I also examined the average effects of students' gender, race/ethnicity, course level, and averaged perceived instructor physics ability beliefs on the above-mentioned relationships. Several independent variables were grand mean centered (physics ability beliefs, perceived recognition, and average perceived instructor ability beliefs) to make their interpretations more meaningful. In each circumstance, I tested if the coefficient was significantly different from zero. I also examined whether there was significant within-student and between-student variation in ability and social belonging after accounting for my included predictors.

Research Question 2b. *On average, are there significant linear relationships between a student's physics belonging (ability and social), perceived recognition, and physics identity over*

time? Do these relationships depend on a student's gender, race, ethnicity, course level, physics ability beliefs and perceived instructor ability beliefs?

In equation (D8), a student's self-reported physics identity acts as an outcome variable, with physics ability beliefs, ability belonging, social belonging, and perceived recognition serving as predictors. In this analysis, I focused primarily on γ_{20} (the average within-student relationship between recognition and identity), γ_{30} (the average within-student relationship between belonging and identity), and γ_{40} (the average within-student relationship between physics ability beliefs and identity. I also examine the average effects of students' gender, race/ethnicity, course level, and perceived instructor ability beliefs on the above-mentioned relationships. Several independent variables were grand mean centered (physics ability beliefs, perceived recognition, ability belonging, social belonging, and average perceived instructor ability beliefs) to make their interpretations more meaningful. In each circumstance, I tested if the coefficient was significantly different from zero. I also examined whether there were significant within-student and between-student variations in physics identity after accounting for my included predictors.

Research Question 2c. *On average, are there significant linear relationships between a student's physics belonging (ability and social), perceived recognition, physics identity, and intent to persist in the physics major? Do these relationships depend on a student's gender, race, ethnicity, course level, physics ability beliefs and perceived instructor ability beliefs?*

In equation (D10), a student's intended persistence in their physics major acts as an outcome variable, with physics ability belonging, social belonging, identity, perceived recognition, and physics ability beliefs serving as predictors. I focused on γ_{10} (the average within-student relationship between physics identity and intended persistence), γ_{20} (the average

within-student relationship between physics belonging and intended persistence), γ_{30} (the average within-student relationship between perceived recognition and intended persistence), and γ_{40} (the average within-student relationship between physics ability beliefs and intended persistence). I also examined the average effects of students' gender, race/ethnicity, course level, and perceived instructor ability beliefs on the above-mentioned relationships. Several independent variables were grand mean centered (physics ability beliefs, perceived recognition, ability belonging, social belonging, physics identity, and average perceived instructor ability beliefs) to make their interpretations more meaningful. In each circumstance, I tested if the coefficient was significantly different from zero. I also examined whether there was significant within-student and between-student variation in intended persistence after accounting for my included predictors.

Ethical Issues

Internal Review Boards (IRB) at my study institution helped to ensure that I ethically collected and analyzed data. The primary ethical considerations of this study involved ensuring the confidentiality and security of student data. I maintained participant confidentiality in several ways. First, surveys will be distributed via an anonymous link. Student names and official identification numbers were not retained in the dataset. Instead, each student participant was assigned a number (1,2,3,4, etc.). An encrypted, password-protected file was be created that coded the number assigned to each participant to their student ID. This file allowed me to pair demographic and academic background information with survey responses and to match responses gathered across the semester to specific individuals.

Positionality Statement

I identify as a white, middle-class, queer, cisgender woman. I obtained a bachelor's and a master's degree in a biology field, the latter of which came from a large research-intensive institution similar in size, structure, and demographic make-up to the institutions in the present study. I thus have personal experience navigating postsecondary scientific spaces as a woman and am in certain ways an insider to my population of interest. In addition, I am a trained higher education practitioner and researcher who is extremely invested in increasing diversity, equity, inclusion, and justice across STEM fields. I advise undergraduates in the biological sciences at Southeastern University and through conversations with my advisees, I witness instances of exclusion and inequity in postsecondary STEM education on a regular basis. At the same time, I do not have personal experience as a student in the discipline of physics. As a white, middle-class individual from a largely college-educated family, I possess extensive privileges due to my race, class, and familial education background. I am in these ways an outsider to this study's population. My dual position as an insider and an outsider is helpful in providing me with direct experiences with issues of diversity, equity, inclusion, and justice in STEM and with a certain degree of legitimacy and trustworthiness among my study population as a woman in STEM. It is also a bit dangerous in that my own identity as a science person (as well as a white, educationally and economically privileged person) may prevent me from fully seeing certain power structures at play.

Results

In this section, I first provide the construct validity and reliability estimates for my survey scales. I next present findings for each component of my two research questions. My first research question examined the contextual dynamics through undergraduate physics majors' domain-specific ability beliefs and perceived recognition from instructors and peers shifted and

changed on a weekly basis over the course of a semester. My second research question explored the relationships between physics majors' personal and environmental contexts, their physics ability beliefs, their perceived recognition, their ability and social belonging, their physics identity, and their short-term persistence over a semester.

Validity & Reliability

I used CFA with the robust weighted least squared estimator (WLSMV) to evaluate the construct validity of each of the five survey scales. The robust weighted least squared estimator was necessary as the distribution of item responses was often skewed, a common trait of Likert-type questions (Kline, 2016). Given the heterogeneity of existing literature, I began by using participants' beliefs about their own physics abilities to analyze whether the seven items of the Physics Ability Beliefs Scale were best represented as one or two ('entity' and 'incremental') correlated latent factors (van Aaldernen-Smeets et al, 2018; Limeri et al., 2020b). A two-factor model produced a better global fit between the model and the observed data (RMSEA = 0.163, CFI = 0.941, SRMR = 0.042). All parameter loadings were well above the 0.4 cutoff, indicating strong factor loadings and residual analysis did not point to any issues. I next evaluated the fit of the two-factor model on students' perceptions of their instructor's physics ability beliefs, which resulted in a strong fit (RMSEA = 0.043, CFI = 0.998, SRMR = 0.011). I averaged participants' responses to the four incremental items in each scale to obtain a score that represented the extent to which students perceived their physics abilities as malleable at a given time point and another score that represented the extent to which students perceived that their instructor believed students' physics abilities were malleable. These scores were then used as the self-perceived and perceived instructor physics ability belief variables in the multilevel models described below.

I next confirmed the factor structure of the remaining scales. Four of twelve items on the Ability Belonging Scale loaded poorly onto the latent ability belonging factor and were also removed, which resulted in an acceptable local and global fit for this scale (RMSEA = 0.089, CFI = 0.974, SRMR = 0.050). The four items on the Social Belonging Scale loaded strongly onto the social belonging latent variable (RMSEA = 0.175, CFI = 0.963, SRMR = 0.045). One item on the 'Intent to Persist' scale loaded comparatively poorly onto the intended persistence latent variable and was thus removed. The two items on the Physics Recognition Scale and Physics Identity Scale each loaded strongly onto their respective latent constructs (recognition and physics identity).

All scales displayed adequate to high within-person and between-person reliability except for the Intent to Persist Scale, which showed high between-person, but not within-person reliability (R_{WP} = 0.28, R_{BP} = 0.95). Calculating reliability by individual items revealed that the one reverse-coded item displayed low within-person reliability, while the other two items displayed adequate to strong within-person reliability. As such, the reverse-coded item was removed from further analyses. The within- and between-person reliability estimates of scales used in inferential analyses appear in Table 3.3. Removed survey items are italicized in Appendix C. After confirming factor structures and calculating reliability, I averaged participants' responses to remaining items within each scale to obtain an ability belonging, social belonging, intended persistence, perceived recognition, and physics identity score for each student at each time point measured for use in multilevel modeling.

Table 3.3

Within- and Between-Person Reliability Estimates

	R_{WP} (Within-person reliability)	R_{BP} (Between-person reliability)
Physics ability beliefs scale (student)	0.99	1.00
Physics ability beliefs scale (instructor)	0.75	0.90
Ability belonging scale	0.60	0.98
Social belonging scale	0.74	0.98
Perceived recognition scale	0.57	0.99
Physics identity scale	0.70	0.93
Intent to persist scale	0.66	0.95

Multilevel Models

All multilevel models met assumptions of linearity and normality and homoscedasticity of residuals at Level 1. In addition, multicollinearity was not present among predictors. The subsections below summarize findings for each component of my two research questions.

Research Question 1a

The first part of research question one examined whether there was significant, linear within-student change in physics ability beliefs over the course of the semester. I then explored the extent to which this change depended on a student's gender, race, ethnicity, course level, perceived academic struggle, type of academic task encountered during a week, and perceived instructor physics ability beliefs. In multilevel modeling, it is important to begin with a preliminary model (formally known as a fully unconditional or null model) to establish that there is sufficient variability at Level 1 (within students) and Level 2 (between students) to justify

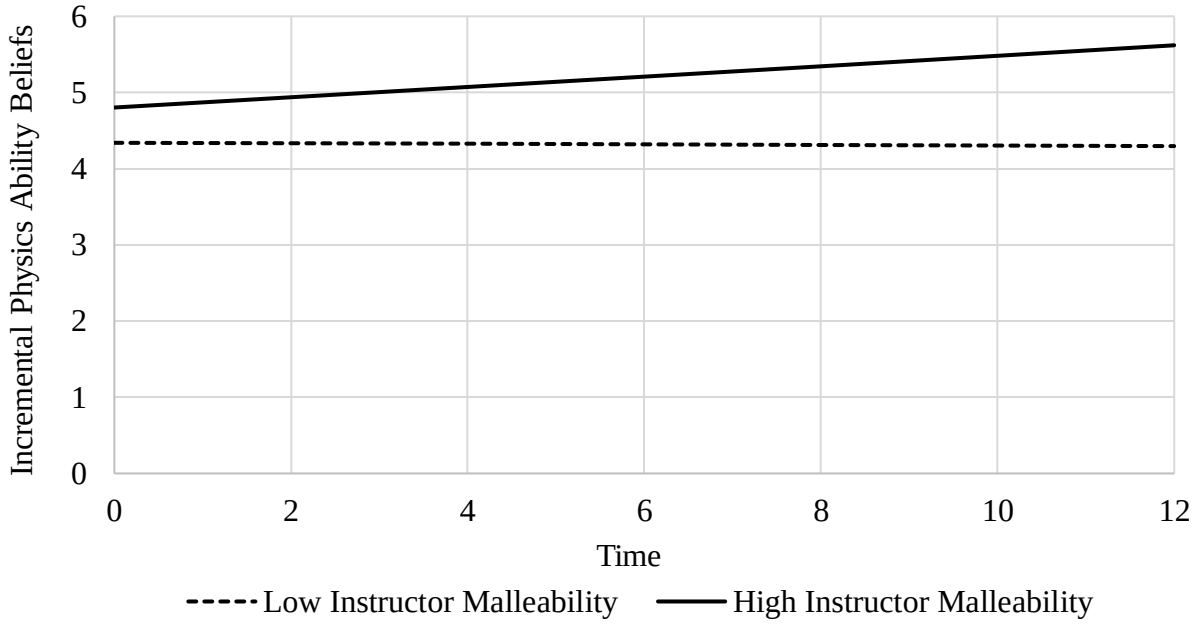
continued analysis. The fully unconditional model determines the amount of variability at Level 1 and Level 2 in the absence of any predictors and estimates the mean value of physics ability beliefs across all time points (Level 1) and students (Level 2) (Raudenbush & Bryk, 2002). Results of this model revealed that 66% of variability in physics ability beliefs was between students ($\tau_{00} = 0.56$, $z = 4.66$, $p<0.0001$) and 33% was within students ($\sigma^2 = 0.27$, $z = 14.35$, $p<0.0001$). Such findings indicated that there was enough within- and between-student variability in physics ability beliefs to warrant further analysis. The mean value of physics ability beliefs across all time points and students (γ_{00}) was 4.86. This signified that, on average, students agreed that their physics abilities were malleable with effort and time.

On average, there was a slight but significant decrease in the malleability of students' physics ability beliefs over the course of the semester ($\gamma_{10} = -0.03$, $t = -2.67$, $p = 0.008$), and there was significant interindividual variability in the rate of change over time ($\tau_{11} = 0.005$, $z = 3.87$, $p <0.0001$). Adding Level 1 and Level 2 predictors revealed that students in the introductory physics course had on average more malleable physics ability beliefs than students in the advanced physics course ($\gamma_{01} = 0.55$, $t = 3.14$, $p = 0.004$). At the same time, introductory students had a significant decline in the malleability of their physics ability relative to advanced students over the course of the semester ($\gamma_{11} = -0.10$, $t = -4.02$, $p < 0.0001$). Students' physics ability beliefs also varied based on their perceptions about their instructor's physics ability beliefs. Specifically, students on average reported more malleable beliefs about their physics abilities when they perceived that their instructor ascribed to growth-oriented beliefs about their students' physics abilities ($\gamma_{04} = 0.35$, $t = 2.77$, $p = 0.006$). In addition, students who perceived that their instructor ascribed to growth-oriented beliefs about students' physics abilities reported more

malleable beliefs about their own physics abilities over time ($\gamma_{14} = 0.05$, $t = 2.91$, $p = 0.004$; Figure 3.2).

Figure 3.2

Interaction Between Time, Perceived Instructor Physics Ability Beliefs, and Students' Incremental Physics Ability Beliefs



Students on average reported more malleable beliefs about their physics abilities in weeks when they engaged in an interactive in-class activity ($\gamma_{40} = 0.15$, $t = 2.67$, $p = 0.008$) or completed an exam ($\gamma_{50} = 0.11$, $t = 2.22$, $p = 0.03$). There were no differences in average physics ability beliefs or rates of change over the course of the semester based on students' gender, race, ethnicity, perceived academic struggle, or participation in an experimental lab activity (Table 3.3). The full model accounted for 64% of between-student and 46% of within-student variability in physics ability beliefs (Table 3.4).

Table 3.4

Unstandardized Coefficients (And Standard Errors) of Multilevel Model of Physics Ability Beliefs Containing All Level 1 and Level 2 Predictors (Level 1 = 406; Level 2 = 49)

Fixed Effects	Coefficient (SE)
Physics Ability Beliefs, β_0	
Intercept, γ_{00}	4.57*** (0.21)
Course Level, γ_{01}	0.55** (0.18)
Gender, γ_{02}	0.16 (0.17)
Race/ethnicity, γ_{03}	-0.02 (0.21)
Perceived instructor ability beliefs, γ_{04}	0.35** (0.12)
Time slope, β_1	
Intercept, γ_{10}	0.03 (0.03)
Course Level, γ_{11}	-0.10*** (0.02)
Gender, γ_{12}	0.003 (0.02)
Race/ethnicity, γ_{13}	-0.005 (0.03)
Perceived instructor ability beliefs, γ_{14}	0.05** (0.02)
Academic struggle slope, β_2	
Intercept, γ_{20}	-0.09 (0.08)
Time X Academic struggle slope, β_3	
Intercept, γ_{30}	0.002 (0.01)
Exam slope, β_4	
Intercept, γ_{40}	0.11* (0.05)
Activity slope, β_5	
Intercept, γ_{50}	0.15** (0.06)
Experimental lab slope, β_6	
Intercept, γ_{60}	0.09 (0.06)
Random Effects	
Physics Ability Beliefs, τ_{00}	0.1999** (0.06)
Time slope variation, τ_{11}	0.004** (0.001)
Within-student variation, σ^2	0.141*** (0.01)
$R^2_{between}$	0.64
R^2_{within}	0.48

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Research Question 1b

The second part of my first research question considered whether there was significant linear change in a physics student's perceived recognition as an exemplary physics student over time, and tested if this change depended on gender, race, ethnicity, course level, incremental physics ability beliefs, academic struggle, type of task encountered during the week, and perceived instructor ability beliefs. The unconditional model indicated that 74% of variability in perceived recognition was between students ($\tau_{00} = 0.80$, $z = 4.87$, $p<0.0001$) and 26% was within students ($\sigma^2 = 0.28$, $z = 14.29$, $p<0.0001$). Such findings signified that there was enough within- and between-student variability in physics ability beliefs to warrant further analysis. The mean level of perceived recognition across all time points and students (γ_{00}) was 2.18. In other words, students on average perceived *a little bit* of recognition from their instructors and peers as an exemplary physics student.

On average, students' perceived recognition did not change significantly over time ($\gamma_{10} = -0.01$, $t = -1.03$, $p = 0.31$), though there was significant interindividual variability in the rate of change ($\tau_{11} = 0.002$, $z = 2.66$, $p = 0.004$). Students' perceived recognition varied significantly in relation to their physics ability beliefs. Specifically, students perceived greater recognition as an exemplary physics student in weeks when their physics ability beliefs were more malleable than their average ($\gamma_{20} = 0.55$, $t = 2.59$, $p = 0.01$), though the magnitude of this difference decreased over the course of the semester ($\gamma_{40} = -0.03$, $t = -2.13$, $p = 0.03$; Figure 3.3). Testing simple slopes supported that perceived recognition initially differed significantly between students with above and below average malleability of physics ability beliefs, but that these differences diminished over time (0.21 ± 0.10, $t = 2.14$, $p = 0.03$). There were no significant differences in average perceived recognition or rate of change in perceived recognition based on students' physics course, gender, race, ethnicity, perceptions of instructor ability beliefs, perceived

academic struggle, or type of academic task encountered during a week (Table 3.5). The full model accounted for 15% of between-student variation and 23% of within-student variation in perceived recognition.

Figure 3.3

Interaction Between Time, Physics Ability Beliefs, and Perceived Recognition

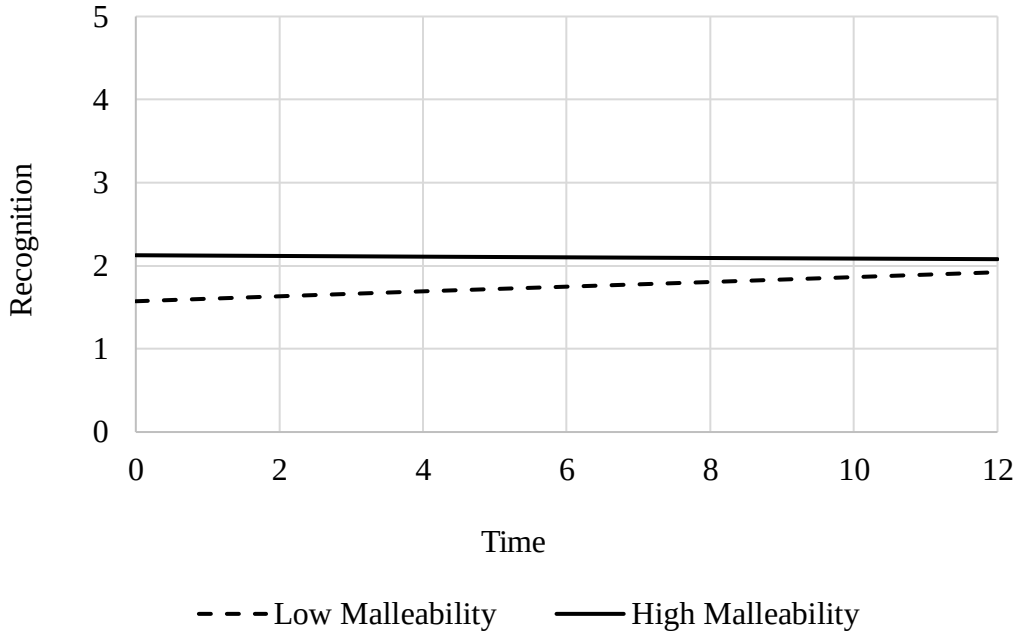


Table 3.5

Unstandardized Coefficients (And Standard Errors) of Multilevel Model of Perceived Recognition Containing All Level 1 and Level 2 Predictors (Level 1 = 406; Level 2 = 49)

Fixed Effects	Coefficient (SE)
Perceived Recognition, β_0	
Intercept, γ_{00}	1.85*** (0.34)
Course Level, γ_{01}	0.46 (0.29)
Gender, γ_{02}	0.33 (0.29)
Race/ethnicity, γ_{03}	-0.57 (0.36)
Perceived instructor ability beliefs, γ_{04}	0.19 (0.20)
Time slope, β_1	
Intercept, γ_{10}	0.01 (0.40)
Course Level, γ_{11}	-0.03 (0.03)
Gender, γ_{12}	0.02 (0.02)
Race/ethnicity, γ_{13}	-0.03 (0.03)
Perceived instructor ability beliefs, γ_{14}	0.003 (0.02)
Physics ability beliefs slope, β_2	
Intercept, γ_{20}	0.55* (0.21)
Course Level, γ_{21}	-0.09 (0.14)
Gender, γ_{22}	-0.03 (0.13)
Race/ethnicity, γ_{23}	-0.20 (0.18)
Perceived instructor ability beliefs, γ_{24}	-0.05 (0.09)
Academic struggle slope, β_3	
Intercept, γ_{30}	-0.06 (0.10)
Time X Physics ability beliefs slope, β_4	
Intercept, γ_{40}	-0.03* (0.02)
Time X Academic struggle slope, β_5	
Intercept, γ_{50}	0.002 (0.01)
Physics ability beliefs X Academic struggle slope, β_6	
Intercept, γ_{60}	0.01 (0.09)
Activity slope, β_7	
Intercept, γ_{70}	0.03 (0.07)
Experimental lab slope, β_8	
Intercept, γ_{80}	-0.14 (0.08)
Exam slope, β_9	
Intercept, γ_{90}	0.006 (0.06)
Random Effects	
Perceived recognition, τ_{00}	0.682

Table 3.5 *(continued)*

Time slope variation, τ_{11}	0.003* (0.001)
Within-student variation, σ^2	0.216
$R^2_{between}$	.15
R^2_{within}	.23

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Research Question 2a

The first part of my second research question examined whether there were significant linear relationships between a student's incremental physics ability beliefs, perceived recognition, and academic belonging (ability belonging and social belonging) over time. It also considered the extent to which these relationships depended on a student's gender, race, ethnicity, academic level, and perceived instructor ability beliefs. Results of the unconditional model revealed that 76% of variability in ability belonging was between students ($\tau_{00} = 0.89$, $z = 4.42$, $p<0.0001$) and 26% was within students ($\sigma^2 = 0.28$, $z = 6.15$, $p<0.0001$). The average level of ability belonging across all students and weeks as 3.37, which corresponds to between *slightly agree* and *slightly disagree.* Men on average had a higher level of ability belonging than women ($\gamma_{01} = 0.69$, $t = 2.64$, $p = 0.01$) and Black and Latine students had a lower average ability belonging than white and Asian students ($\gamma_{02} = -0.73$, $t = -2.19$, $p = 0.03$). Students in the introductory physics course had a lower average ability belonging in the major than students in the advanced course ($\gamma_{03} = -0.60$, $t = -2.30$, $p = 0.03$). In addition, students who perceived that their instructor had more malleable beliefs about their students' abilities reported a higher average ability belonging ($\gamma_{04} = 0.44$, $t = 2.13$, $p = 0.04$). Ability belonging did not vary based on time ($\gamma_{10} = -0.004$, $t = -0.47$, $p = 0.64$), students' perceived recognition ($\gamma_{20} = 0.12$, $t = 1.28$, $p = 0.21$), physics ability beliefs ($\gamma_{30} = -0.02$, $t = -0.21$, $p = 0.84$), or the interaction between

perceived recognition and physics ability beliefs (γ_{40} = 0.06, t = 0.71, p = 0.50). The full model accounted for 33% of between-student and 0% of within-student variability in ability belonging.

Results of the unconditional model for social belonging revealed that 73% of variability in social belonging was between students (τ_{00} = 1.06, z = 4.31, p<0.0001) and 27% was within students (σ^2 = 0.39, z = 6.15, p<0.0001). The average level of social belonging across all students and weeks as 3.98, which corresponds to just under *slightly agree.* Men had a higher average social belonging than women (γ_{01} = 0.60, t = 2.13, p = 0.04). A positive relationship existed between a student's social belonging and their perceived recognition (γ_{20} = 0.34, t = 3.58, p = 0.0006). While a significant relationship did not exist between a student's social belonging and physics ability beliefs (γ_{30} = 0.18, t = 1.62, p = 0.11), there was a significant interaction between physics ability beliefs, recognition, and social belonging (γ_{40} = -0.24, t = -2.66, p = 0.01). Testing simple slopes revealed that greater recognition significantly increased the social belonging of students with less malleable (0.58±0.14, t = 4.28, p < 0.0001), but not more malleable physics ability beliefs (0.09±0.13, t = 0.79, p = 0.43). Physics students with low recognition and less malleable physics ability beliefs reported the lowest level of social belonging. Social belonging did not vary according to time (γ_{10} = -0.01, t = -0.58, p = 0.56), physics course (γ_{03} = -0.42, t = -1.19, p = 0.13), race and ethnicity (γ_{02} = -0.42, t = -1.19, p = 0.23), or perceived instructor physics ability beliefs (γ_{04} = 0.11, t = 0.51, p = 0.61). The full model accounted for 39% of between-student and 10% of within-student variability in social belonging.

Research Question 2b

The second part of my second research question investigated if there were significant linear relationships between a student's physics belonging (ability and social), perceived recognition, and physics identity over time. It also examined whether these relationships

depended on a student's gender, race, ethnicity, academic level, physics ability beliefs and perceived instructor ability beliefs. Results of the unconditional model revealed that 46% of variability in physics identity was between students ($\tau_{00} = 0.51$, $z = 3.34$, $p = 0.0004$) and 54% was within students ($\sigma^2 = 0.60$, $z = 6.25$, $p<0.0001$). As such, there was sufficient within- and between-student variability in physics identity to justify further analyses. The mean level of physics identity across all weeks and students (γ_{00}) was 2.58. Students on average identified *a little bit* to *somewhat* as an exemplary physics student and a physicist.

Adding Level 1 and Level 2 predictors indicated that students who perceived greater recognition from peers and instructors were more likely to identify as an exemplary physics student and a physicist, both on average ($\gamma_{20} = 0.59$, $t = 3.08$, $p = 0.003$) and over time ($\gamma_{50} = 0.03$, $t = 2.09$, $p = 0.04$). In addition, students with a greater sense of ability belonging ($\gamma_{30} = 0.18$, $t = 2.20$, $p = 0.03$) and social belonging ($\gamma_{30} = 0.16$, $t = 2.17$, $p = 0.03$) also on average reported a greater average physics identity. These dynamics did not vary based on students' gender, race, ethnicity, physics course, physics ability beliefs, or perceived instructor ability beliefs (Table 3.6). The full models accounted for 88% of between-student and 27% of within-student variability in physics identity.

Table 3.6

Unstandardized Coefficients (And Standard Errors) of Multilevel Model of Physics Identity Containing All Level 1 and Level 2 Predictors (Level 1 = 125; Level 2 = 54)

Fixed Effects	Ability Belonging Predictor Coefficient (SE)	Social Belonging Predictor Coefficient (SE)
Physics identity, β_0		
Intercept, γ_{00}	2.67*** (0.23)	2.66*** (0.23)
Course Level, γ_{01}	0.03 (0.23)	-0.02 (0.22)
Gender, γ_{02}	-0.10 (0.22)	-0.03 (0.22)
Race/ethnicity, γ_{03}	0.12 (0.32)	0.14 (0.32)
Perceived instructor ability beliefs, γ_{04}	-0.10 (0.17)	-0.04 (0.17)
Time slope, β_1		
Intercept, γ_{10}	-0.02 (0.02)	-0.02 (0.02)
Course Level, γ_{11}	-0.02 (0.02)	-0.01 (0.02)
Gender, γ_{12}	0.002 (0.02)	-0.003 (0.02)
Race/ethnicity, γ_{13}	-0.01 (0.03)	-0.01 (0.03)
Perceived instructor ability beliefs, γ_{14}	-0.01 (0.02)	-0.01 (0.02)
Recognition slope, β_2		
Intercept, γ_{20}	0.59** (0.19)	0.59** (0.19)
Course Level, γ_{21}	-0.11 (0.15)	-0.20 (0.15)
Gender, γ_{22}	-0.01 (0.17)	0.02 (0.17)
Race/ethnicity, γ_{23}	-0.47 (0.25)	-0.36 (0.25)
Perceived instructor ability beliefs, γ_{24}	0.08 (0.12)	0.14 (0.11)
Belonging slope, β_3		
Intercept, γ_{30}	0.18* (0.08)	0.16* (0.08)
Physics ability beliefs slope, β_4		
Intercept, γ_{40}	0.14 (0.10)	0.10 (0.11)
Time X recognition slope, β_5		
Intercept, γ_{50}	0.03* (0.01)	0.03* (0.01)
Random Effects		
Physics identity, τ_{00}	0.06	0.07
Within-student variation, σ^2	0.433***	0.424***
$R^2_{between}$	0.88	0.86
R^2_{within}	0.27	0.29

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Research Question 2c

The third and final part of my second research question asked if there were significant linear relationships between a student's physics belonging (ability and social), perceived recognition, physics identity, and intent to persist in the physics major. It also explored whether these relationships depended on a student's gender, race, ethnicity, academic level, physics ability beliefs and perceived instructor ability beliefs. The unconditional model signified that 66% of variability in persistence intentions was between students ($\tau_{00} = 0.896$, $z = 4.08$, $p<0.0001$) and 34% was within students ($\sigma^2 = 0.461$, $z = 6.16$, $p<0.0001$). As such, there was sufficient within- and between-student variability in intended persistence to justify further analysis. The mean level of intended persistence across all time points and students (γ_{00}) was 4.97 (just under *agree*). In other words, students on average agreed that they intended to persist in the physics major over time.

I next added Level 1 and Level 2 predictors, running a model with ability belonging and social belonging predictors separately to account for the maximum number of Level 1 predictors allowed for 3 measurement points. Table 3.7 presents the results of both models. When ability belonging was included as a predictor, students in the advanced course reported greater persistence intentions than students in the introductory course ($\gamma_{03} = -0.92$, $t = -2.88$, $p = 0.006$). Significant relationships did not exist between physics identity, perceived recognition, ability belonging, and persistence intentions (Table 3.7). At the same time, a significant interaction appeared between race and ethnicity, ability belonging, and persistence intentions, such that the relationship between ability belonging and intended persistence was stronger for white and Asian students than it was for Black and Latine students ($\gamma_{22} = -0.87$, $t = -2.80$, $p = 0.007$). In addition, a significant interaction existed between course level, perceived recognition, and intended

persistence (γ_{33} = 0.76, t = 2.68, p = 0.01). Testing simple slopes indicated that students in the introductory course who perceived a low level of recognition had significantly lower persistence intentions than those in the advanced course who perceived a low level of recognition (-1.68±0.45, t = -3.76, p = 0.0004), though persistence intentions did not vary between students in the introductory and advanced course who perceived a high level of recognition (-0.16±0.41, t = -0.40, p = 0.69).

While a within-student relationship did not exist between incremental physics ability beliefs and persistence intentions (γ_{40} = 0.47, t = 1.74, p = 0.09), a significant interaction existed between gender, incremental physics ability beliefs, and persistence intentions, such that the positive relationship between incremental physics ability beliefs and intended persistence was stronger for women than it was for men (γ_{41} = -0.44, t = -2.97, p = 0.04). The model including ability belonging accounted for 5% of between-student and 29% of within-student variability in intended persistence.

When social belonging (as opposed to ability belonging) was included as a predictor, a positive within-student relationship existed between intended persistence and social belonging (γ_{20} = 0.69, t = 2.87, p = 0.006). The same dynamics between physics course level and persistence was apparent, such that students in the advanced course expressed stronger persistence intentions than those in the introductory course (γ_{03} = -0.71, t = -2.23, p = 0.03). In addition, a significant interaction effect also appeared between race, ethnicity, and social belonging, such that the positive relationship between social belonging and persistence was stronger for white and Asian than for Black and Latine students (γ_{12} = -0.59, t = -2.48, p = 0.02). The model including social belonging accounted for 7% of between-student and 32% of within-student variability in persistence intentions (Table 3.7).

Table 3.7

Unstandardized Coefficients (And Standard Errors) of Multilevel Model of Intended Persistence Containing All Level 1 and Level 2 Predictors (Level 1 = 125; Level 2 = 54)

Fixed Effects	Ability Belonging Predictor Coefficient (SE)	Social Belonging Predictor Coefficient (SE)
Intended persistence, β_0		
Intercept, γ_{00}	5.30*** (0.36)	5.45*** (0.34)
Gender, γ_{01}	0.18 (0.34)	-0.09 (0.33)
Race/ethnicity, γ_{02}	-0.53 (0.48)	-0.25 (0.47)
Course level, γ_{03}	-0.92** (0.32)	-0.71* (0.32)
Perceived instructor ability beliefs, γ_{04}	0.03 (0.26)	0.01 (0.25)
Identity slope, β_1		
Intercept, γ_{10}	0.0004 (0.28)	-0.23 (0.29)
Gender, γ_{11}	0.32 (0.23)	0.47 (0.26)
Race/ethnicity, γ_{12}	-0.43 (0.21)	-0.33 (0.22)
Course level, γ_{13}	-0.03 (0.25)	0.03 (0.24)
Perceived instructor ability beliefs, γ_{14}	0.07 (0.21)	-0.11 (0.21)
Belonging, β_2		
Intercept, γ_{20}	0.27 (0.27)	0.69** (0.24)
Gender, γ_{21}	0.06 (0.23)	-0.36 (0.23)
Race/ethnicity, γ_{22}	-0.87** (0.31)	-0.59* (0.24)
Course level, γ_{23}	-0.27 (0.25)	0.08 (0.22)
Perceived instructor ability beliefs, γ_{24}	0.24 (0.16)	0.17 (0.16)
Recognition slope, β_3		
Intercept, γ_{30}	-0.33 (0.34)	0.16 (0.34)
Gender, γ_{31}	-0.41 (0.29)	-0.45 (0.30)
Race/ethnicity, γ_{32}	-0.21 (0.40)	-0.33 (0.39)
Course level, γ_{33}	0.76* (0.28)	0.54 (0.28)
Perceived instructor ability beliefs, γ_{34}	-0.44 (0.24)	-0.33 (0.25)
Physics ability beliefs slope, β_4		
Intercept, γ_{40}	0.47 (0.27)	0.52 (0.25)
Gender, γ_{41}	-0.44* (0.21)	-0.33 (0.39)
Race/ethnicity, γ_{42}	0.11 (0.32)	0.12 (0.31)
Course level, γ_{43}	-0.14 (0.26)	-0.28 (0.26)

Table 3.7 *(continued)*

Random Effects		
Intended persistence, τ_{00}	0.846*** (0.22)	0.831*** (0.22)
Within-student variation, σ^2	0.327*** (0.06)	0.312*** (0.06)
$R^2_{between}$	0.05	0.07
R^2_{within}	0.29	0.32

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Discussion

This study adds insight into the short-term contextual dynamics of the disciplinary ability beliefs, identity development, and persistence intentions of undergraduate physics majors enrolled in physics courses that incorporated an interactive instructional approach. Findings point to important connections between these factors and illuminate the role that domain-specific ability beliefs at the instructor level play in shaping students' beliefs and perceptions. The results from this study also offer important implications for undergraduate physics programs and instructors.

In line with recent work, students' own physics ability beliefs separated into two covarying, dynamic constructs (entity and incremental) as opposed to one continuous score (entity to incremental) (Kalender et al., 2022; Limeri et al., 2020a; Malespina et al., 2022). Although participants overall agreed that their physics abilities could grow and change with effort, the malleability of undergraduates' ability beliefs decreased over the course of the semester. Students in the introductory physics course on average conveyed more incremental beliefs about physics abilities than students in the advanced physics course. At the same time, students in the introductory course reported a significant decline in the malleability of their physics ability beliefs during the semester, while students in the advanced course reported slightly more malleable physics ability beliefs over time. Several studies have similarly observed

that college STEM students communicate less malleable beliefs about their abilities in specific domains as they move through their introductory STEM courses (Dai & Cromley, 2014; Flanigan et al., 2016; Marshman et al., 2018; Malespina et al., 2022; Shively & Ryan, 2013). This trend suggests that the learning environments of introductory STEM courses discourage students from viewing their own abilities as capable of growth and change. Empirical work documents that introductory college STEM courses are often structured in a fast-paced, rigorous manner than encourages competition among students to prove their academic abilities, and that this course dynamic that inhibits the development of incremental ability beliefs (Mervis, 2011; NRC, 2013; Seymour & Hunter, 2019). It seems likely that a competitive introductory course culture would be intensified in disciplines such as physics that are stereotypically perceived as requiring a high, innate intelligence for success (Leslie et al., 2015). Importantly, my results emphasize that undergraduates can acquire less malleable beliefs about their abilities in a particular subject in an introductory STEM course even with the incorporation of an interactive instructional approach.

Students' beliefs about their physics abilities varied according to their perceptions of their instructors' physics ability beliefs. Notably, undergraduates reported less malleable physics ability beliefs both on average and over time when they perceived that their course instructor held less malleable beliefs about their students' physics abilities. A growing body of literature points to the important role that ability beliefs conveyed at the environmental level play in shaping students' beliefs, perceptions, and experiences (Canning et al., 2020; Dweck and Yeager, 2019; Good et al., 2012; LaCosse et al., 2020; Muenks et al., 2020; Murphy & Dweck, 2010). My findings align with those of Good et al. (2012), who found that college students' beliefs about their own math abilities correlated with their perceptions of the math ability beliefs

promoted by their learning environment. The present study extends existing work by indicating that college students' domain-specific ability beliefs not only differ but also differentially change in accordance with their perceptions of their instructor's ability beliefs. It is possible that a student's own ability beliefs interact reciprocally with their perceived instructor physics ability beliefs over time, as an individual's perceptions of their environment are undoubtedly influenced by their own ability beliefs (Good et al., 2012). Nonetheless, my results support that students' perceptions of their instructor's physics ability beliefs play an important role in shaping their own physics ability beliefs over time (Limeri et al., 2020a).

In agreement with qualitative findings from Little et al. (2019), students' physics ability beliefs also varied based on the weekly context of their academic tasks. Students reported more malleable physics ability beliefs during weeks in which they completed an interactive in-class activity or an exam, but not in weeks when they engaged in an experimental lab activity. These trends did not depend on the extent to which a student struggled academically during a given week. While it is expected that students would convey more incremental ability beliefs after participating in a formative, interactive activity it is surprising that they also expressed more incremental ability beliefs alongside exams, which are more high stakes and summative in nature. I am aware from qualitative research on Southeastern University's physics program that physics exams are entirely short-answer and that instructors offer a great deal of partial credit. Perhaps that the process of preparing for and completing exams reminds students of spurs students to reflect on the effort and growth involved in learning physics. Ongoing data collection and analysis will explore this finding in greater detail.

Undergraduates' physics ability beliefs did not vary according to their weekly perceptions of academic struggle in a physics course. In examining the dynamics of

undergraduates' physics ability beliefs over the course of three semesters at Southeastern University, students experienced ongoing academic struggle in a course reported less malleable beliefs about their physics abilities over time, a finding that has also been observed by others (Limeri et al., 2020a; Thomas, 2023). Importantly, these two referenced studies only asked students about their degree of academic struggle during a semester at the end of a term, whereas the present study asked students to report their academic struggle on a weekly basis. It is possible academic struggle only influences a student's physics ability beliefs when it is measured over a longer time period (such as a semester or multiple semesters), as opposed to from week to week.

Students' physics ability beliefs also did not vary based on their gender, race, or ethnicity. This contrasts with results from several recent studies, which determined that women had less malleable beliefs about their physics abilities than men and that such differences grew over time due to oppressive stereotypes that position women as possessing less natural ability in the discipline (Kalender et al., 2022; Malespina et al., 2022; Marshman et al., 2018). This divergent finding could stem in part from the fact that the present study focused on undergraduates enrolled in courses meant for physics majors, whereas other studies surveyed students in algebra- and calculus-based physics courses intended for students majoring in a variety of STEM fields. It seems likely that women, Black, and Latine undergraduates who are majoring in physics have more incremental physics ability beliefs than those who take a physics course as a requirement for a different STEM major. It is also possible that the low number of women, Black, and Latine participants (an artifact of the lack of diversity in the undergraduate physics major) obscured differences that might appear in a larger sample size.

This study offers novel insight into the relationship between students' physics ability beliefs and their perceived recognition as an exemplary physics student. Overall, undergraduates

reported only a small amount of positive recognition from their peers and instructors. At the same time, participants perceived greater recognition as an exemplary physics student during weeks in which their own physics ability beliefs were more malleable than average, though the magnitude of this relationship decreased over the course of the semester. The dynamics of this relationship did not vary based on students' gender, race, ethnicity, course level, academic struggle, or perceived instructor ability beliefs. While my findings could not discern the causes behind the connection between incremental physics ability beliefs and recognition, more malleable physics ability beliefs might correspond to greater self-esteem and engagement in the learning process, which then generates greater perceived recognition from others (Robin & Pals, 2002). It is also possible that a reciprocal relationship exists between incremental physics ability beliefs and recognition, such that as students perceive greater recognition, they are more confident that their physics abilities can grow and change. The magnitude of this dynamic could decrease as one approaches the end of a semester in part due to students with less malleable physics ability beliefs achieving recognition in the form factors such as academic success in a course (Dweck, 2012; Mendoza-Denton et al., 2008).

Although women, Black, and Latine students perceived lower levels of recognition from their peers and instructors than their peers during the semester, these differences were not statistically significant. This contrasts with existing literature, which documents that physics students with marginalized gender, racial, and ethnic identities commonly report significantly less recognition from others in their learning environment than non-marginalized students (AIP, 2020; Carter et al., 2019; Doucette & Singh, 2020; Fries-Britts et al., 2010; Hazari et al., 2017; Hyater-Adams et al., 2019; Kalender et al., 2019a; Kalender et al., 2019a; Godwin et al., 2016; Li & Singh, 2021; Lock et al., 2019; Rodriguez et al. 2019). Given the comparatively low

number of women, Black, and Latine participants in the study, it is not possible to say with certainty whether this lack of a difference is due more to inclusive aspects of the physics courses or to the dearth of participants with these identities. Ongoing data collection and analysis will provide greater clarity in the future.

As a whole, students were not particularly confident about their ability or social belonging in the physics major. At the same time, women, Black and Latine students reported significantly lower levels of ability belonging than their non-marginalized peers. In addition, women reported lower levels of social belonging in the physics major than men. Though the present study could not reveal the specific causes of these disparities, women, Black, Latine, and Indigenous individuals commonly feel that they do not belong intellectually or socially in physics spaces due oppressive interpersonal dynamics, cultures, and structures that exclude and isolate those who do not embody the discipline's white, masculine standard (AIP, 2020; Banchefsky et al., 2019; Bjorkquist et al., 2019; Fries-Britt & Holmes, 2012; Gonsalves et al., 2016; Lewis et al., 2016; Lewis et al., 2017; Ong, 2005; Prescod-Weinstein, 2020; Sax, 1994; Sax et al., 2015; Settles et al., 2006; Seyranian et al., 2018). In addition, collaborative, interactive activities in college physics courses can spur greater peer exclusion and stereotype-driven stress for marginalized students (Maries et al., 2020; Pollock et al., 2007). My findings stress that disparities in physics ability and social belonging can remain even after accounting for the effects of recognition, physics ability beliefs, and perceived instructor ability beliefs.

Students' sense of belonging also varied based on their course level, perceived instructor ability beliefs, and recognition. Undergraduates in the introductory class reported lower levels of ability belonging than those in the advanced class. In addition, students felt more confident that they possessed the abilities needed to belong in the physics major when they perceived that their

instructor believed that students' physics abilities could grow over time. Past research has determined that college STEM students report a lower sense of belonging in courses when they perceive that their instructor ascribes to entity ability beliefs (LaCosse et al., 2020; Muenks et al., 2020). My results expand these findings by indicating that perceived instructor ability beliefs can shape students' sense of belonging in their entire major. While others have observed the relationship between perceived classroom-level ability beliefs and sense of belonging to be stronger for women than for men, gender differences did not appear in the present study (Good et al., 2012; LaCosse et al., 2020). Students who perceived greater recognition from their instructors and peers reported a greater sense of social belonging in the physics major, a finding also obtained by Hazari et al. (2020). Interestingly, the positive relationship between recognition and social belonging was significantly stronger for students with less malleable ability physics beliefs. In other words, undergraduates who were less certain that their physics abilities were capable of growth were more dependent on recognition from others to achieve a sense of social belonging in the major than those who believed their physics abilities to be malleable. This dynamic perhaps stems from students with less malleable beliefs about their own abilities relying more on external cues to confirm that they belong in the major.

Participants were also overall not very confident in their disciplinary identity as an exemplary physics student or a physicist. In line with existing empirical evidence, students who reported greater recognition from peers and instructors expressed a stronger physics identity, both on average and over time (Carlone & Johnson, 2007; Gee, 2000; Hazari et al., 2010; Hazari et al., 2017; Hazari et al., 2020; Kalender et al., 2019b). Positive relationships were also present between students' physics identity and their ability and social belonging in the physics major. While Hazari et al. (2020) determined that a sense of belonging in physics was more influential

on the physics identity development of upperclassmen than underclassman, the nature of this relationship did not vary by course level in the present study. Taken together, these results emphasize that physics majors' self-perceptions as an exemplary physics student and a physicist are strongly tied to the interpersonal dynamics of their undergraduate physics learning spaces (Avraamidou, 2022; Hazari et al., 2020; Johnson, 2020). Physics majors develop a physics identity when they feel recognized as an individual who belongs both intellectually and socially in their undergraduate program. These dynamics did not depend on students' gender, race, or ethnicity. While the comparatively low number of women, Black, and Latine students potentially contributes to this absence of a difference, such findings also point to the fact that positive recognition and a sense of belonging are important for the physics identity development of all students.

Undergraduates' physics ability beliefs and perceived instructor physics ability beliefs did not directly impact their physics identity. This differs from results obtained by Cribbs et al. (2021), who found that college freshmen with incremental math ability beliefs reported a stronger identification with math. Importantly, Cribbs et al. (2021) surveyed freshmen interested in a range of STEM and non-STEM majors. It seems possible that domain-specific ability beliefs play less of a direct role in disciplinary identity development compared to factors such as recognition and ability and social belonging for students who have decided to major in a particular domain. As previously discussed, individual and environmental-level physics ability beliefs did directly relate to key components of physics identity development (recognition and belonging). These results stress the importance of considering contextual nature of college students' disciplinary identity development (Hazari et al., 2020).

Unsurprisingly, students in the advanced course expressed greater persistence intentions than those in the introductory course. A significant interaction was present between course level, perceived recognition, and persistence such that low recognition deterred the persistence of introductory but not advanced physics students. It is possible that when students enter the major as freshmen, they rely more heavily on external cues to inform their persistence intentions than upperclassmen, who perhaps rely on a greater range of internal and external factors (such as career goals or extracurricular experiences). This finding emphasizes the vital role that positive recognition from instructors and peers plays in promoting the persistence of undergraduates early on in their postsecondary path.

A significant interaction also appeared between gender, physics ability beliefs, and persistence such that women with less malleable physics ability beliefs reported particularly low persistence intentions. Good et al. (2012) determined that women are less likely to persist in a STEM field when they perceive that others in their learning environment promote entity ability beliefs. My findings add to this work by indicating that women are significantly less likely to express intentions to persist in a STEM discipline when they believe that their *own* disciplinary abilities are not malleable. While the present study did not explicitly measure students' stereotypes about women's STEM abilities, it is possible that believing one's physics abilities are malleable with time and effort reduces the impact of negative intelligence stereotypes on women's persistence intentions in physics.

Overall, students' sense of social of belonging, but not physics identity, ability belonging, recognition, or ability beliefs, significantly influenced their persistence intentions in the field over the course of a semester. Such findings highlight the central role that perceiving oneself as a legitimate, valued member of a disciplinary community plays in promoting a student's retention

in said discipline (Banchefsky et al., 2019; Good et al., 2012; Perez-Felkner et al., 2017). At the same time, significant interactions were present between race and ethnicity, ability belonging, social belonging, and persistence, such that the relationships between ability belonging, social belonging and persistence were stronger for white and Asian students than for Black and Latine students. Given that Black and Latine students often report lower levels of ability and social belonging in physics than white and Asian students, it is likely that the predominant dynamics of the major are less welcoming and supportive of minoritized students than they are of non-minoritized students (AIP, 2020; Fries-Britts et al., 2010; Fries-Britt & Holmes, 2012; McGee, 2016). As such, Black and Latine students who persist in the major are perhaps more reliant on other factors. For example, Hyater-Adams et al. (2019) found that Black undergraduates and graduate students in physics were commonly motivated to persist in part through a desire to make the discipline more welcoming for future Black physics students. This finding speaks to the high level of determination and resiliency employed by individuals in physics with marginalized racial and ethnic identities (Ferguson & Martin-Dunlop, 2020). It is extremely important that physics programs actively work to expand who can belong socially and intellectually in the discipline, so that students with marginalized social identities no longer need to employ disproportionate levels of resilience in order to persist in the field (Wright & Riley, 2020).

Conclusions

Overall, results substantiate that undergraduate physics students' domain-specific ability beliefs, perceived recognition, sense of belonging, disciplinary identity, and persistence intentions vary and change over the course of a semester in accordance with individual and environmental factors. Changes in students' own incremental physics ability beliefs were

influenced both by their course level and by components of their physics courses, notably their perceptions of their instructor's physics ability beliefs and the type of academic task(s) encountered in a week. Incremental physics ability beliefs related to students' perceived recognition as an exemplary physics student, which in turn related to their social belonging and disciplinary identification. Incremental physics ability beliefs at the classroom level also corresponded to students' level of ability belonging, while ability belonging and social belonging related to their physics identity. Physics social belonging correlated with greater persistence intentions in the field. At the same time, women, Black, and Latine students reported lower levels of belonging in physics after accounting for physics ability beliefs and perceived recognition. Such findings emphasize that students with marginalized social identities contend with numerous threats to their belonging in physics courses that incorporate an interactive instructional component.

Directions for Future Research

This study included multiple limitations and opportunities for further inquiry. First, while the demographics of survey respondents closely matched the demographics of the undergraduate physics major at Southeastern University, white and male participants greatly outnumbered women, Black, and Latine participants and there were no Indigenous participants. Given the relatively low number of participants with marginalized gender, race, and ethnic identities, it was not possible to inferentially analyze the beliefs, perceptions, and intentions of students it individual racial and ethnic identities. It is also possible that analyses underrepresented the strength of certain dynamics. In addition, I was not able to address the intersectional nature of marginalization through interaction effects given the comparatively low number of women and people of color in the sample. On top of this, the physics major at Southeastern University is

itself rather small, which led to smaller sample sizes than one would obtain in a larger undergraduate program. Ongoing data collection will partially ameliorate these limitations through the addition of more study participants, though expanding the study to multiple institutions could also aid in this matter. Results from this study also potentially underestimated the relationship between academic struggle and physics ability beliefs, as students who experienced ongoing academic struggle were undoubtedly more likely to withdraw from a physics course and thus not continue to participate in the study over time. Second, my study employed a correlational design and as such could not assert causal conclusions about the relationship between various factors. Third, there exists a paucity of context-specific survey measures that discern the mechanisms underlying individuals' domain-specific ability beliefs over time. Since the start of this study, another research team (Kalender et al., 2022) published a physics mindset survey that overlaps substantially with the Physics Ability Beliefs Scale. Future work should continue to evaluate and modify domain-specific measurements to ensure that they are best capturing physics ability beliefs. Fourth, ongoing research should consider modifying and expanding the scale used to measure students' perceived recognition and physics identity to include items that operationalize these constructs in ways that move beyond the term *exemplary*, as participants were reluctant to describe themselves as such, which limited its capacity to document variations in these perceptions. Fifth, multilevel modeling does not take into account the potential influence of measurement error, nor does it examine complex relationships between latent and observed variables. The sample size of the present study did not allow for multilevel structural equation modeling, though such a technique would address this limitation. Fifth, the present study surveyed physics majors enrolled in courses that incorporated an interactive instructional approach, but it did not discern how specific components of the approach

influenced students' beliefs, perceptions, and intentions. Lastly, for practical purposes I focused only on relationships among several factors previously posited as influential on physics students' ability beliefs, disciplinary identification, and short-term persistence. I could not capture all variables that influenced the dynamics of these outcomes over time. Much room exists to explore and examine additional factors that shape the students' beliefs, perceptions, and experiences over time.

Practical Implications

The present study illustrates that the intellectual ability beliefs conveyed by physics instructors play a key role in shaping the beliefs, perceptions, and intentions of undergraduate physics majors. When designing and implementing interactive instructional approaches, it is extremely important that instructors critically reflect on their own intellectual belief systems and intentionally foster classroom cultures and structures that support students in perceiving their own physics abilities as malleable with strategic effort (Yeager et al., 2019; Zeeb, Ostertag, & Renkl, 2020). Binning et al. (2020) a classroom activity with documented efficacy in increasing the malleability of students' ability beliefs in college physics contexts. Examination and grading techniques that prioritize students' process over the final answer are beneficial for emphasizing the iterative nature of learning and doing physics (Dweck, 2012; Miller, Kestin, & Miller, 2022; Zeeb et al., 2020). Resources exist for instructors to require students to critically reflect on their feelings and ability beliefs following summative assessments and to make a concrete plan for improvement (FLAMEnet, 2023). Instructors and TAs should also work to normalize the trial-and-error process of learning and doing physics by offering low-stakes opportunities such as the experimental lab activities that allow students to fail without penalty.

Alongside this, it is vital that undergraduate physics programs proactively expand what it means to be an exemplary physics student and a physicist, so that students are more easily able to be recognized by themselves and others as such (Hyater-Adams et al., 2019). Societal representations of physicists commonly depict a lone, socially awkward genius who is typically white and male (Cheryan et al., 2017; Gonsalves & Danielsson, 2020; Leslie et al., 2015). Postsecondary physics spaces have the potential to reshape and expand conceptions of *exemplary* physics students and physicists in ways that embrace diverse ways of thinking, doing, and being (Hyater-Adams et al., 2019; McNeill et al., 2022; Ong et al., 2018). For example, instructors could incorporate lessons into interactive physics courses about the academic and professional journeys of physicists with various social identities, backgrounds, and interests. Physics programs could also host seminar speakers that expose students to the range of skills, approaches, and applications valued by professional physicists. In addition, programs and instructors should actively involve students in fostering learning environments that broaden what success looks like in the discipline. Instructors themselves should also reflect on their own assumptions and biases about what is necessary to be *exemplary* in physics.

My results confirm the central role that a sense of belonging plays in students' persistence intentions in the discipline. At the same time, women, Black, and Latine physics majors faced threats to their ability and social belonging in their interactive physics courses even after taking into account the impact of physics ability beliefs and perceived recognition. Such findings emphasize that increasing diversity, inclusion, equity, and justice in postsecondary physics spaces requires a proactive commitment to disrupting the multitude of oppressive interpersonal, cultural, and structural barriers. For example, literature documents that women and marginalized students of color in STEM are often hesitant to actively participate in interactive

instructional activities due to the increased self-doubt peer exclusion that comes from interacting with peers in white, masculinized learning spaces (Bando et al., 2019; Eddy et al., 2015; Ernest et al., 2019; Reinholz et al. 2022; Setren et al., 2021). Instructors and TAs should structure such activities so that students with marginalized social identities are not singled out or left out of actively engaging in the learning process (Doucette & Singh, 2022). Undergraduate physics programs should also implement lessons and activities that support students and instructors with a diversity of social identities and backgrounds in developing an awareness, understanding, and commitment to ameliorate inequities in the discipline (Byrd, 2022; Byrd, 2023; Arielle-Evans et al., 2019; Dalton & Hudging, 2020; Decker & Daane, 2017; Lock & Hazari, 2016; Watts et al., 2011). Such ongoing, intentional actions are necessary for creating physics learning spaces that allow individuals with traditionally marginalized social identities to comfortable and authentically engage as recognized, competent, and legitimate disciplinary members (Johnson, 2020).

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CHAPTER 4

AN INTERSECTIONAL NARRATIVE EXPLORATION OF THE DISCIPLINARY IDENTITY DEVELOPMENT OF UNDERGRADUATE PHYSICS MAJORS

Over the past 20 years, the number of physics bachelor's degrees awarded annually in the United States has practically tripled (Mervis, 2022). However, this growth trend is not consistent across students with various social identities and backgrounds. Women, Black, Latine, and Indigenous individuals remain perpetually underrepresented and marginalized in postsecondary physics spaces (APS, 2020; Porter & Ivie, 2019). Less is known about the physics representation and experiences of students with various LGBTQ+ identities, disabilities, and socioeconomic statuses, though data documents that LGBTQ+, lower socioeconomic status, and disabled students also experience barriers to inclusion and persistence in the field (Atherton et al., 2016; Barthelemy et al., 2022; Miller-Friedmann, 2020; Traxler & Blue, 2020). Postsecondary physics credentials prepare students for high-paying careers in a number of science, technology, engineering, and mathematical (STEM) sectors, from medical diagnostics to renewable energy development (NRC, 2013). Increasing diversity, inclusion, equity, and justice in undergraduate physics spaces is essential for both broadening access to high-paying STEM careers and improving the discipline of physics as a whole.

To date, most empirical work in physics education research takes a deficit-based lens that characterizes gaps in physics preparation, performance, and attitudes between students with different genders, races, or ethnicities (Traxler et al., 2016). Such a framing fails to acknowledge the ways in which physics educational settings marginalize and exclude students from achieving success and disciplinary membership and places the responsibility on underrepresented students to resolve cultural and structural problems they did not create (McGee, 2020; Nissen et al., 2021;

Traxler et al., 2016). A growing body of scholarship focuses instead on exploring how physics learning environments support or deter the persistence of college students with underrepresented and marginalized social identities, as these environments shape both *who* has access to the field and *what* is necessary to become a physicist (Gonsalves et al., 2014; Hyater-Adams et al., 2019; Johnson, 2020; Kalender et al., 2019b; Li & Singh, 2021; Ong., 2005; Ong, Smith, & Ko, 2018; Rosa & Mensah, 2021).

Disciplinary identity development plays a key role in shaping students' educational persistence and career aspirations in physics (Hazari et al., 2010; Potvin & Hazari, 2013). Physics education researchers commonly define physics identity as being recognized by the self and others as a "physics person," an "exemplary physics student, or a "physicist" (Hazari et al., 2020; Hazari et al., 2010; Potvin & Hazari, 2013). This definition draws from Gee's (2000) work on identity in education, which frames students as having multiple identities, each with varying levels of relevance and salience in different contexts. A wealth of empirical work examines factors that inform and shape the physics identity development of students with various gender, and less commonly racial, and ethnic identities at different academic levels (Hazari et al., 2010; Hazari et al., 2020; Hyater-Adams et al., 2019; Kalender et al., 2019a; Kalender et al., 2019b; Li & Singh, 2021; Potvin & Hazari, 2013; Ong, 2005). This literature emphasizes that factors important for fostering a strong physics identity are not uniformly accessible to students with various social identities (Nespor, 1994). Instead, *who* can achieve internal and external recognition as an exemplary physicist student or a physicist is strongly tied to the sociocultural and structural power relations of the discipline (Avraamidou, 2022; Gonsalves & Danielsson, 2020; Johnson, 2020).

Presently, most research in physics education takes a "single-axis" approach to studying how physics students with marginalized social identities navigate their disciplinary identity development (Crenshaw, 1989, pg. 140; Nissen et al., 2021; Traxler et al., 2016). The majority of literature in this area only considers students' gender, which is generally framed through a binary lens (Traxler et al., 2016). Studies exploring the experiences of women of color often capture individuals' lived experiences without situating them in specific cultural, structural, and institutional contexts (Gayles & Smith, 2019; Metcalf et al., 2018). Very little research takes into account students' sexual orientations, disabilities, and socioeconomic statuses, even though data documents that LGBTQ+, lower socioeconomic status, and disabled students also report lower levels of inclusion in physics (Atherton et al., 2016; Barthelemy et al., 2022; Miller-Friedmann, 2020; Traxler & Blue, 2020). A great need exists for scholarship that applies an intersectional lens to elucidate how physics learning environments support or deter the disciplinary identity development of students with a diversity of marginalized and multiple marginalized social identities (Gayles & Smith, 2019; Johnson, 2020; Metcalf et al., 2018; Traxler et al., 2016).

Intersectionality helps illuminate the reality that individuals with multiple marginalized social identities navigate "interlocking, mutually constructing or intersecting systems of power," which cannot be understood or ameliorated by viewing these identities in isolation (Collins & Bilge, 2016, p. 28). Women of color in physics, for example, face a "cumulative disadvantage" in their disciplinary spaces that stems from the complex dynamics of both sexism and racism within the context of white male dominated spaces (Kachchef et al., 2015, p. 175). While intersectionality first emerged as an instrument of critical praxis for women of color, it has since been applied as both a theoretical framework and an analytic tool to examine and address the ways in which the dynamics of oppression shape the experiences of individuals with multiple

marginalized social identities (Cho et al., 2013; Collins, 2015; Crenshaw, 1991). Taking an intersectional approach to students' experiences in their learning environments captures nuances that would otherwise be left out.

Patricia Hill Collins (2009) provides an ideal framework for applying an intersectional lens to uncover how power is used and abused in a particular postsecondary physics setting (Johnson, 2020). Her Domains-of-Power Framework outlines four distinct yet interrelated domains that together describe the organization of power in a particular context: the interpersonal, the cultural, the structural, and the disciplinary (Collins, 2009; Collins & Bilge, 2016). The *interpersonal* domain organizes power relations at an individual level. Interpersonal displays of power include overt, aggressive messages of inferiority as well as more subtle microaggressions, or slights that convey bias against a marginalized group (Johnson et al., 2017). The *cultural* domain legitimizes existing power relations by uplifting certain values, norms, and traditions as not only important, but "commonsense" (Collins, 2009, p. 302). The *structural* domain manages power relations via social structures and institutions that dictate how power is distributed. The *disciplinary or disciplining* domain enforces power relations through the differential implementation of rules and practices (Collins, 2009). Johnson (2020) recently employed the Domains-of-Power Framework to gather and interpret data on how the power dynamics of a specific undergraduate physics setting constrained or supported the physics identity development of individuals with multiple marginalized social identities. Following her recommendation, the present study applies this framework to explore the lived experiences and physics identity development of undergraduate physics majors with multiple marginalized social identities in major-specific physics courses that incorporate an interactive instructional component.

Interactive Instructional Approaches in College Physics Courses

Traditional lecture-based college physics courses frequently contribute to the marginalization of students by fostering a competitive culture that elevates inherent, exceptional physics abilities over intellectual growth and malleability (Aguilar et al., 2014). Newer interactive instructional approaches exist in part to shift classroom cultures by promoting collaborative engagement, problem-solving, and malleable ability beliefs in college physics courses (NRC, 2013). Existing evidence on the effectiveness of interactive instructional approaches in supporting the inclusion and persistence of college physics students with marginalized social identities is mixed and most research in this area focuses solely on the magnitude of gender differences in academic achievement and 'expert-like' attitudes (Karim et al., 2018; Pollack et al., 2007). When studying the impacts of interactive instructional approaches in physics classrooms, it is important to explicitly investigate not only performance outcomes but also how various aspects of students' course experiences influence their beliefs and perceptions (NRC, 2013). Such insight is necessary in order to discern whether and how courses that incorporate such approaches are reshaping undergraduate physics environments in such a way that promotes diversity, inclusion, equity, and justice in the field (Johnson, 2020).

Purpose of Study

This narrative study explored the lived experiences and disciplinary identity development of undergraduate physics students with various, often intersecting marginalized social identities in major-specific physics courses that incorporated an experimental lab activity. Specifically, I applied Collins' (2009) Domains-of-Power Framework to investigate how students characterized their lived experiences and physics identity development in the context of the interpersonal, cultural, structural, and disciplining dynamics of major-specific physics courses at a large, public,

predominantly white institution (PWI) in the Southeastern United States (referenced to as Southeastern University).

Research Question

How do undergraduates with marginalized or multiple marginalized social identities perceive and interpret their lived experiences and physics identity development in the context of the interacting interpersonal, cultural, structural, and disciplinary power dynamics of major-specific physics courses that incorporate an experimental lab component?

Literature Review

This literature review synthesizes existing research in multiple areas pertinent to the present study. I begin by providing a theoretical and empirical background on science and physics identity development. I then introduce the concept of intersectionality, detail intersectionality's applications as an analytic tool, and introduce Collins' Domains-of-Power Framework. Next, I highlight the need for more scholarship in STEM education that employs an intersectional lens and outline existing research that utilizes an intersectional approach. I end by synthesizing empirical work on how interpersonal, cultural, structural, and disciplining features of undergraduate physics programs shape the experiences and disciplinary identity development of physics majors with marginalized identities.

Physics Identity: A Disciplinary-Specific Science Identity

Over the past several decades, science identity has emerged as a vital psychological component of students' engagement and persistence in various scientific fields (Carlone & Johnson, 2007; Chemers et al., 2011; Eddy & Brownell, 2016; Estrada et al., 2011). Science education researchers commonly root their investigations of the construct in Gee's (2000) definition of identity as "being recognized as a certain kind of person in a given context" (p. 99).

Gee's (2000) conceptualization of identity positions individuals as having multiple identities, each with varying levels of relevance and salience in different contexts (Stets & Burke, 2000; Roccas & Brewer, 2002; Vignoles et al., 2011). He frames these identities as being less connected to a person's "internal states" and more to their "performances in society" and emphasizes recognition from others rather than recognition from the self as central to identity development (Gee, 2000; p. 99). Theoretical extensions of Gee's work revisit this dichotomy and point out that external recognition as a "certain kind of person" is unlikely to influence one's identity if not also accompanied by an internal self-recognition as such (Potvin & Hazari, 2013). Current studies of science identity focus on the dynamics through which students both recognize themselves and are recognized by others in their environment as the *kind of person* deemed legitimate in a particular science discipline (Avraamidou, 2022; Carlone & Johnson, 2007). Internal and external processes of identity recognition are shaped by an interplay of individual, interpersonal, institutional, and sociocultural forces (Brickhouse, 2000; Burke & Stets, 2009; Gee, 2000; Stets & Burke, 2000; Syed et al., 2011; Vignoles et al., 2011). Students possess a degree of agency over their own science identity development (Carlone & Johnson, 2007). At the same time societal structures and scientific learning environments control the extent to which individuals have access to a particular science identity (Brickhouse, 2001). Importantly, while empirical work suggests that a student's science identity is fairly stable in a given time period and context, science identity development is best thought of a trajectory, one that shifts and changes over time and space (Brickhouse, 2000; Hazari et al., 2020; Potvin & Hazari, 2013; Wenger, 1998). In investigating the development of students' science identity, it is thus useful to examine both the micro-level, contextually situated dynamics in which processes of identity recognition occur as well as macro-level, reflexive narrations of students' identity negotiation

(Carlone & Johnson, 2007; Hazari et al., 2020; Potvin & Hazari, 2013). The present study takes the latter approach.

Gender, Race, Ethnicity, & Physics Identity Development

A rich body of literature characterizes factors that influence the general and disciplinary-specific science identity development of students at various academic levels with various social identities (Carlone & Johnson, 2007; Ceglie & Settlage, 2016; Chemers et al., 2011; Estrada et al., 2011; Hazari et al., 2010; Hazari et al., 2020; Hyater-Adams et al., 2019). Given the construct's importance for students' persistence in scientific fields, much work focuses on illuminating the dynamics of science identity development for students with social identities traditionally underrepresented and marginalized in scientific spaces (Brickhouse, 2000; Carlone & Johnson, 2007; Estrada et al., 2011; Gonsalves & Danielsson, 2020; Hazari et al., 2020; Hyater-Adams et al., 2019). Studying the narrated experiences of 15 women college students of color majoring in a scientific discipline over a span of six years, Carlone and Johnson (2007) isolated three interacting dimensions that together promoted a strong science identity - competence, performance, and recognition. The women of color gained competence as they developed a solid foundation in scientific content knowledge through science experiences both in and out of the classroom. Performance allowed for demonstration of their competence at scientific events such as seminars and poster sessions. Recognition involved being explicitly and implicitly acknowledged by themselves and others in their field as a "science person" (p. 1190). Conceptual frameworks specific to physics identity development commonly draw from Carlone and Johnson's (2007) model to examine how students come to see themselves as a "physics person," an "exemplary physics student," and a "physicist" (Hazari et al., 2010, p. 989; Hazari et al., 2020, p. 1593; Potvin & Hazari, 2013). In a recent survey study of the disciplinary identity

development of introductory and upper-level women undergraduate physics majors, Hazari et al. (2020) found that the women's competence and performance in physics collapsed into a single component (competence/performance) that represented their perceptions of their knowledge and skills in physics relative to others in their major. The combined competence/performance factor aligned closer with the notion of academic self-concept, or self-perception of one's abilities, than to students' actual academic performance in physics (Hazari et al., 2020; Shavelson et al., 1976). Women physics students' competence/performance strongly related to the extent to which they felt recognized both externally and internally as an "exemplary physics student." Perceived competence/performance and recognition together influenced women students' self-perceptions as an "exemplary physics student" and as a physicist. In addition, a sense of belonging in physics, or a subjective feeling of connection and legitimacy as a valued member of a physics community, corresponded closely with women's self-reported competence and recognition (Hazari et al., 2020). For upper-level women undergraduates in their sample, a sense of belonging in physics also promoted a physics identity (Baumeister & Leary, 1995; Hazari et al., 2020). In addition, an interest in physics, conceptualized as a "desire or curiosity to think about and understand the discipline," indirectly shaped the women's physics identity through its positive association with both competence/performance and recognition (Hazari et al., 2020, p. 1599). While prior findings suggest that an interest in physics strongly relates to students' decision to pursue a major and a career in the discipline, it makes sense that this factor plays less of a role in differentially influencing college students' physics identity once they have already decided to major in physics (Hazari et al., 2010). Nonetheless, an interest in physics continues to influence women physics majors' perceived competence and recognition in the field (Hazari et al., 2020).

Dissecting factors that influence college students' physics identity development allows for deeper explorations into how students with underrepresented and marginalized identities navigate their disciplinary identity development in their physics learning settings. In white male-dominated fields such as physics and math, women, Black, Latine, and Indigenous students often self-report lower levels of perceived competence than their non-marginalized peers, even when their actual academic performance is quite strong (Goetz et al., 2013; Sax, 1994; Sax et al., 2015). As they advance through school, students with these social identities also commonly show a decline in their interest in physics (Baran, 2016; Kalender et al., 2019a; Kalender et al., 2019b). In addition, students with these marginalized identities commonly report less recognition from others and are also less likely to recognize themselves as a physics person, an exemplary physics student, or a physicist (Doucette & Singh, 2020; Hyater-Adams et al., 2019; Kalender et al., 2019a; Li & Singh, 2021). On top of this, women, Black, Latine, and Indigenous physics students frequently possess a lower sense of belonging in both K-12 and postsecondary physics spaces (AIP, 2020; Banchefsky et al., 2019; Lewis et al., 2016; Lewis et al., 2017; Rainey et al., 2018; Seyranian et al., 2018). These empirical trends emphasize that factors that promote physics identity development are not uniformly available to students with various gender, racial, and ethnic identities (Nespor, 1994). Indeed, *who* can acquire competence, interest, recognition, and belonging in physics is strongly tied to the interpersonal, cultural, structural, and historical dynamics of the field (Avraamidou, 2022; Gonsalves & Danielsson, 2020).

Though it is often framed as being neutral and objective, physics as a discipline was constructed by and for white, middle- and upper-class, cisgender men (Archer et al., 2020a; Traxler et al., 2016). Differential competence, interest, recognition, and belonging reproduces disciplinary norms that position white masculinity as a standard for identification with the

physics community (Avraamidou, 2022; Gonsalves et al., 2014). A growing area of physics education research focuses on how physics students with marginalized social identities negotiate perceived conflicts between their gender, racial, and/or ethnic identities and their developing physics identities (Archer et al., 2020a; Archer et al., 2020b; Gonsalves et al, 2014; Gonsalves & Danielsson, 2020; Irving & Sayre, 2015; London et al., 2011). Most of this work draws on poststructuralist notions of gender to explore how women (and sometimes also men) perform their gender identities as they interact in their physics learning environments (Butler, 1990; Danielsson, 2012; Gonsalves et al., 2014; Gonsalves & Danielsson, 2020). Several scholars have applied a similar poststructuralist lens to examine how women of color perform both their gender and racial/ethnic identities in physics spaces (Jammula & Mensah, 2020; Ong, 2005). Findings suggest that the dynamics of these identity performances are variable and complex (Traxler et al., 2016). White women and women of color adopt a range of strategies to manage their identities as they navigate their physics spaces. Some women intentionally downplay aspects of their gender, racial, and/or ethnic identities to achieve recognition and to fit in as physicists, while others rework what it means to be a physicist in a way that allows for greater internal compatibility between their various identities (Archer et al., 2016; Gonsalves et al., 2014; Ong, 2005). Each of these identity management strategies often require a great deal of work and inner turmoil on behalf of the individual. They place the onus on marginalized students to assimilate into existing physics cultures and structures rather than changing physics environments themselves (Archer et al., 2016; McGee, 2020). The present study seeks in part to isolate specific features and structures of physics learning environments that reduce the need of such students to spend time managing these identities in the first place (Rosa & Mensah, 2021; Ong et al., 2018; Wright & Riley, 2020).

Sexual Orientation, Disability, Socioeconomic Status, & Physics Identity Development

To date, comparatively little research has investigated how physics learning environments shape the disciplinary identity development of students with not only marginalized gender, racial, and ethnic identities but also various sexual orientations, abilities, and socioeconomic statuses. Such insights are important, as data documents that LGBTQ+, lower socioeconomic status, and disabled students report greater exclusion and lower levels of belonging and persistence in physics than their peers (Atherton et al., 2016; Barthelemy et al., 2022; Miller-Friedmann, 2020; Traxler & Blue, 2020). A need exists for scholarship that applies an intersectional lens to elucidate how physics learning environments support or deter the disciplinary identity development of students with multiple marginalized social identities (Gayles & Smith, 2019; Metcalf et al., 2018).

Intersectionality

Intersectionality provides a powerful theoretical and analytical tool for understanding how students with multiple marginalized identities experience various aspects of their physics learning environments in ways that support or inhibit their physics identity development (Gayles & Smith, 2019; Johnson, 2020; Metcalf et al., 2018). The concept of intersectionality emerged from social activist movements in the United States led by Black, Chicana, Latina, Asian-American, and Indigenous women in the 1960s-1980s (Collins, 2015; Collins & Bilge, 2016). Grassroots community organizers recognized that liberation from oppressive forces could not be achieved by focusing on categories such as gender, race, and class alone. Social inequalities stemmed from "mutually constructing systems of oppression of race, class, gender, and sexuality," though mainstream feminist and antiracist social movements largely erased the intersectional realities and needs of women of color (Collins, 2015, p. 8; Collins & Bilge, 2016).

Black, Chicana, Latina, Asian-American, and Indigenous women's movements of the 1960s-1980s sought not only to highlight the unique, situated experiences of women with multiple oppressed identities, but to empower women of color through individual and collective agency (Collins & Bilge, 2016). Legal scholar and advocate Kimberly Crenshaw later coined the term *intersectionality* to illuminate how existing cultural responses and social structures failed to address violence against women of color (Crenshaw, 1989, 1991). While it remains an instrument of critical praxis, intersectionality has since been applied extensively in numerous fields as both a theoretical framework and an analytic tool to examine and address the complex ways in which systems of power and oppression contextually situate and constrain the experiences of individuals with multiple marginalized social identities (Cho et al., 2013; Collins, 2015; Crenshaw, 1991).

Intersectionality as an Analytic Tool

Collins and Bilge (2016) outline six core principles that guide intersectionality's application as an analytic tool. The first core principle centers the need to understand and ameliorate complex social inequalities caused by the oppression of individuals and groups with interacting social identities such as race, gender, and sexuality. The second principle highlights the ways in which "race, class, gender, sexuality, age, disability, ethnicity, nation, and religion, among others, constitute interlocking, mutually constructing or intersecting systems of power" (Collins & Bilge, 2016, p. 28). Intersectional analyses explore the ways power relations develop and function between different forms of oppression (such as racism, sexism, and classism). In addition, they consider how power is organized within different domains of a society (Collins, 2009; Collins & Bilge, 2016). The third principle, relationality, favors "both/and" over "either/or" thinking and emphasizes connections between different entities such as racism and

sexism and theory and practice rather than solely considering differences. The fourth core principle involves situating intersectional analyses in the specific socio-historical contexts of a population being studied (Collins & Bilge, 2016). The fifth principle encourages researchers to embrace the inherent complexity of intersectional scholarship. The sixth and final core principle promotes intersectional analysis as a tool for social justice work that challenges societal inequalities and systems of oppression. Collins and Bilge (2016) stress that these six core principles are not uniformly present across scholarly work that applies intersectionality as an analytical tool, but that they together serve as "guideposts" for intersectional scholarship (p. 27).

The Domains-of-Power Framework. Collins' work offers further insight and guidance into how an intersectional lens can be applied to understand how power is organized in a particular setting or society. In her seminal book, *Black Feminist Thought*, she argues that power in a given setting can be thought of as an "intangible entity that circulates within a particular matrix of domination and to which individuals stand in varying relationships" (p. 292). Collins then introduces and outlines a Domains-of-Power Framework to distinguish four different yet interrelated domains that together describe the organization of power in a particular context: the interpersonal, the cultural, the structural, and the disciplinary (Collins, 2009; Collins & Bilge, 2016).

The *interpersonal domain* deals with everyday interactions between individuals who, due to their various social identities, are "differentially position[ed]" to hold and express power in an environment (Collins, 2009; Collins & Bilge, 2016, p. 16). Daily interpersonal displays of power include overt, aggressive messages of inferiority as well as more subtle microaggressions, or slights that convey bias against a marginalized group (Johnson et al., 2017). While they can be intentional, they are often unconscious and so commonplace that they go unnoticed by

individuals in advantaged positions (Collins, 2009). Regardless of their conscious intention, interpersonal displays of power have important consequences. The *cultural domain* concerns the power that comes with whose values, norms, and traditions are viewed as important and legitimate. As Collins (2009) describes, "to maintain their power, dominant groups create and maintain a popular system of "commonsense" ideas that support their right to rule" (p. 302). The *structural domain* relates to how social structures and institutions dictate how power is distributed (Collins, 2009; Collins & Bilge, 2016). In the United States, social institutions such as legal, housing, banking, and educational systems, as well as the media, collectively subjugate and disenfranchise individuals and groups with intersectionally marginalized social identities. Collins (2009) elaborates that in an era of color-blind racism, social institutions enforce oppression in part by denying that structural racism exists in a post-Civil Rights America. The *disciplinary or disciplining domain* pertains to how rules and practices are differentially implemented and enforced for various individuals and groups in an organization or institution (Collins, 2009). Collins and Bilge (2016) elaborate, "power operates by disciplining people in ways that put [their] lives on paths that make some options seem viable and others out of reach" (p.16).

The four domains described above work together to coordinate power relations in a given setting. The structural domain organizes power, the disciplining domain enforces it, the cultural domain legitimizes it, and the interpersonal domain expresses it at an individual level (Collins, 2009). Together, the "particular contours of each domain of power illustrate how intersecting oppressions of race, class, gender, sexuality, and nation are organized in unique ways" (Collins, 2009, p. 294). Importantly, while the Domains-of-Power Framework provides a useful analytic tool for examining intersectional dynamics of oppression, it can also be used to highlight

instances of resistance and empowerment that challenge existing power relations within and across domains (Collins, 2009). The sections below discuss the application of intersectionality as an analytic tool in STEM education research and expand on the utility of Collins' (2009) Domains-of-Power Framework as a lens for exploring how power is organized, enforced, and contested in postsecondary physics settings (Johnson, 2020).

Intersectionality as an Analytic Tool in STEM Education Research

Despite its theoretical and practical significance, intersectionality remains an underutilized tool in STEM education research (Gayles & Smith, 2019; Metcalf et al., 2018). Quantitative studies frequently take a "single-axis" approach to social identity, considering factors such as gender, race, and ethnicity only as separate variables (Crenshaw, 1989, pg. 140; Nissen et al., 2021; Traxler et al., 2016). Qualitative inquiries often capture individuals' lived experiences without situating them in classroom, departmental, disciplinary, and institutional power structures (Gayles & Smith, 2019; Metcalf et al., 2018). Metcalf et al. (2018) surveyed literature related to diversity, equity, and inclusion in STEM and found that very little research included an intersectional perspective. They argue that dominant analytical approaches in STEM education research act to further exclude multiple marginalized students in STEM and point to the need for future inquiries that avoid exclusionary pitfalls. Traxler et al. (2016) offer similar critiques of scholarship in physics education research. Empirical work in this field commonly frames gender as a discrete, static category and places the performance, attitudes, and beliefs of male physics students as a standard that women should strive to match. Intersections such as race, ethnicity, class, sexuality, ability, and nation are often absent entirely from analyses (Traxler et al., 2016). The authors stress the need for more physics education research that

acknowledges the complex, intersectional, contextually situated dynamics of marginalized students' social identities.

In the last few decades, multiple scholars have applied intersectionality as an analytic tool for exploring the marginalization of women of color in STEM (Akudo et al., 2022; Fries-Britt & Holmes, 2012; Johnson, 2017; Johnson, 2020; Kachchaf et al., 2015; Ko et al., 2014; Leyva, 2022; Ong et al., 2005; Ong et al., 2018; Quichocho et al., 2019; Rosa & Mensah, 2016; Santana & Singh, 2022; Schipull et al., 2019). Ong (2005) interviewed a group of 10 women of color in physics annually about both their experiences and aspirations and their perceptions of gender and race in their field. She later narratively analyzed how the women of color navigated the fact that their gender and race placed them outside of sociocultural notions of "ordinary scientists" (p. 596). Kachchaf et al. (2015) used narrative inquiry to explore the career-life balance of three women of color at different points in their professional journeys in physics, math, and engineering. Using an intersectional lens, they analyzed how the women of color's multiple marginalized identities placed them outside of the "ideal worker norm" in their respective fields through processes of "cumulative disadvantage" (p. 175). Ko et al. (2014) employed a narrative analysis of interviews with 22 women of color in physics and astronomy to isolate specific interpersonal strategies that they undertook at their postsecondary institutions to achieve agency despite their marginalization. Rosa & Mensah (2016) explored the lived experiences of six Black women physicists to learn about the strategies and structures that supported their persistence over time. Ong et al. (2018) interviewed 39 undergraduate and graduate women of color in STEM about the availability and utilization of *counterspaces*, physical, relational, or ideological spaces in which they could be valued and seen, in their STEM departments. Quantitative intersectional analyses are difficult to conduct in postsecondary physics environments due to the small size of

most physics programs and the small number of students with multiple marginalized identities, thus necessitating the use of larger datasets collected from multiple institutions to account for lack of diversity in physics majors (Nissen et al., 2021). Nissen et al. (2021) drew from a large national dataset to quantitatively analyze how undergraduate student attitudes about learning physics vary based on their racial, ethnic, and gender identities. Taking a social justice lens, they argued that white male physics students on average held more "expert-like" physics attitudes due to the discipline's legacy of racism and sexism, which creates a narrow definition of who can be considered an "expert" in the field (p. 010116). While these studies draw valuable insights into the experiences of women of color in physics settings, most focus more on interpersonal dynamics rather than on how departmental and classroom cultures, structures, and disciplinary practices influence the overarching power dynamics in such settings. In addition, most do not include how students' other identities such as class, sexual orientation, and nationality factor into their physics experiences.

Johnson (2020) recently applied the Domains-of-Power Framework to gather and interpret data about how the power dynamics of a postsecondary physics setting constrained or supported the physics identity development of individuals with marginalized and multiple marginalized identities. She used the four domains of power detailed in Collins' (2009) framework as a guide for constructing her sample, deciding her research methods, generating her interview questions, conducting her data analysis, and forming her conclusions. The author interviewed six undergraduate women (three of whom were women of color) in a single physics department about their "life story in physics" and attended a major-specific physics course to probe students about their experiences in their physics major. In addition, the author interviewed four physics faculty members about their individual approaches to teaching and supporting

students as well as their perceptions of their department and institution's philosophy and actions (Johnson, 2020). In analyzing this data, Johnson (2020) focused on both how students and faculty conceptualized their own physics identity and how the four interrelated domains of power dictated who was able to belong in and identify with the physics department in question. The current study followed Johnson's (2020) recommendation to employ this framework to explore the intersectional, situated dynamics of physics identity development. The following sections synthesize existing literature on how interpersonal, cultural, structural, and disciplining features of undergraduate physics programs shape the experiences and disciplinary identity development of physics majors with marginalized identities.

The Interpersonal Domain. The dynamics of interpersonal interactions in postsecondary physics spaces play an important role in shaping the lived experiences and disciplinary identity development of women, Black, Latine, Indigenous, LGBTQ+, and disabled students (Doucette et al., 2020a; Johnson, 2020; Laws et al., 1995; Mujtaba & Reiss, 2013; Seymour & Hunter, 2019; Traxler & Blue, 20202; Whitten et al. 2003). As described earlier, both a sense of belonging and positive recognition from peers and instructors as a physics person stand out as key components of physics identity development (AIP, 2020; Carter et al., 2019; Fries-Britts et al., 2010; Hazari et al., 2017; Hazari et al., 2020; Kalender et al., 2019a; Li & Singh, 2022; Rodriguez et al. 2019). At the same time, empirical work documents that women, Black, Latine, Indigenous, and LGBTQ+ students frequently report feelings of exclusion and isolation in their physics learning environments that stem in large part from negative interactions with their faculty, mentors, and peers (AIP, 2020; Atherton et al., 2016; Barthelemy et al., 2016; Bjorkquist et al., 2019; Doucette et al., 2020a; Johnson et al., 2017; Traxler & Blue, 2020). Given both the low number of individuals with these identities in physics and pervasive cultural stereotypes about who is

capable of success the field, students in these groups are perpetually aware of situational cues that threaten the legitimacy of their presence in physics settings (Cheryan et al., 2009; Boucher & Murphy, 2017; Hughes et al., 2015; Lewis et al., 2017; Walton & Cohen, 2007). As Hazari et al. (2017) point out, "[positive] recognition acts as an artifact of the power dynamics in a community" (p. 96).

The Role of Instructor Inclusivity. In an extensive investigation into factors that promote or deter the persistence of undergraduates in various STEM majors, Seymour and Hunter (2019) isolated unapproachable and unsupportive instructors as a prominent reason for students' decisions to switch out of STEM. Accessible, supportive instructors, on the other hand, repeatedly show up as key components of students' persistence across STEM fields (Seymour & Hunter, 2019; Johnson, 2020; Whitten et al., 2003; Whitten et al., 2007). While negative instructor interactions deterred students with a diversity of identities, Seymour and Hunter (2019) determined that they had an outsized impact on the persistence of women, Black, Latine, and Indigenous individuals. Work suggests that the mechanisms behind this trend may relate to such instructors explicitly and implicitly conveying messages about who can succeed and belong in STEM fields (Clark et al., 2021; Cheryan et al., 2013; Doucette et al., 2020a; LaCosse et al., 2020; Rattan et al., 2018). Oppressive societal stereotypes unjustly position women, Black, Latine, and Indigenous individuals as less intellectually talented than their male, white, and Asian peers (Bian et al., 2018; Leslie et al., 2015; Storage et al., 2016). Such stereotypes promote bias against these individuals in disciplinary settings that emphasize innate brilliance over dedication and hard work (Leslie et al., 2015). Negative intelligence stereotypes can also lead women, Black, Latine, and Indigenous individuals to question their own capacity to succeed, belong, and persist in brilliance-focused fields such as physics and math (Bian et al., 2018; Dar-

Nimrod & Heine, 2006; Leslie et al., 2015; Murphy & Zirkel, 2015; Steele et al., 2002). Empirical work documents that Black, Latine, and Indigenous students receive significantly lower grades than white and Asian students in STEM courses with instructors who view intelligence as innate and unchanging (Canning et al., 2019). Women in physics are also quite in-tune to cues from their instructors that enforce or challenge negative intelligence stereotypes about women in science and math (Hazari et al., 2015). LaCosse et al. (2020) observed that women anticipate significantly worse course experiences from instructors who they perceive endorse fixed beliefs about intelligence than do their male peers. Indeed, the impact of negative stereotypes about women's intelligence on physics performance is so pronounced that Marchand & Taasoobshirazi (2012) found that their detrimental effect only disappears when physics instructors explicitly inform students before taking an assessment that prior findings show no gender differences in test results.

Gender-Based Interactions. In male-dominated fields such as physics, female-identified students report a range of negative, gender-based interpersonal interactions, which range from microaggressions to overt sexism, harassment, and discrimination that together keep them from feeling a sense of safety and belonging in their classrooms and labs (Aycock et al., 2019; Bjorkquist et al., 2019; Gonsalves et al., 2016; Johnson et al., 2017; Settles et al., 2006). A recent survey of undergraduate women in physics revealed that 74.3% had experienced at least one type of sexual harassment while in a physics setting (Aycock et al., 2019). Barthelemy et al. (2016) interviewed 21 women completing graduate programs in physics and astronomy about their disciplinary-specific experiences and interactions. Sixteen (76%) of the women described experiencing gender-based microaggressions from their peers and instructors within their graduate programs. Gendered microaggressions included sexist language, objectification,

isolation, and assumptions of intellectual inferiority (Barthelemy et al., 2016). Five women reported instances of hostile sexism and sexual harassment. These negative interactions prevented the women from "interacting with physics or astronomy as full participants" and thus acted as a tool for maintaining oppressive interpersonal power relations in these respective disciplines (Barthelemy et al., 2016, p. 020119-11).

Multiple scholars have examined the gendered dynamics of group work in undergraduate physics classroom and lab settings (Alexopoulou & Driver 1996); Danielsson, 2012; Day et al., 2016; Doucette et al., 2020a; Doucette et al., 2020b; Johnson et al., 2020; Laws et al., 1995). Doucette et al. (2020b) observed that during introductory college physics labs, women commonly adopted one of two peer group roles: the "Secretary archetype" or the "Hermione archetype" (p. 035702-1). Women who adopted the "Secretary archetype" took on the role of their group's recorder and data analyzer, while those who adopted the "Hermione archetype" took on the role of their group's manager. Women in each of these roles had less of an opportunity to engage directly with the experimental aspects of their lab, a result that mirrors findings by other researchers (Day et al., 2016; Doucette et al., 2020b). Indeed, other work by Doucette et al. (2020a) suggests that women report significant gains in physics self-efficacy, or belief in their ability to achieve a desired outcome, when lab partners participate equally in various components of a lab rather than delegating specific tasks to various group members (Bandura, 1986).

Race & Ethnicity-Based Interactions. Positive faculty and peer interactions are important in supporting the postsecondary experiences and trajectories of Black, Latinx, and Indigenous physics students (AIP, 2020; Fries-Britt et al., 2010; Ong et al., 2018). At the same time, negative faculty and peer interactions are also exceedingly common for racially and

ethnically minoritized students in physics spaces (AIP, 2020; Fries-Britts et al., 2010; McGee, 2016). Negative interactions create hostile, isolating learning environments that deter Black, Latine, and Indigenous students from seeing themselves as physicists and persisting in the field over time (AIP, 2020; Castellanos, 2018). Studies exploring the experiences of Black and Latine physics undergraduates reveal that such students face microaggressions, negative intelligence stereotypes, a lack of recognition, and other forms of racial and ethnic hostility and discrimination from their instructors, mentors, and peers (AIP, 2020; Carter et al., 2019; Fries-Britt & Holmes, 2012; Hyater-Adams et al., 2018; McGee, 2016; Rodriguez et al. 2019). Importantly, while negative faculty and peer interactions are more prevalent at predominantly white institutions, physics departments at minority-serving institutions can and do transmit exclusionary messages as well, particularly as plenty of faculty members at these institutions are not themselves from underrepresented racial and ethnic groups (McGee, 2016). In physics departments at predominantly White institutions, underrepresented students of color must also contend with marginalization by their college or university as a whole (Dortch & Patel, 2017; Walton & Cohen, 2007).

***Gender, Race, & Ethnicity-Based Interactions*.** Research documents that Black, Latine, and Indigenous women in physics commonly experience particularly high amounts of interpersonal racism and sexism in the form of microaggressions, stereotype threat, and exclusion from their peers, instructors, and colleagues (Akudo et al., 2022; Avraamidou, 2022; Fries-Britt & Holmes., 2012; Johnson et al., 2017; Ko et al., 2014; Rosa & Mensah, 2016). Given their small numbers in many STEM programs, underrepresented women of color frequently describe intense isolation that comes from feeling both ignored and hyper-visible (Johnson et al., 2017; Santana & Singh, 2022). Discerning the disciplinary narratives of six Black female

physicists, Rosa and Mensah (2016) found that most felt excluded from their graduate study groups, which they described as limiting their social integration into their programs. Akudo et al. (2022) recently analyzed the dynamics through which undergraduates negotiated roles in a physics lab. They observed that the one Black woman in the lab group was excluded by her male and female peers from actively engaging in the lab work (Akudo et al., 2022). In other words, women of color often navigate numerous interpersonal assaults that challenge their place and detract them from focusing on learning in their physics environments (Santana & Singh, 2022).

For many women of color, acknowledgement from family and community as a competent physics person offers a positive source of recognition and identity development (Avraamidou, 2022). At the same time, explicit and implicit recognition from established members of the physics community remains key for both disciplinary identity development and persistence (Avraamidou, 2022). In a qualitative, longitudinal analysis exploring the "politics of recognition" in physics settings, Avraamidou (2022) determined that, particularly for women of color, recognition as a physics person is far more dynamic and variable than it is often represented in the literature (p. 58). Women of color in physics' perceived external and internal recognition as a physics person can vary considerably over time as they interact with others in and outside of their physics learning spaces (Avraamidou, 2022).

LGBTQ+-Based Interactions. Until recently empirical work exploring the experiences of LGBTQ+ physics students and professionals were largely absent from the literature (Atheron et al., 2016; Barthelemy, 2020; Feder, 2022; Barthelemy et al., 2022; Quichocho et al., 2019). Two recent studies analyzed a survey of 324 LGBTQ+ physicists at the undergraduate level and up about their experiences, perceptions, and persistence in physics settings (Barthelemy, 2020; Barthelemy et al., 2022). While most respondents felt comfortable in their physics environment,

22% reported that they were excluded or harassed in the past year and 36% had considered leaving their institution (Barthelemy et al., 2022). Forty-nine percent of transgender physicists experienced exclusion or harassment, and transgender physicists of color reported the highest rate of exclusion (Barthelemy et al., 2022). Analysis of open-ended survey responses revealed that individuals most commonly were excluded for being a woman or for their gender expression (Barthelemy, 2020). Individuals who experienced or observed exclusionary behavior were more likely to consider leaving. On average, LGBTQ+ men felt more comfortable in their physics environments than LGBTQ+ women or non-binary physicists. LGBTQ+ physicists who could be out felt more comfortable than those who remained closeted (Barthelemy et al., 2022).

Literature documents that LGBTQ+ physicists of color encounter negative interpersonal interactions at particularly high rates. Atheron et al. (2016) determined that LGBTQ+ physicists of color report feeling excluded from spaces meant for each of their marginalized identities. In a recent case study, two Black queer STEM students in an introductory physics class described feeling hyper-visible due to their race, uncertain of their due to negative intelligence stereotypes, and unsure as to whether their instructors felt biased against them (Leyva, 2022). Both Black queer students in the study hid their LGBTQ+ identities in the classroom in an attempt to reduce the extent of their oppression. Leyva (2022) and others emphasize the importance of actively fostering positive, inclusive environments for LGBTQ+ physicists with various racial and ethnic identities (Feder, 2022; Barthelemy et al., 2022).

The Cultural Domain. In 1988, anthropologist Sharon Traweek published an extensive ethnographic study of several prominent high energy physics laboratories in the United States and Japan. She ended her account with a description of how the physicists she interacted with over the course of her study positioned their discipline as existing in an “extreme culture of

objectivity: a culture of no culture" (p. 162). Other scholars have also discerned that both students and practitioners of physics often perceive the field as being removed from the subjectivities and biases that infiltrate other disciplines (Archer et al., 2016; Due, 2012; Hughes, 2001; Gonsalves et al., 2014; Traxler et al., 2016).

Framing physics as existing outside of culture serves as a tool for maintaining power relations in physics spaces. Physicist and Black feminist scholar Chanda Prescod-Weinstein (2020) coined the term *white empiricism* to describe "the phenomenon through which only white people (particularly white men) are read as having a fundamental capacity for objectivity," which makes them the only 'legitimate' practitioners of physics (p. 421). In discussing the systematic exclusion of women from scientific fields, feminist scholar Evelyn Fox Keller similarly described how binary notions of gender and cultural alignments of masculinity, objectivity, and rationality together position women as "inauthentic" practitioners of science (Keller, 1985, p. 174). At the same time, physics' purported "culture of objectivity" serves to invalidate instances of oppression brought to light by marginalized members of the field (Prescod-Weinstein, 2020; Traweek, 1988, p. 162). "In this context it's not surprising that many of us experience physics, as a social environment, to be fundamentally empathy-deficient," Prescod-Weinstein writes (Prescod-Weinstein, 2021).

Along with being known for its "culture of no culture," the discipline of physics is widely regarded as being the hardest and most intellectually elite scientific field (Archer, 2020a; Cheryan et al., 2017; Frances et al., 2017; Hughes, 2001; Traweek, 1988, p. 162). Societal notions of physicists conjure images of the lone, socially awkward genius, and members of the discipline themselves tend to identify a high innate intelligence as a prerequisite for success in the field (Cheryan et al., 2017; Gonsalves & Danielsson, 2020; Leslie et al., 2015). This *cultural*

of brilliance systematically excludes individuals with social identities that are stigmatized by negative intelligence stereotypes (Bian et al., 2018; Storage et al., 2016).

Empirical evidence documents that physics' dominant cultural dynamics perpetuate the marginalization of women and Black, Latine, and Indigenous individuals in physics environments at all levels, in part through dictating *who* society allows to be recognized for the traits deemed necessary to succeed in and identity with physics (Bjorkquist et al., 2019; Fries-Britt et al., 2010). Interviewing seven young women who expressed an interest in physics on a biannual basis over the course of five years, Archer et al. (2020a) found that, despite their objective academic success, most did not view themselves as naturally "clever enough" to continue in the discipline (p. 15). Even the one young woman in their study who decided to major in physics in college did not view herself as an "effortlessly clever physicist" (p. 18). Men who expressed an interest in physics at a young age, on the other hand, were encouraged to embrace their "cleverness" and "geekiness" (Archer et al., 2016; Archer et al., 2020b). Gender norms position women who persist in physics as "exceptional" (Archer et al., 2020a, p. 2). Even when they persist in physics, women commonly experience *imposter syndrome*, a psychological phenomenon that leads one to question whether they are qualified or competent enough to succeed in a role (Lavender, 2013). Cultural notions of the prototypical physicist commonly lead women in physics to consciously and unconsciously manage their femininity to gain recognition as legitimate, competent physicists (Gonsalves et al., 2014; Gonsalves et al., 2016). Importantly, physics' alignment with masculinity can also discourage men and non-binary individuals who do not self-identify with stereotypically masculine traits such as competitiveness (Connell & Messerschmidt, 2005; Feder, 2022).

While most existing scholarship on the culture of physics focuses solely on gender, several researchers have examined its effect on the experiences and disciplinary identity of women of color. Kachchaf et al. (2015) conducted a narrative study that explored the career-life balance of women of color in physics, math, and engineering. They determined that both gender and race/ethnicity alienated the women of color from their fields' "ideal worker norm" and in doing so presented them with a "cumulative disadvantage" in their physics career. This cumulative disadvantage took the form of exclusion from professional and peer networks and a regular questioning of competence (Kachchaf et al., 2015, p. 175). In an ethnographic study that followed 10 Black, Latine, and Indigenous women majoring in physics during and after their college experience, Ong (2005) observed that, regardless of their level of academic success, the women physicists of color remained perennially aware of how others in their physics community perceived them. Throughout their experience in college and beyond, they were hyperalert to cues that threatened their perceived competence and legitimacy as a "physics person." To manage conflicts between their gender, racial, ethnic, and physicist identities, some women of color in Ong's study attempted to "separate their gendered and racial selves from their scientist selves" to conform as much as possible to the ordinary physics person (p. 600). Other women of color intentionally displayed all their identities and doing so "rejected the ordinary scientist image in favor of a new ideal that consolidates seemingly conflicting gender, racial/ethnic, and scientist identities" (p. 600). This later tactic was not always well-received by established members of the physics community and sometimes led to further exclusion and negative recognition (Ong, 2005).

In the past year, several scholars have called for a *queering* of physics' epistemologies by "recreating physics as a domain that cultivates epistemic diversity" (McNeill et al., 2022, p. 18;

Phillips et al., 2022). Fostering *epistemic diversity* involves accepting the biases and subjectivities present in the field's dominant ways of thinking, welcoming and encouraging different approaches to solving problems, and valuing the diverse perspectives and experiences that individuals with different social identities and backgrounds bring to the discipline (McNeill et al., 2022). As McNeill et al. (2022) point out, "cultivating classroom environments that resist epistemological assimilation are necessary to actualize equity within physics classrooms" (p. 20).

Johnson's (2020) recent ethnography of a physics department presents a localized physics culture that challenges the dominant norms of the field. Through interviewing and observing undergraduate physics students and instructors, she found that the department emphasized that success in physics entailed being "collaborative and working hard" as well as being "curious and engaged" (p. 69). These localized cultural norms helped to foster competence, recognition, and belonging among students with various gender, racial, and ethnic identities. Studying the physics identity perceptions of women of color and LBGT+ women physics majors at a Hispanic Serving Institution, Quichocho et al. (2019) similarly observed that the students and faculty "reject[ed] common stereotypes" of "physicists as white, cisgender, heterosexual male geniuses" and instead framed a physicist as someone who does physics (p. 492). Such findings suggest even localized cultural shifts in physics can help reframe *who* has access to a disciplinary identity in the field.

The Structural Domain. Structures within the K-12 STEM education system in the United States act to marginalize women, Black, Latine, Indigenous, disabled, and lower socioeconomic status students long before they even reach college. Data from the American Physics Society shows that while the proportion of girls in high school physics classes has increased overall in the last 30 years, girls remain less likely to take advanced physics courses in high school than boys (APS, 2011). In addition, Black, Latine, and Indigenous students are less

likely to take physics in high school than white and Asian students (AIP, 2015; AIP, 2019). Physics and calculus courses are less likely to be offered in high schools with high numbers of Black, Latine, and Indigenous students and in high schools that serve lower socioeconomic status students (AIP, 2015; Office for Civil Rights, 2018). On top of this, women, Black, Latine, Indigenous, and lower socioeconomic status students are less likely to have access to informal K-12 physics learning opportunities. Differences in K-12 physics and math preparation play a prominent role in the achievement gaps often found on standardized conceptual assessment (Kost et al., 2010; Kost et al., 2009; Salehi et al., 2019). In addition, Hasse (2002) observed that women in undergraduate physics labs often feel less comfortable tinkering with experimental materials due to their lower exposure to physics-related play as children. Lastly, as a result of the existing demographic makeup of the STEM workforce, women, Black, Latine, Indigenous, and lower socioeconomic status students are less likely to gain a strong STEM-related social or cultural capital (tangible and ideational resources beneficial in a STEM path) from family and/or community members (Archer et al., 2015; Gonsalves, 2021).

College Physics Course Structures. Once students enter college, they often encounter introductory STEM courses that are structured to *weed out* students who do not possess characteristics traditionally framed as important for success in STEM majors (Mervis, 2011; Sax, 1994). Weed-out courses are unnecessarily difficult and time-consuming. They promote a survival-of-the-fittest atmosphere that encourages competition among students to prove their intellectual talent (Seymour and Hunter., 2019). These courses largely blame students for the academic challenges that they encounter and provide limited guidance for helping them navigate material (Seymour and Hunter, 2019). College students who leave STEM majors identify highly competitive, individualistic, unsupportive classroom climates as a reason for their decision to

switch (Seymour and Hunter, 2019). Research documents that weed-out courses are damaging to the learning and engagement of STEM students with a range of social identities and backgrounds (NRC, 2013; Mervis, 2011). Such courses are particularly detrimental to the persistence of women, Black, Latine, Indigenous, disabled, and first-generation college students (Sanabria & Penner, 2017; Salty, Gorbernatz, and Close, 2022; Seymour & Hunter 2019; Thompson, 2019). Women and first-generation college students who perform poorly in introductory STEM courses, for example, are more likely to subsequently switch to majors outside of STEM than men and students from college-education families (Sanabria & Penner, 2017; Thompson, 2019). As described previously, negative intelligence stereotypes can spur elevated instances of bias, exclusion, and self-doubt in environments that promote competition and frame high intellectual ability as necessary for success and belonging (Bian et al., 2018; Rattan et al., 2018). On top of this, women, Black, Latine, Indigenous, and first-generation college students are more likely than their White, Asian, male, and non-first-generation peers to enter college with less K-12 STEM preparation and thus face a steeper initial learning curve in undergraduate STEM courses (Seymour & Hunter, 2019). The competitive, individualistic atmosphere of weed-out courses intensifies the impact of negative intelligence stereotypes and differential K-12 preparation on the persistence of women, Black, Latine, Indigenous, and first-generation college students by suggesting that only a select few students possess "what it takes" to thrive in STEM (Mervis, 2011).

Traditional modes of postsecondary physics instruction follow a lecture-based model that positions students as predominantly passive recipients of established knowledge (NRC, 2013). In such settings, physics instructors present concepts and examples while students take notes and attempt structured practice problems. Recitation and laboratory sessions that typically

accompany traditional introductory physics courses tend to conform to a similarly prescribed format in which students tightly follow predetermined protocols to solve problems and carry out experiments (Etkina & Murthy, 2006; NRC, 2013; Wilcox & Lewandowski, 2016). Decades of empirical research documents the limitations of this traditional lecture-recitation-laboratory format in fostering the development of students' quantitative reasoning, conceptual understanding, experimental skills, and positive attitudes toward physics (Etkina & Murthy, 2006; Hake, 1998; NRC, 2013; Redish et al., 1998; Wilcox & Lewndowski, 2016). Empirical work supports that this instructional format helps to fuel the competitive weed-out classroom cultures that contribute to marginalization in physics spaces (NRC, 2013).

In response to the shortcomings of the traditional lecture-recitation model, physics education researchers have increasingly developed and implemented interactive instructional approaches in college physics classrooms (NRC, 2013). While they vary in structure, scope, and practice, these approaches seek to enhance students' cognitive and affective growth by employing collaborative engagement techniques that support their scientific thinking, problem solving, and metacognition capabilities (Freeman et al., 2014; Karim et al., 2018; NRC, 2013; Theobald et al., 2020). As students engage in these interactive learning endeavors, they receive timely, scaffolded instructor and/or peer feedback that guides and supports them in achieving learning goals (Karim et al., 2018). Examples of such approaches include Peer Instruction (PI), which incorporates electronic clicker questions and small-group discussions into lectures (Mazur, 1997), Modeling Instruction (MI), in which students create models to explore and represent concepts (Brewe et al., 2010), and SCALE-UP, which restructures standard lecture halls into rooms with small tables at which students participate in collaborative learning activities related to the topic at hand (Beicher & Saul, 2003). Another established interactive

approach, the Investigative Science Learning Environment (ISLE), focuses heavily on exposing physics students to the process of learning science through *doing* science (Etkina & Murthy, 2006). This specific approach provides students with scaffolded opportunities to collaboratively construct and test hypotheses, analyze data, and generate conclusions on topics relevant to the physics course at hand (Etkina & Murthy, 2006). A central goal of the ISLE is to "empower" students to think and reason through problems like experimental physicists and in doing so learn to effectively persevere through academic challenges using strategic trial-and-error (Etkina et al., 2021, p. 10).

Evidence suggests that interactive instructional approaches benefit college physics students' academic performance, attitudes, and beliefs (Freeman et al., 2014). Over the past few decades, a number of physics education researchers have explored whether these approaches might serve as a tool for increasing the persistence of physics students with marginalized identities (Karim et al., 2018; Lorenzo et al., 2006; Pollock et al., 2007; Rodriguez et al., 2016). To date, most studies in this area focus on whether various interactive approaches narrow the "gap" in standardized conceptual assessment scores, exam grades, and course passing rates between marginalized and non-marginalized students (Brewe et al., 2010; Karim et al., 2018; Lorenzo et al., 2006; Maries et al., 2020; Pollock et al., 2007). Existing evaluations concerning the effectiveness of interactive physics pedagogies in decreasing gaps in performance are mixed (Karim et al., 2018; Maries et al., 2020; Pollock et al., 2007). In fact, several studies have determined that interactive instructional approaches in STEM settings can disproportionately benefit white, male students, who are often more comfortable and less excluded when engaging in peer and classroom discussions (Bando, Näslund-Hadley, & Gertler, 2019; Eddy et al., 2015; Ernest et al., 2019; Reinholz et al. 2022; Setren et al., 2021). Interactive instructional practices

that appear to reduce achievement gaps include deliberate attention to peer group dynamics and regular, scaffolded feedback that teaches students to view their physics abilities as malleable and effectively navigate academic challenges (Doucette & Singh, 2022; Karim et al., 2018; Maries et al., 2020; Pollock et al., 2007; Quinn et al, 2020; Theobald et al., 2020). In recent years, scholars have rightfully pointed out that focusing solely on achievement comparisons when evaluating interactive instructional approaches promotes a deficit perspective on the underrepresentation of women, Black, Latine, Indigenous, LGBTQ+ and disabled students in physics spaces (Traxler et al., 2016). When empirically examining the educational outcomes of interactive approaches, it is vital to consider how various aspects of marginalized students' course experiences in these reformed classrooms influence their beliefs, perceptions, and feelings about their place in physics (Eddy et al., 2015; NRC, 2013).

Several recent studies in postsecondary STEM education have explored the experiences of neurodivergent and LGBTQ+ students in interactive learning settings (Cooper & Brownell, 2016; Gin et al., 2020; James et al., 2020; Salty et al., 2022; Pfeifer, Codero, & Stanton, 2023). Neurodivergent students include those whose brains function differently that what society defines as the norm due to factors such as attention-deficit/hyper-activity disorder (ADHD), autism, and dyslexia (Princing, 2022). A collaborative autoethnography determined that interactive physics learning structures support the engagement and success of ADHD college students due to their greater openness to flexibility and adaptability in the classroom (Salty et al., 2022). James et al. (2020) previously found that introductory physics students with ADHD appreciated how an interactive classroom structure allowed for greater autonomy and distraction, though that increased distractions and flexibility could deter from learning. Pfeifer, Cordero, and Stanton (2023) discerned that while STEM majors with ADHD or learning disabilities enjoyed

the hands-on, interactive aspects of their active learning classes, they felt increased stress in interactive courses that required long textbook readings and short answer click responses, as well as those that did not provide students with interactive notes or instructor-led explanations of concepts. Cooper and Brownell (2016) documented that LGBTQ+ students felt more aware of their sexual orientation and/or gender identity in interactive than traditional biology classrooms due to the greater need to interact with their peers. Such awareness was positive when it allowed LGBTQ+ students to come out to supportive peers and find community with fellow LGBTQ+ students. At the same time, LGBTQ+ students found interactive classroom settings more stressful when they did not perceive their learning environment as safe for coming out. In addition, transgender and non-binary students were more likely to be overtly misgendered in interactive courses (Cooper & Brownell, 2016). Together, these studies emphasize that the benefits of interactive STEM courses depend largely on the inclusivity of their structures and implementation.

Out-of-Class College Physics Structures. Outside of the classroom, structures such as paid undergraduate research programs, peer mentoring initiatives, structured study groups, formal professional development opportunities, and identity-focused peer support groups can support students with marginalized identities in developing not only knowledge and skills but also a sense of belonging and disciplinary identity in physics (Bjorkquist et al., 2019; Mervis, 2022; Whitten et al., 2003). When conducted in an inclusive and equitable manner, such programs and initiatives can act as *counterspaces* (AIP, 2020). As previously introduced, counterspaces are a type of structure that benefit the sense of belonging and disciplinary identity development of students with marginalized identities (AIP, 2020; Johnson et al., 2017; Ong et al., 2018) These counterspaces, which can be physical or conceptual, exist to provide an

empowering arena for such students to share and validate their negative experiences, build a support system, and network with peers and mentors (Ong et al., 2018). Importantly, counterspaces need not be sequestered in the margins of physics departments. Johnson et al. (2017) carried out an ethnography of an undergraduate physics program at a liberal arts institution and discerned that the department as a whole existed as a counterspace for women and students of color. Common issues such as microaggressions were not entirely absent, though marginalized students reported them without hesitation and faculty addressed these reports as legitimate (Johnson et al., 2017). As a result, undergraduate women of color felt a high sense of belonging, competence, and recognition in the program.

The Disciplining Domain. In postsecondary physics settings, instructors and students reinforce or counteract existing power relations through explicitly and implicitly supporting, challenging, or reforming existing rules, norms, policies, and procedures that perpetuate the underrepresentation of students with marginalized identities (Feder, 2022; Johnson, 2020). For example, in Barthelemy et al.'s (2016) qualitative study of women graduate students in physics and astronomy, one student ("Stevie") struggled to conduct research in her lab due to a male colleague who overtly excluded and discouraged her from lab work due to her gender. Her faculty advisor knew of this sexist dynamic though did nothing to stop it, and as a result Stevie ended up switching labs (Barthelemy et al., 2016). Another woman in this study ("Nancy") experienced hostile sexual harassment from a male teaching assistant, which later evolved into violence. Nancy formally reported his behavior to her department, though the teaching assistant never faced consequences and, due to a lack of personal safety, she eventually left her graduate program (Barthelemy et al., 2016). In each of these instances, a lack of action on behalf of

physics faculty and departmental administration upheld oppressive power relations by explicitly allowing gender discrimination, harassment, and violence against women.

Women of color in physics and astronomy frequently face a *double jeopardy* of sexist and racist harassment that, like the instances described above, often go unchallenged by those in power (Clancy et al., 2017). Clancy et al. (2017) surveyed 474 astronomers and planetary scientists between 2011 and 2015 about their professional experiences. Women of color were significantly more likely than White women to report experiencing verbal harassment due to their gender and significantly more likely than men of color to report experiencing verbal harassment due to their race (Clancy et al., 2017). In addition, 40% felt unsafe at work due to their gender and 28% felt unsafe at work due to their race. These experiences not only reduced well-being and sense of belonging, but also caused them to purposely skip professional events and thus miss out on potential opportunities for professional development and advancement (Clancy et al., 2017).

Johnson's (2020) intersectional analysis of a physics department cites instances in which faculty proactively apply the disciplining domain of power in such a way that promotes inclusion and equity in the classroom by disrupting instances of microaggressions, harassment, and exclusion. During undergraduate physics labs, faculty described reprimanding students who failed to divide up tasks equitably and/or who excluded women and students of color from completing hands-on, experimental aspects of lab work. Students with marginalized gender, racial, and/or ethnic identities in this department communicated to her in interviews that they trusted departmental faculty to proactively intervene in instances of sexism and racism and did not feel the need to stay silent when such instances occurred (Johnson, 2020). Ong et al. (2018) similarly found that STEM departments can act as counterspaces for marginalized students when

they actively acknowledge and work against oppression, in part by not tolerating discriminatory behavior.

Intersectionality in Physics Education Research: Moving Forward

Intersectionality recognizes that systems of oppression are complex, multifaceted, and cannot be truly understood or challenged by focusing on social identities such as gender, race, ethnicity, class, and sexual orientation as separate, isolated factors (Collins, 2015). Collins' (2009) Domains-of-Power Framework is an ideal conceptual and analytic tool for studying the dynamics of physics identity development, as it situates the lived experiences of physics students with intersectionally marginalized identities in the distinct yet overlapping interpersonal, cultural, structural, and disciplining features of their specific physics spaces (Johnson, 2020). The present study applied this framework to explore the lived experiences and physics identity development of undergraduate physics majors who completed a major-specific physics course that incorporated an experimental lab activity. In addition to investigating how undergraduate physics majors with marginalized gender, racial, and/or ethnic identities navigate their disciplinary identity in such a learning environment, I also examined how physics students' sexual orientations, disabilities, and socioeconomic statuses factor into their physics identity development. As previously described, comparatively little is known the experiences of lesbian, gay, bisexual, transgender, and queer (LGBTQ+) physics students, students with disabilities, and students who come from families with a lower socioeconomic status (Feder, 2022; Traxler & Blue, 2020; Miller-Friedmann, 2020). Students with disabilities also frequently struggle with being misunderstood and excluded in their physics learning environments (Chini & Scanlon, 2022; Coffie et al., 2022; Traxler & Blue, 2020; Thurston et al., 2017). Furthermore, such students often struggle to acquire official and unofficial accommodations to meet their learning

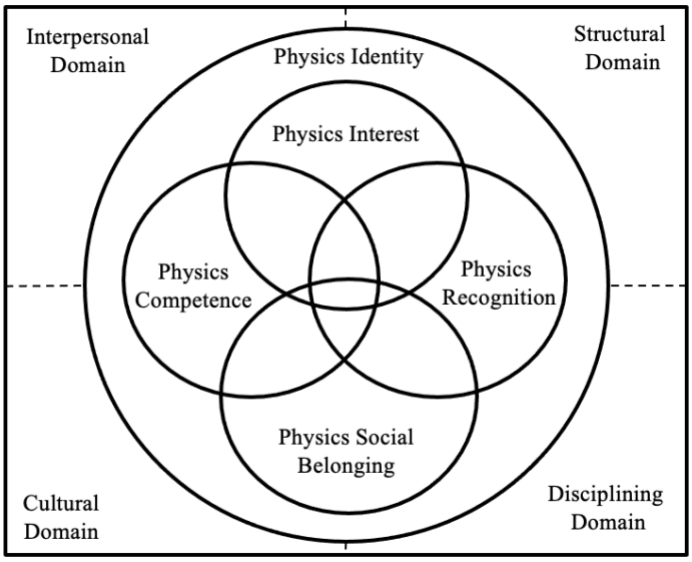
needs due to interpersonal, cultural, structural, and disciplining barriers (Chini & Scanlon, 2022). Work suggests that physics students from lower socioeconomic status also contend with negative intelligence stereotypes, exclusion, and a lack of structural resources and opportunities (Miller-Friedmann, 2020). More research is needed that explores how these identities influence students' interpersonal interactions in their physics learning spaces.

Conceptual Framework

This study relies on a conceptual framework that situates Hazari et al.'s (2020) conceptual model of physics identity development in Collins' (2009) Domains-of-Power Framework (see Figure 4.1 for a visual). I applied this framework to examine how undergraduate physics students with marginalized social identities navigate their disciplinary experiences and identity development while enrolled in major-specific physics courses that incorporate an interactive instructional approach.

Figure 4.1

Conceptual Framework Depicting the Dynamics Between the Four Domains of Power in a Physics Setting and an Undergraduate Physics Major's Physics Identity (Adapted from Collins, 2009 and Hazari et al., 2020)



Hazari et al.'s (2020) model isolates four factors that directly or indirectly influence the physics identity development of undergraduate women majoring in physics: competence/performance (which I shorten to *competence*), recognition, and sense of belonging. *Competence* represents students' perceptions of their knowledge and skills in physics relative to others in their major. *Recognition* represents the extent to which students feel recognized both externally and internally as "exemplary physics students." In Hazari et al.'s (2020) model, competence/performance fluctuates with recognition, and both factors directly influence students' physics identity. For upper-level women undergraduates, a *sense of belonging* in physics, defined as a subjective feeling of connection and legitimacy as a valued member of a physics community, also directly shapes physics identity (Baumeister & Leary, 1995; Hazari et al., 2020). Sense of belonging also fluctuates with competence/performance and recognition for all physics students in their model. A fourth factor, *interest* in physics, defined as a "desire or curiosity to think about and understand the discipline," indirectly shapes physics identity through its positive influence on competence/performance and recognition (Hazari et al., 2020, p. 1599). Together, competence, recognition, a sense of belonging, and interest shape the extent to which undergraduate women physics majors both see themselves and feel seen as the *kind of person* who identifies as a strong physics student and a physicist (Hazari et al., 2020). The present study expands the focus of Hazari et al.'s (2020) model to explore how the above-mentioned factors shape the physics identity development of undergraduate physics majors with a variety of social identities traditionally marginalized in postsecondary physics spaces.

Collins' (2009) Domains-of-Power Framework distinguishes four different yet interrelated domains that together describe the organization of power in a particular context: the interpersonal, the cultural, the structural, and the disciplinary (Collins, 2009; Collins & Bilge,

2016). The *interpersonal domain* deals with everyday interactions between individuals who, due to their various social identities, are "differentially position[ed]" to hold and express power in an environment (Collins, 2009; Collins & Bilge, 2016, p. 16). Daily interpersonal displays of power include overt, aggressive messages of inferiority as well as more subtle microaggressions, or slights that convey bias against a marginalized group (Johnson et al., 2017). While they can be intentional, they are often unconscious and so commonplace that they go unnoticed by individuals in advantaged positions (Collins, 2009). Regardless of their conscious intention, interpersonal displays of power have important consequences. In college science settings, for example, women of color report experiencing exclusion from their classmates during group work scenarios, which leads to their lack of belonging and perceived recognition as a good science student (Johnson, 2007). The *cultural domain* concerns the power that comes with whose values, norms, and traditions are viewed as important and legitimate. As Collins (2009) describes, "to maintain their power, dominant groups create and maintain a popular system of "commonsense" ideas that support their right to rule" (p. 302). While it is often framed as being neutral and objective and therefore removed from cultural subjectivities, physics is rooted in "white empiricism" which elevates white men as the only group capable of true scientific objectivity and thus the only group that truly belongs in scientific spaces (Prescod-Weinstein, 2020, p. 421). Framing science as removed from cultural biases helps to legitimize the underrepresentation of individuals with marginalized gender, racial, and ethnic identities as an issue of individual merit rather than cultural oppression (Traxler et al., 2016). The *structural domain* relates to how social structures and institutions dictate how power is distributed (Collins, 2009; Collins & Bilge, 2016). In the United States, social institutions such as legal, housing, banking, and educational systems, as well as the media, collectively subjugate and disenfranchise individuals and groups

with intersectionally marginalized social identities. Collins (2009) elaborates that in an era of color-blind racism, social institutions enforce oppression in part by denying that structural racism exists in a post-Civil Rights America. Structural oppression presents itself in science education in part through inhibiting which students have access to advanced science and math courses, high-quality learning materials, experienced teachers, and extracurricular science experiences (AIP, 2015; Office for Civil Rights, 2018).

The *disciplinary or disciplining domain* pertains to how rules and practices are differentially implemented and enforced for various individuals and groups in an organization or institution (Collins, 2009). Collins and Bilge (2016) write, "power operates by disciplining people in ways that put [their] lives on paths that make some options seem viable and others out of reach" (p. 16). In the context of science education, the disciplining domain appears in numerous forms, such as through teachers offering extra help and encouraging some students to persevere through academic challenges, while informing others that they are not cut out for science.

The four domains described above work together to coordinate power relations in a given setting. The structural domain organizes power, the disciplining domain enforces it, the cultural domain legitimizes it, and the interpersonal domain expresses it at an individual level (Collins, 2009). Together, the "particular contours of each domain of power illustrate how intersecting oppressions of race, class, gender, sexuality, and nation are organized in unique ways" (Collins, 2009, p. 294). Importantly, while the Domains-of-Power Framework provides a useful analytic tool for examining intersectional dynamics of oppression, it can also be used to highlight instances of resistance and empowerment that challenge existing power relations within and across domains (Collins, 2009).

In the present study, I situate the four dimensions of college physics majors' physics identity development in the four domains of power (Figure 4.1). Interpersonal interactions with instructors and peers, cultural norms and structural features, and enforcement of rules and policies in the physics classroom and program work together to shape the dynamics in which physics majors with multiply marginalized identities feel a sense of physics interest, competency, recognition, and belonging in their disciplinary environments.

Methods

A qualitative approach was utilized for this study. Qualitative research is ideal for centering the voices of individuals and groups, particularly those who are underrepresented and marginalized in a particular setting. It allows for a deep, inductive exploration of the meanings that participants ascribe to their experiences (Creswell & Creswell, 2018). This methods section begins by detailing the specific qualitative research design, setting, data collection, data analysis, validity and reliability procedures used in the present study. It ends by describing the study's ethical considerations and researcher positionality.

Research Design

This study employed a dynamic narrative inquiry design (Daiute, 2014). The dynamic narrative approach views the act of narrating as an interactive "cultural tool" that people use to "manage self-society relationships" and make sense of their environment (p. 19). It recognizes that individuals' stories are inherently situated in the sociocultural and symbolic systems and power relations in which they live. The practice of dynamic narrative inquiry is rooted in four core principles: use, relation, materiality, and diversity (Daiute, 2014). The first principle, *use*, highlights discourse as an activity that participants use to "mediate individual and societal interactions" and make sense of the world around them (p. 20). In gathering narratives on a topic

of interest, a researcher may ask a participant to tell stories from the perspectives of various individuals involved (such as from the perspective of an instructor and a student). The second principle, *relation*, acknowledges that participants construct their stories "interactively in relation to others likely to communicate with and/or judge them" (p. 28). In other words, the manner in which an individual conveys a particular event to a friend will most likely be somewhat different from the manner in which they convey that same event to a professor. The third principle, *diversity*, recognizes that narrating is not neutral, but instead "defined by the perspectives of people in positions of difference influence" (p. 28). When conducting a dynamic narrative inquiry, it is thus beneficial to gather narratives from a range of individuals involved or invested in a particular topic or event (such as physics instructors and physics students with different social identities and backgrounds). The goal in doing so is not to position any one individual or group as the norm, but to recognize how various positionings contribute to the dynamics of a setting. The fourth principle, *materiality*, focuses on storytelling as a "physical process rooted in the settings, scenarios, expressive features, and social relations of daily life" (p. 29). In collecting and interpreting narratives, it is thus important to record and analyze not only participants' words, but also physical and symbolic features of their settings as well as the ways that they convey and emphasize meaning through their emotions and gestures (Daiute, 2014).

Dynamic narrative inquiry employs an "activity-meaning system" approach that implements specific narrative activities relevant to the space, time, and purpose of one's research questions (Daiute, 2014, p. 39). Drawing on the four principles described above, the activity-meaning system research design intentionally solicits narratives from various relevant stakeholders (recognizing that their narrations of various topics or events will most likely differ in meaningful ways). In addition, it constructs narrating activities that allow participants to

recount events from different points of view and/or imagine how events could unfold in a different time or place. Throughout narrative activities, the researcher observes how individuals reference material aspects of their environment (Daiute, 2014). Dynamic narrative inquiry is an ideal research design for the present study. Narrative inquiry is commonly used to gather reflexive accounts of science identity development (Carlone & Johnson, 2007; Gonsalves et al., 2014). Gathering dynamic narrative accounts via an activity-meaning system allowed me to uncover how participants with different roles and social identities perceive and interpret their lived experiences in the context of the interacting interpersonal, cultural, structural, and disciplinary power dynamics of their physics course settings (Daiute, 2014).

I utilized a critical constructivist epistemology in my work, which acknowledges the socially constructed nature of reality and examines and challenges dominant discourses and oppressive power structures in which individuals' realities are constructed (Kincheloe, 2005). Such an epistemology actively involves research participants in the research process, ideally spurring societal transformation (Jones et al., 2013).

Research Site

This study took place at a large, predominantly white, public land-grant institution in the southeast (referred to in the study as Southeastern University). The academic institution has many STEM degree programs, with 61% of the undergraduate student population enrolled in a STEM major. The Department of Physics at Southeastern University contains 59 faculty, 130 graduate students, and 137 undergraduate students. Approximately 20% of physics undergraduates identify as women. Of those women, 74% are white, 11% are Asian, 11% are Latine, and 4% are Black. Men makeup 80% of undergraduates in the major. Seventy-seven percent of these men are white, 13% are Asian, 5% are Latine, 3% are Black, and less than 1%

are Indigenous. Faculty in the Department of Physics at Southeastern University engage in research in numerous subfields, including astrophysics, nuclear physics, biophysics, condensed matter physics, optical physics, and physics education research.

Interactive Instructional Approach: Experimental Lab Activity Program

In 2013, a faculty member in the Department of Physics developed a collection of experimental lab activities to provide undergraduate physics majors and minors with the opportunity to conduct short, inquiry-based experiments in the department's shared research facility as part of their physics courses. Each fall and spring semester since its inception, 3-5 physics courses have incorporated an experimental lab activity as an official course component. Specific experiments are designed and modified each term by course instructors in collaboration with the lab activity director and a graduate teaching assistant. Examples of existing experimental lab activities include carbon dating of Brazil nuts, observation of chaotic motion, and measuring the absorption spectrum of molecules of different sizes and modeling this behavior as a quantum-mechanical particle in a box. The activities are meant to authentically expose undergraduates to the process of experimental physics and the trial-and-error nature of science. Undergraduates work in small groups of 2-4 to develop hypotheses and collect and analyze data, though they each write up and submit their findings independently. Instructors and TAs grade student write-ups using intentional growth and process-oriented feedback. Prior to the development of the experimental lab activities, the undergraduate physics curriculum at Southeastern University offered traditional cookie-cutter labs for students during their first three semesters of college, and no inquiry-based course or lab work until their senior year capstone course. Based on internal program evaluations, the activities appear to support undergraduate physics students in their self-reported confidence and understanding in experimental physics.

While experimental lab activities were initially restricted to advanced physics courses at Southeastern University, in Fall 2021, the program was expanded to also include introductory major-specific physics courses. As such, most undergraduates majoring or minoring in physics at this institution are enrolled in a physics course each semester that incorporates such an activity.

Participants

This study relied on a purposeful, criterion-based sampling techniques (Merriam & Tisdell, 2016). To be eligible to participate, individuals feel under one of the following categories: 1) Undergraduates currently majoring or minoring in physics at Southeastern University who completed at least one physics course that incorporated an experimental lab activity during the 2021-2022 academic year, and 2) Physics faculty or graduate teaching assistants (TA) who led or supported a physics course at Southeast University that incorporated an experimental lab activity during the 2021-2022 academic year.

When conducting dynamic narrative inquiry, it is important to gather narratives from individuals with diverse roles and power relations. As such, I employed a purposeful sampling technique known as maximum variation sampling (Merriam & Tisdell, 2016). Maximum variation sampling involves recruiting individuals who represent a range of identities, roles, and/or perspectives concerning a topic of interest (Glaser & Strauss, 1967). Given that this study is primarily interested in exploring the experiences, perceptions, and beliefs of undergraduate physics majors with traditionally marginalized gender, racial, ethnic, and/or sexual orientation identities, I purposely sought out participants who possessed these identities. To do so, I sent out several recruitment emails in the summer of 2022 with a brief synopsis of the study and an invitation to participate to all undergraduate physics students who completed at least one of the 9 physics courses that incorporated an experimental lab activity during the 2021-2022 academic

year. My recruitment email specified that students with gender, racial, ethnic, socioeconomic status, disability, and/or sexual orientation identities traditionally marginalized in physics were especially encouraged to participate. I also recruited eligible physics faculty members and graduate TAs. All participants received a $30 Amazon gift card.

Data Collection

To inform my research question for this study, I collected two sources of data: an online questionnaire and semi-structured individual interviews. The following sections describe data collection strategies for each of the data sources.

Online Questionnaire

Prior to each interview, undergraduate participants completed a 20-question online questionnaire that asked them about their social identities, background, interests, and career goal(s) (see Appendix E for complete questionnaire). In addition, the questionnaire asked participants to list words that they felt describes them as a person and as a student and had them create a pseudonym for the study. During interviews, I asked students to expand on aspects of their questionnaire answers. Including this questionnaire aligned with the dynamic narrative principles of relation, diversity, and materiality (Daiute, 2014). The manner in which participants conveyed their identities, background, and ambitions in an online survey could differ from how they described such things verbally in an interview.

Semi-Structured Interviews

I completed one remote semi-structured interview per participant, with each interview lasting approximately 45-60 minutes. Taking a semi-structured approach allowed me to utilize an interview protocol that incorporated questions related to the study's purpose, research questions, and conceptual framework. Additionally, the interview protocol consisted of verbal narrating

activities modeled after Daiute's (2014) activity-meaning system approach in which participants elaborated on their identities, experiences, interactions, and perceptions of their undergraduate physics courses and program. At the same time, semi-structured interviews provided the opportunity for participants to expand upon their statements, offering richer, more detailed stories. After generating an initial semi-structured interview protocol, questions I evaluated against Seidman's (2005) and Merriam and Tisdell's (2016) strategies for effective interviewing (for instance, no leading or compound questions, no reinforcement of responses, and tips for eliciting elaboration). My student, TA, and instructor interview protocols appear in Appendix F. Specific interview questions are labelled with the corresponding component(s) of my conceptual framework that guided their conception (Appendix F). Participant interviews were audio recorded and transcribed verbatim in Zoom. I later careful listened to audio recordings to fix errors in Zoom transcriptions. During this time, I created an analytic memo for each participant in which I summarized and reflected upon participant narratives, questionnaire responses, and field notes that I jotted down during interviews in relation to the study's purpose and research question (Saldana, 2015).

Data Analysis

To analyze participant narratives, I employed a paradigmatic mode of analysis (Polkinghorne, 1995). Such a strategy identifies common patterns within and between stories to isolate themes present within and across participants' narratives. I began by compiling and organizing each participant's transcript, analytic memo, and (for undergraduate participants) questionnaire responses in Dedoose. Drawing upon this information, I typed up a profile for each participant that re-storied their narrative and supported my keeping each narrative intact (Riessman, 1993). I then undertook an iterative, inductive process of open coding. In the first

cycle, I assigned descriptive, in vivo, and value codes to sentences or passages of participants' transcripts. Descriptive codes label data with nouns or short phrases for later categorization, while in vivo codes use participants' own words (Saldana, 2015). Value codes identify values, attitudes, and beliefs, which is important when one is interested in the cultural dynamics of a setting (Saldana, 2015). In the second coding cycle, I organized and grouped first cycle codes into patterns and themes (focusing on the content, chronological positioning, and relational components of each) (Daiute, 2014; Saldana, 2015). Dynamic narrative inquiry seeks to identify patterns of "similarity, difference, and change" to gather "an account of cultural meaning and nuance gleaned from narrating by people in diverse positions with diverse interests in a system" (Daiute, 2014, p. 242). At times, "conflict and contradiction" appeared within and between participants' narrations of their experiences and perspectives (Daiute, 2014, p. 242). In such instances, I generated versus codes to represent the dichotomies that appeared from these tensions (Saldana, 2015). Throughout the second cycle coding process, I frequently revisited participant profiles, transcripts, and my conceptual framework and expanded upon my analytic memos. The second cycle coding process resulted in 9 themes and 22 subthemes. I assigned each theme and its corresponding subthemes into one of the four domains of power (Collins, 2009). I then utilized this codebook to recode transcripts using my final themes and subthemes. While recoding, I conducted a significance analysis on the narrative segments applied to these themes. This approach focuses the evaluative devices (psychological state expressions, intensifiers, qualifiers, causal connections, and negotiations) that narrators employed, allowing for analysis of *how* participants conveyed their stories (Daiute, 2014). I recorded and organized evaluative devices that appeared within each subtheme and later incorporated their insight when interpreting findings.

Validity & Reliability

To promote internal validity and reliability in this study, I relied on triangulation, member checks, reliability, and researcher positionality (Miles et al., 2019). Collecting data via multiple methods served as a form of triangulation. I employed member checks by providing each participant with a document that contained a copy of their participant profile and a table consisting of final themes and subthemes alongside bullet points containing their applications of these themes that I gleaned from analysis. I asked participants to review their document and provide feedback to ensure that my analyses both accurately depicted their experiences and perceptions and protected their anonymity. Given the low number of women and students of color in the physics program, I wanted to ensure that undergraduates could not be reidentified in my manuscript by departmental members. I also promoted validity by critically reflecting on my own position in relation to my research, as described below. In addition, I promoted external validity by describing both my study site and each participant, so that the reader can decide how applicable my findings are to various scenarios.

Researcher's Role & Ethical Considerations

In this narrative study, I acted as the primary research instrument, as I directly interviewed participants (Creswell & Creswell, 2018). While I am not a member of the physics department at Southeastern University, I began a scholarly collaboration with the faculty member who developed the experimental lab activities in early 2021. As a woman in physics, this faculty member is very invested in increasing diversity, inclusion, equity, and justice in her field. Since that time, I have met with this faculty member on a regular basis to coordinate two related quantitative studies, discuss physics education literature, and learn more about the physics department at Southeastern University. This faculty member has also acted as my

"gatekeeper" to the physics department at Southeastern University. Over the course of the past two years, she has introduced me to a number of physics faculty and graduate students in the program, who I also interact with to collect data for the two related quantitative studies. As such, my existence is now fairly well-known in this department.

The Internal Review Board (IRB) at my study institution helped ensure that I ethically collected and analyzed data. The primary ethical considerations of this study involved ensuring the confidentiality and security of participants' data, two things that I maintained in several ways. First, each participant generated their own pseudonym, which they then used as a temporary Zoom name during their interview. Second, I used Southeastern University's Google Forms, Calendar, and Docs to coordinate all interview scheduling and to communicate with participants. Third, participant names were stored only in a university Qualtrics account and only pseudonyms were included in saved questionnaire responses and analytic memos. Fourth, audio files were saved to my university Zoom cloud. Fifth, I careful removed identifying features present in participant narratives, and rephrased potentially identifying events (such as instances of gender harassment) in a vague manner. I then asked relevant participants to affirm that my rephrasing removed identifying details but maintained their narratives during member checks.

Subjectivity Statement

I identify as a white, middle-class, queer, cisgender woman. I obtained a bachelor's and a master's degree in a biology field, the latter of which came from a large research-intensive institution similar in size, structure, and demographic make-up to the institutions in the present study. I thus have personal experience navigating postsecondary scientific spaces as a queer woman and am in certain ways an insider to my population of interest. In addition, I am a trained higher education practitioner and researcher who is extremely invested in increasing diversity,

equity, inclusion, and justice across STEM fields. I advise undergraduates in the biological sciences at Southeastern University and through conversations with my advisees, I witness instances of exclusion and inequity in postsecondary STEM education on a regular basis. At the same time, I do not have personal experience as a student in the discipline of physics. As a white, middle-class individual from a largely college-educated family, I possess extensive privileges due to my race, class, and familial education background. I am in these ways an outsider to this study's population. My dual position as an insider and an outsider is helpful in providing me with direct experiences with issues of diversity, equity, inclusion, and justice in STEM and with a certain degree of legitimacy and trustworthiness among my study population as a woman in STEM. It is also a bit dangerous in that my own identity as a science person (as well as a white, educationally and economically privileged person) may prevent me from fully seeing certain power structures at play or authentically connecting with racially, ethnically, and/or socioeconomically marginalized students in my study.

Results

In this section, I first provide a synopsis of the study's undergraduate, graduate TA, and instructor participants. I next present the findings of my analyses of participants' narratives, which focused on discerning how undergraduates with marginalized or multiple marginalized social identities perceived and interpreted their lived experiences and physics identity development in the context of the interacting interpersonal, cultural, structural, and disciplinary power dynamics of major specific physics courses that incorporated an experimental lab activity (Collins, 2009; Hazari et al., 2020).

Participant Characteristics

Twenty-two individuals, including seventeen undergraduate students, three physics faculty, and two graduate student teaching assistants (TAs) for the experimental lab activities, participated in this narrative study. Tables 4.1 and 4.2 summarize information about undergraduate participants' demographic, background, and academic characteristics. Undergraduate participants included 2 Latina women, 1 Asian woman, 4 white women, 6 white men, 1 Latino man, 1 Black man, 1 Asian man, and 1 non-binary Asian student. Seven undergraduates identified as LGBQ+ and three as neurodivergent. Six came from lower- or working-class backgrounds and three specified that they will be the first people in their families to obtain a bachelor's degree. At the time of their interviews, six were sophomores, 5 were juniors, and 6 were seniors. All but two were physics majors. One participant, James, switched physics to a minor after several years as a double major in physics and engineering. Another, Peter, decided on an engineering major with a physics minor. Two undergraduate participants had double majors in other STEM areas. Ten had minors in disciplines in or outside of STEM. Three transferred to Southeastern University from a community college. When asked to describe their career interests and goals, participants provided a range of environments, roles, and specificities. Nine expressed an interest in working in industry and four in academia. Fourteen identified professional interests in experimental and applied areas of physics or engineering and three in theoretical physics.

Table 4.1

Demographic and Background Profile of Undergraduate Participants

Pseudonym	Gender	Race + Ethnicity	LGBQ+	Disability	SES	First-Gen College Student	Transfer Student	Job
Bo	Non-Binary	Asian/Indian	Yes		Middle			
Diana	Woman	White	Yes	ADHD	Lower		Community College	Yes
Mari	Woman	White	Yes		Lower	Yes		Yes
Rose	Woman	Latina/white			Middle			
Katherine	Woman	White	Yes		Middle			
Ria	Woman	Asian			Middle			
Selena	Woman	Latine/Mexican	Yes		Lower			
Jessica	Woman	White			Working	Yes		
Forat	Man	Black			Middle			Yes
Paul	Man	White	Yes		Middle			
Peter	Man	White			Middle			Yes
George	Man	White	Yes	Autism	Middle		Community College	Yes
Kevin	Man	White		ADHD	Working		Early College	Yes
Patrick	Man	White			Middle			Yes
James	Man	White	PNS*		Working	Yes		
Zach	Man	Asian/Indian			Middle			Yes
Tom	Man	Latino/white			Middle			

**PNS = "preferred not to say"*

Table 4.2

Postsecondary Academic and Professional Profile of Undergraduate Participants

Pseudonym	Academic Year	Major	Minor(s)	Career Interest(s)
Bo	Sophomore	Physics and Computer Science		Computational physics, software engineering, quantum computing specialist, entrepreneur
Diana	Senior	Physics and Math	Anthropology	Research in academia or industry
Mari	Senior	Physics		Nuclear physics and academia
Rose	Sophomore	Physics	Math	Quantum computing and astrophysics
Katherine	Junior	Physics	Rhetoric, Writing, and Communication	International involvement in physics
Ria	Junior	Physics	Statistics	Statistics related to aerospace industry
Selena	Sophomore	Physics		Research in astrophysics and meteorology
Jessica	Senior	Physics, Biology	Math	Quantum computing and biosensing
Forat	Junior	Physics	Math	Quantum gravity research and academia
Paul	Senior	Physics		Attending graduate school in physics
Peter	Sophomore	Mechanical Engineering	Physics	Engineering research and development and academia
George	Senior	Physics		Physics research
Kevin	Junior	Physics	Computer Science	Soft matter research and XD development
Patrick	Sophomore	Physics		Work for NASA
James	Senior	Aerospace Engineering	Physics and Computer Science	Astronautics industry
Zach	Sophomore	Physics		Science communication and research
Tom	Junior	Physics	Math	Attending graduate school in physics

All three physics faculty member participants were tenure-track (two associate and one full professor). Two were men (one white and one a person of color) and one a white woman. One specified that he was an international, first-generation undergraduate who worked his way through college. Both graduate TAs (Stacey and Connie, pseudonyms) were women (Stacey is a white woman and Connie is a woman of color). Stacey described that she plans to work in industry after obtaining her PhD, while Connie plans to primarily teach.

Physics Identity Development in the Context of the Four Domains of Power

Undergraduate participants offered several perspectives on what they perceive is required to identify as a physicist. Nine (Tom, Forat, Zach, Kevin, George, Patrick, Jessica, Bo, and Rose) stressed that while they see themselves as developing physicists, they do not yet feel qualified to assert this identity outright, as they do not have the level of knowledge, academic credentials, or contributions required to do so. Six (Paul, Selena, Mari, Katherine, Ria, and Diana) explained that they currently identify as physicists given their internal dedication, their existing knowledge and skill base, and their perceptions of external recognition by others in the field. Most undergraduates who shared that they currently identify as a physicist were upperclassmen, with the exception of Selena, who recently completed her freshman year.

Participants also conveyed varying and sometimes multiple definitions of what it means to belong in physics. Ten (Rose, Ria, Katherine, Jessica, Zach, Paul, Forat, Mari, James, and Bo) emphasized that belonging involves feeling recognized as part of the physics community. Seven (George, Selena, Zach, Patrick, Mari, Diana, and Peter) described that it entails enjoying the subject. Three (Paul, Peter, and Diana) aligned belonging with academic competence. Three (Rose, Tom, and Zach) explained that it means seeing one’s future in the field, and two (Rose and Bo) clarified that it requires ascribing to a certain way of thinking.

The subsequent sections expand on these perceptions by detailing how undergraduate participants characterized their lived experiences and physics identity development in the context of the interpersonal, cultural, structural, and disciplining dynamics of their physics learning environments at Southeastern University. Paradigmatic, value, and significance analyses within and across participants' narratives yielded 9 major themes and numerous subthemes that I further categorized into the four power domains (Collins, 2009; Table 4.3).

Table 4.3

Major Themes and Subthemes Organized into the Four Domains of Power

Power Domain	Themes and Subthemes
Interpersonal	Peer interactions • "In it together" vs. peer disconnection • Peer comparisons as a source of reassurance vs. self-doubt • Identity-based hypervisibility and invisibility • Gender-based harassment Peer-instructor interactions • Open and caring vs. formal and inflexible • Inclusive vs. exclusionary
Cultural	Ways of being in physics • Physicists as passionate about STEM • Physicists as deep, accomplished thinkers • Physicists as problem solvers • Physicists as inclusive vs. exclusive Ways of doing physics • Doing physics requires dedication and perseverance • Doing physics is an iterative process • Doing physics is a collaborative endeavor
Structural	Unequal foundations • Unequal K-14 education foundations • Unequal informal education foundations Course structures • Challenging course content • Clear course alignment • Low-stakes assignments vs. high-stakes tests • Active, hands-on, and applied engagement Out-of-class structures • Undergraduate research and internships • Diversity, equity, inclusion, and justice (DEIJ) and affinity groups • Departmental and university engagement opportunities
Disciplining	Importance of flexibility and accommodations Importance of awareness, acknowledgement, and intervention that supports DEIJ

The Interpersonal Domain

The interpersonal domain focuses on how power is demonstrated and negotiated through everyday interactions in an environment. Interpersonal interactions influence who is "included or excluded, praised or criticized, [and] honored or overlooked" (Johnson, 2020, p. 56). In the present study, interpersonal interactions helped shape the extent to which students with varying identities and backgrounds felt competent, comfortable, and recognized in their physics learning spaces. I isolated two primary themes within participants' narrations of their interactions with others in the physics program at Southeastern University: *Peer interactions and peer-instructor interactions*.

Peer Interactions

All undergraduate participants described how interactions with their physics peers played a pronounced part in shaping their overarching experiences and self-perceptions in the physics program. Peer-peer interactions influenced students' perceptions of their academic competence, sense of belonging, and recognition as a physicist or developing physicist. As detailed below, four subthemes emerged within and across undergraduates' narrations of peer interactions: *"In it together" vs. peer disconnection*, *peer comparisons as a source of reassurance vs. self-doubt*, *identity-based hypervisibility and invisibility*, and *gender-based harassment*.

"In It Together" vs. Peer Disconnection. Fifteen undergraduates highlighted positive peer interactions as a key component of their academic competence, sense of belonging, ongoing persistence, and/or enjoyment of the physics program. Students with a range of identities and backgrounds described how physics students "band together" to work on assignments, study for tests, and "commiserate" over the difficulty of the major (George, Selena). Some mentioned that they first take time to "struggle through" material individually, then come together with peers to

help each other as needed (Tom). George emphasized, “We know we have to work together to make it through the material…I don’t see how you could survive in the physics major and not have a network of people to rely on.” Conversations with physics peers affirmed for students that they were not alone in finding class content, problem sets, and tests challenging. Paul shared, “it’s nice to know that you’re not wrong somehow for finding something difficult.” Several students conveyed that working together provided them with a sense of competence, as peers recognized each other’s insights as contributing to understanding concepts and solving tough problems. In addition to fostering competence and recognition, seven students detailed that the practice of coming together over course material provided them with a sense of belonging in the major. Selena recounted:

> I felt the greatest sense of community, whenever we have tests, because it's all of us bonding over either, like how good we feel about the test, or how bad we feel about the test. And it’s just like us talking about the material going through it. And it builds a sense of community. It's like, oh, I belong here. I'm part of the community.

In describing the physics program, ten students explained how the small size of the major created a “tight-knit,” “intimate” environment that in itself promoted a sense of community among students across undergraduate levels (Mari, Rose). Jessica detailed, “We have a discord where everybody talks and there’s always homework support, talk about career opportunities, all of that. [My peers] really truly want to support each other and see each other succeed.” Another student, Bo, added that they “really love” being surrounded by peers who share a similar passion for physics to which they could “talk openly about [their] interests without the fear of boring someone else.” Qualifiers such as “all” and “everyone” appeared across a number of narratives

of physics peer dynamics, emphasizing the overarching communal nature that many students felt in the major.

Four students clarified that, while they did not feel close to all students in the major, strong friendships with certain peers had a positive impact on their experience. Mari expressed, "I would say I know everyone in the program. Like not super well, but I've made my closest friends in the program." Students described how building friendships within the major made going to class and studying together more "fun." Two women mentioned that their friends within the major encouraged them of their physics abilities, which helped motivate them to remain in the major over time. While students detailed connecting with peers across identities and backgrounds, some recounted the positive impact of friendships with individuals who shared similar identities. Diana shared that most of her friends are neurodivergent, while Paul mentioned that making friends with fellow LGBQ+-identified students has been "extremely positive." Ria, an officer in the program's affinity group for women in physics, described how the group's social and career events help to foster a sense of support and community for women in the major.

Importantly, not all student participants perceived a sense of support and camaraderie from their physics peers. Five described instances of peer disconnection that stemmed from negative interactions centered on aspects of their identities. Katherine shared that while she feels like she belongs in the discipline of physics itself, she does not feel that she "completely fit[s] in" with her classmates:

> There isn't like very much like connection between us, besides, like our mutual study, and I don't think that some of the interactions I've had with other physics majors who represent that majority have been very welcoming to me.

Ria similarly mentioned how she tries to minimize interactions with a subset of male peers who "really like to talk about how great they are at physics and math" in a way that she finds unnecessarily competitive and off-putting. Mari added that she experienced negative gender-based peer interactions in her introductory physics courses in particular. Diana detailed that she has not "built bridges" with her neurotypical classmates, who she assumes see her as "aloof" or "private" due to her tendency to keep to herself in her physics learning spaces. Bo described how some, but not all individuals in the major are accepting of their non-binary, gay identity:

> All of my super close friends are accepting and they're great people…But then, some of the friends I made in physics, not so much, so I tend to interact with them more on the academic and professional level instead of being as personal with them. But some of the other physics students who I feel more comfortable being myself around, I don't really have that many problems interacting with them.

Two other students mentioned feelings of peer disconnection that stemmed from reasons that they did not perceive as related to their social identities. Forat shared that he just, "didn't really interact with a lot of physics students outside of the classroom," his freshman year, even though he observed that most of his peers did so. James conveyed that he's never felt welcomed by his physics peers, which he attributes in part to taking a different introductory physics course sequence that most students and thus joining major-specific physics classes at a time when "everyone already knew each other." Thus, while most undergraduate participants highlighted positive peer connections as important for success and belonging in the physics major, instances of peer disconnection emphasize that a sense of peer community was not uniformly available to all students.

Peer Comparisons as a Source of Reassurance vs. Self-Doubt. Eleven students discussed comparing their own abilities and experiences in physics to those of their peers. For some students, peer comparisons served as a source of reassurance of their competence and belonging in the major. Peter conveyed an overarching confidence about his place in physics courses, saying that he is generally the first student to respond and that his peers "get mad at [him] for getting good grades." Paul and Tom perceived that their classmates "all have the same knowledge base, roughly" and thus "see each other as equals." Four students described how peer comparisons brought a sense of reassurance that their lower self-confidence and academic struggle in physics was normal and not an indication that they were lacking in a quality needed to succeed and belong in the major. Maria, Ria, and Bo stated that, while they often experience imposter syndrome in physics, they know that others do as well, which makes the feeling more manageable. Mari elaborated, "I feel like no one in the major feels like very confident. I think we all have like some pretty bad imposter syndrome." Rose described how becoming close friends with a male student in the program who regularly got good grades reduced her feelings of self-doubt, as she learned that he too "struggled" with the material and had to "work hard" to succeed.

For other students, peer comparisons fostered a sense of self-doubt and a questioning of one's place in the major. In recounting his freshman year, Zach isolated a moment in which he realized that he and his classmates were "not on equal footing":

> We're allowed a formula sheet [on tests]. I would fail every test without that formula sheet. This man just came in for a test blank…like a pen that's it. And I looked at him and thought like, "Why can't I do that?" That really started like a cycle.

Kevin described how having ADHD caused him to "view [himself] poorly in relation to [his] peers in [his] abilities." Four women struggled with a self-doubt that stemmed largely from awareness of negative stereotypes about the abilities of women and people of color in STEM. Katherine explained that, despite succeeding academically in her classes:

> In general, I think that I doubt myself more than like my male peers. Like whenever someone asks a question, I like double check before I say anything, while I found that men will constantly state the wrong answer more frequently.

When she was spoken over by some of her male peers in her introductory physics courses, Mari did not feel that she "had a place" to challenge or report the behavior, as she thought:

> Maybe I am just really stupid and maybe I don't know what I'm talking about. It's just easier to let people talk over me and not have my ideas heard just because I felt like they weren't as valid as other people's.

Selena described her feelings of imposter syndrome as a "constant record playing in [her] head" that relayed thoughts such as, "Is this right for me? Am I supposed to be here? Am I smart enough to do this? Do I have the ability to do this? Do I have the will to do this?" While she said that she is getting better at using internal "logic" to push away these thoughts ("I wouldn't have gotten this far if I wasn't like good at doing something"), being the only woman of color in her physics courses prevents her from being able to receive affirmation that her feelings are "valid" from others who share her identities.

Identity-Based Hypervisibility & Invisibility. Six students with identities traditionally marginalized in physics settings brought up feeling that their identities made them either hyper-visible or invisible in their learning spaces at varying levels of regularity. Rose stated that, while she has never perceived that people see less of her due to her gender or ethnicity, she

immediately noticed and felt puzzled by the small number of women in her physics courses. Rose's mother is an engineer and many of her female relatives also work in STEM fields, so she was raised to view women in STEM as the norm, not the exception. Forat shared that he has "barely had to think" about being a Black man in physics, aside from realizing that he was one of two students in the university's society for Black physics students ("Wow – it's only me and you?!). In other words, both students were marginalized by their postsecondary physics spaces as a result of their drastic underrepresentation, despite not directly experiencing negative peer interactions due to their identities.

Katherine described how her love of dressing up in a traditionally feminine manner caused her to "stand out" among her physics peers:

> I very much like fashion and like girly stuff…I feel like a lot of [women in STEM] feel like they have to masculinize themselves…I want to look super put together, wearing my really girly clothing while also doing really well in my courses.

She went on to explain that, while she receives compliments on her style from physics community members, she doesn't feel like her presentation connects her to her peers.

Four women conveyed that they've felt either hesitant to actively engage in classes due to the pressure of representing their identities or overlooked as valuable contributors. Katherine stated, "I feel like I have to do more to ensure that whatever I say or provide isn't incorrect because it'll impact how I'm viewed more and, my qualifications more [than a man]." Ria mentioned that she at times has felt "scared" to participate in class for fear of "getting it wrong in front of everybody and reinforcing that stereotype of like, women can do STEM." Mari similarly shared that being one of five girls in her introductory physics courses made it "scary to ask questions in class, because you would have people turn around and look at you like, "who's

asking that question right now? It wasn't a welcoming or friendly environment." She further elaborated that, as the only woman in her introductory physics lab section, "it was really easy [for her ideas] to be overlooked":

> I did basically all of the work but, just like the writing for it. Like I did all the lab reports, while everyone got to do the actual labs. And it felt like that was just very annoying to me.

Selena described being ignored by her classmates during group activities, despite her competence in the material:

> I made it known that I understood the concept…but I felt like some of my classmates, specifically the men, were going to everyone else in the group and ignoring me, were like, dismissing me as a resource as someone who knew what they were talking about. And it is something that I do feel even to this day in my classes. Even if it's unconscious sexism, I still feel what's there.

She explained that in such circumstances, she felt unsure as to which aspect of herself spurred such a reaction from her peers:

> There are three big things that are unavoidable for me: I'm a woman, I'm a person of color, and I am a heavier woman. So, I don't know which part of my identity is causing an aversion to them. It could be one of them. It could be two of them. It could be all three. And yeah, it hit me hard first semester. I was not having a good time, it was rough. And specifically in physics with so few women. I was like, "I don't know, if I'm gonna be able to deal with being surrounded with so many men that like, I feel don't respect me in a way because of who I am." It was definitely tough.

Selena added that being the only woman of color in her physics courses "felt very isolating" as there was no one in her cohort who could understand her experiences of marginalization.

Gender-Based Harassment. Two undergraduate women described instances of overt, peer-driven, gender-based harassment that they either directly experienced or learned about from a friend in the major. Katherine elaborated on two separate experiences of gender-based harassment that made her "super uncomfortable." The first involved a male peer openly "questioning her abilities" at her in an out-of-class setting as she described her approach to a physics problem to a group of peers. The second instance entailed a male peer aggressively challenging her right to take up space in a physics classroom. The experience left her feeling "anxious", "unsafe", and "distracted" from learning "for a long time."

Mari described an instance in which a female friend came to her "very upset" after a male peer openly implied that she was stupid in the physics student lounge. Mari and her friend reported the instance together to the department, during which time Mari shared that certain male peers had also made her feel like she was not smart enough to be in the program. Their reporting of the instance contributed to the department requiring all students to attend a diversity, equity, and inclusion-focused training to continue to utilize the physics student lounge space. The department's response made Mari feel assured that gender-based harassment was taken seriously and not tolerated.

Peer-Instructor Interactions

In addition to peer-peer interactions, participants mentioned peer-instructor interactions as central in encouraging or discouraging their academic, professional, and personal growth and well-being. Peer-instructor interactions also informed participants' perceptions of the overall inclusive or exclusionary nature of their physics learning environments, which shaped the extent

to which students with traditionally marginalized identities felt that they belonged in the program. Two subthemes characterize the dynamics of peer-instructor interactions: *Open and caring vs. formal and inflexible* and *inclusive vs. exclusionary*.

Open & Caring vs. Formal & Inflexible. All students who participated in the study emphasized the central role that open and caring physics faculty members played in supporting their knowledge and skill development, sense of belonging, positive recognition, and overall well-being in the physics program. Fourteen students with a range of identities and backgrounds described their physics instructors as all-around enthusiastic to help students truly understand the material at hand by welcoming questions during and after class and offering regular office hours. Qualifiers such as, "all," "always," and "every" were frequently present in descriptions of instructors' dedication to support students' success, which emphasized that many experienced this commitment as the norm. Patrick explained, "if I ever needed help, I could ask." Forat added, "they're always screaming out their office hours." James elaborated that one of his professors went "out of the way" to answer students' questions, even if they were a bit off-topic, "because the most important thing to him would be that you were learning things that you were interested in." Five students mentioned that they greatly appreciated how open faculty in the department were to talk about their research, show students around their labs, and connect students with research and internship opportunities. Diana stated, "there are ridiculously good professors in like cutting edge fields that you can just talk to as much as you want. I don't know where else you would ever get that. It's a huge resource."

Twelve students described the importance of physics instructors who not only helped them to learn and grow as physics students but who also took an understanding, patient, personable, and caring approach when teaching and interacting with students. Katherine

explained, “I think my professors who are just very approachable and down to earth, like very casual. Those professors have been very like motivating to keep me here and to keep like or to really enjoy the environment of physics.” Three detailed specific incidences in which their instructors “worked with [them]” when external factors caused them to miss classes and assignments. Kevin conveyed that his physics professors have, “always been very understanding” and open to help, even when he feels lost or behind due to ADHD. Several women included that some of their professors have openly discussed topics such as mental health and imposter syndrome in class, which helped to normalize these topics in the major. Six students described how they appreciate being able to connect with their physics instructors as individuals. Ria explained, “I've been able to gain courage to talk to my professors about like career related things or personal things. Because they, in a sense, they almost already knew me.” George elaborated, “I feel more cared about in our department than I have anywhere else professionally in my entire life.”

The two graduate student TA and three instructor participants all conveyed that they value creating open, comfortable, supportive educational environments for undergraduates. Stacey and Connie both decided to take their particular TA positions as they felt that guiding students through the experimental lab activities would “make more of a difference” than a traditional physics TA role. Connie shared that as a developing educator, she is committed to not only teaching students physics but supporting and advocating for their socioemotional well-being and growth. She noticed during the experimental lab activities that many underclassmen, particularly those with identities traditionally marginalized in physics, were “looking to connect with a scientist on an authentic and genuine level” and she ended up sharing some of her

struggles and successes in the discipline in a manner that she hoped "empowered" them to pursue their interests and goals.

Three students emphasized that not all interactions with physics professors have been entirely positive and supportive. They mentioned that some instructors tend to take a more formal and inflexible approach when teaching and interacting with students, a dynamic that can be discouraging and intimidating. Jessica perceived that some instructors "look down upon" students who ask "simple questions" or exhibit "uncertainty" in class, which she notes creates a "harsher" learning environment than can be alienating to marginalized students in particular. Ria recounted an instance in which an instructor told her class that their grade on the first exam was a solid indicator of their final grade in the class. Ria, who had scored a lower grade than usual on the exam due to external events, felt anxious upon hearing this assertion (she ultimately succeeded in the class). Diana described how some instructors create a "barrier" to their office hours in which students must "give a reason and then schedule, and then they'll see if the reason is valid, or if they want to help you and then they help you."

Jessica observed a gendered dynamic to the varying ways in which physics instructors interact with students. Female professors, she noted, tend to be less "relaxed and open" in class with "harsher grading policies" than male professors. She acknowledged that her female professors, "probably had to fight a lot harder to get to where they are now" in physics, which she thinks could explain their greater level of formality. One graduate TA, Stacey, explained that she felt more tense when interacting with lab groups that consisted only of men, as it brought to mind "messages about women not belonging" in the discipline, even though all students treated her respectfully. In other words, Stacey's own experiences of gendered marginalization in

physics inhibited her ability to be fully relaxed and open leading groups of male undergraduates, even though she occupied a position of relative authority.

Inclusive vs. Exclusive. Fourteen shared general and specific ways in which physics instructors promoted a welcoming and inclusive learning environment through their interactions with students. Ria emphasized that physics instructors "care about diversity and inclusion and just being inclusive." Selena elaborated, "all the physics professors I've had is they made it very clear that we all have a place here, which was very reassuring for me, especially as a first-year student last year." Instructors fostered inclusivity by encouraging all students to actively participate in class (and preventing any one student from dominating class participation), ensuring that students have study groups, and welcoming different approaches and ways of thinking. Mari remembered her introductory physics instructor telling the class, "You're all physicists now!" after they stood up on the first day of class and recited a quote from Isaac Newton. Since that moment, she's felt that she can identify as a physicist.

A number of students with identities traditionally marginalized in physics brought that they perceive their professors value individuals with diverse identities and backgrounds. Six undergraduate women mentioned that many physics instructors are vocal about supporting and retaining women in the major. Katherine described how seeing "a lot of women and non-American" faculty in the department helped her feel like she belongs in physics. LGBTQ+ students shared that their instructors have all been very accepting of their identities. All student participants of color conveyed that they did not feel like professors treated them differently due to their race or ethnicity.

Graduate student TA and instructor participants communicated a strong commitment to fostering inclusivity in physics learning spaces. They valued students feeling "comfortable" in

such spaces and promoted community building among students in the major. One physics instructor described how his experiences working through college as an immigrant and a first-generation college student make him more sensitive to the challenges and obstacles faced by some undergraduates in the major. Connie stated:

> One of my biggest values as an educator is I want to create safe spaces for students. I'm very passionate about advocating for mental health. And one of the things that personally I care about is being an advocate for students that struggle with trauma-related learning issues, because of my own story and my own journey, and not understanding why I was struggling so much in different learning environments.

At the same time, two women brought up situations in which an instructor interaction left them questioning whether their professor believed that they belonged in a classroom space. Selena described an instance in which an instructor declared after returning an exam, “I think I made that test too easy,” then looked “directly” at her and a female friend, who did well on the exam. She recalled thinking in the moment, “I don't know whether like that was a joke if I should feel offended, but I did feel a little bit hurt. Because what are they implying?” She explained that while all male instructors proclaim that they support women in the major, such statements “don’t feel as sincere sometimes.” Jessica mentioned an instance in which an instructor questioned whether she should be taking a certain class when she momentarily forgot about a conceptual rule and asked her instructor to reiterate it. She added that physics professors tend to “have really high expectations” for students, a tendency that can take the focus away from learning and growth, especially for female students.

Connie, a TA, shared that her commitment to inclusivity as an educator is influenced in part by the instances of exclusion and discouragement that she experienced as an undergraduate.

She switched into physics her junior year of college after initially studying art, which she recalled as "grueling and brutal." Physics learning environments, she noted, are not always accepting of "nontraditional" paths or different ways of learning.

The Cultural Domain

The cultural domain specifies the values, norms, and traditions that are centered and legitimized in a setting. Those in power assert their values as "commonsense" to perpetuate their continued dominance (Collins, 2009, p. 302). An examination of the cultural features of a particular environment provides insight into how dominant values, norms, and traditions are emphasized or "contested" in that environment (Johnson, 2020, p. 57). The cultural dynamics of a physics learning environment influence the extent to which individuals with various identities and backgrounds are recognized as legitimate disciplinary members. In this study, I classified the cultural features of the physics program at Southeastern University into two major themes: *Ways of being in physics* and *ways of doing physics*.

Ways of Being in Physics

Participants named certain characteristics that they perceived to be associated with physicists. Undergraduates viewed certain ways of being as valued by their instructors and embodied by individuals who achieved competence, recognition, and belonging in the discipline. In several instances, participants noted ways of being in physics that needed disrupting to increase diversity, inclusion, equity, and justice in the field. Four subthemes highlight the primary ways of being in physics as identified by participants: *Physicists as passionate about STEM, physicists as deep, accomplished thinkers, physicists as problem solvers, physicists as inclusive vs. exclusive*.

Physicists as Passionate about STEM. All student participants emphasized strong interests in science, math, computer science, and/or engineering as motivators for pursuing physics. Many described intrinsic fascinations with science, space, and programming that originated anywhere between childhood and community college and became more specialized and substantiated over time. Words such as, "passion" and "love" appeared frequently as students elaborated on their enjoyment of various STEM subjects. Tom recalled going down the "rabbit hole of physics" as a kid on YouTube and realizing, "Wow! This is really interesting. I want to learn more about this, this is really cool!" Diana became "pretty hooked" on physics after discovering in community college that it "studied the questions [she had]" about the nature of the world around her. Zach, Jessica, and Bo similarly realized a passion for physics upon learning that it was "at the root" of other STEM fields. For Peter, Ria, Jessica, Zach, and Forat, physics' appeal stemmed in part from a love of math, while Bo, Kevin, and James shared strong parallel interests in computer science. Regardless of its origin and focus, students highlighted a deep interest in physics as important for belonging and/or identifying with the field over time. Zach explained:

> If physics does not excite you. If it feels like a tedious chore. If it feels like all you're doing is trying to satisfy yourself or someone else like your parents, maybe, this is not the course for you. You really need passion to be in the sciences.

Other students supported Zach's assertion when discussing their self-perceptions and experiences in the program. George mentioned that physics was without a doubt a special interest, which caused autism to benefit his persisting in the major despite various obstacles. Mari described how her strong enjoyment of the subject helped to keep her in major when she experienced

negative gender-based interactions in her freshman year. Ria conveyed that being a physicist is "definitely part of [her] identity" because she "loves physics a lot."

Several undergraduates shared that they perceive physics instructors value an intrinsic interest in the subject in their students. Instructor participants backed this perception when describing the physics program. One remarked how he enjoys that physics majors are generally very interested in course material and excited to learn. Another described how physics as a discipline is well-suited for people who "love science at its core." She stressed that one of her goals as an educator is to help ensure that individuals who, like her, derive a "basic joy from learning something new" feel that they belong in the physics program.

Connie noted that, while undergraduates in the major love science, they also express interests in other areas and worry that this is not acceptable when one is in physics:

> A lot of students are telling me like, you know, I love music, I love art, I'm really passionate about these other things. And I feel this, this cult type of feeling from physicists in the physics department where you have to choose [physics] as your one true calling. And I'm like, "Oh, I still don't really know what I want to do with my life. Like, you can have lots of things brewing a lot of different dreams. And that's totally okay and allowed."

Physicists as Deep, Accomplished Thinkers. All undergraduate participants mentioned that being in physics requires a love of learning, a genuine curiosity, and a desire to ask probing questions and make connections in a manner that leads to a deeper understanding. Forat explained, "physics is hard, but it's a weird kind of hard…it's a lot more involved that other disciplines. You have to adjust your thinking." Jessica added:

> In physics, you'll be presented with a lot of variables, and you have to make an equation that states how they connect with each other. That's really difficult to visualize for people. But you really have to start visualizing and thinking deeper about the relations between things.

Many students described themselves as curious individuals with a "strong focus on learning." Diana stated, "I've always been curious about how stuff works around me. I think that's probably like the basis of everybody in the field." George recounted how he regularly takes on the role of "devil's advocate" when studying with peers, asking "why" questions that help the group reach a stronger grip on the material. Peter explained how he prefers to derive equations to "figure out where they come from and then be able to understand them better" rather than simply memorize them, even when doing so is not required in a class.

In addition to identifying these qualities in themselves, students perceived them as valued by physics professors in the department. Seven mentioned that their instructors define good physics students as those who ask questions that "dig deeper", who "think outside of the box", who make connections, and who focus on deriving and understanding. Three underclassmen shared that they were currently focused on connecting deeper with topics and taking time to work through problems, as they noticed these actions where both valued by the department and led to a greater learning. Instructor participants reiterated that curiosity and deep thinking are valued in the physics program. One noted that he appreciates how "80-90% of students [in his classes] really, really want to understand the details rather than [just] know the equations so they can get an A in the class and move on." Another stressed that success in upper-level physics courses requires a "level of mathematical maturity," as students are presented with math in a way

that “they’ve never seen it before.” A third described how she strives to develop experimental lab activities that “get students thinking deeper” about the material that they are learning in class.

As previously introduced, when asked if they currently see themselves as physicists, nine students conveyed that they do not yet possess the depth of knowledge and record of accomplishments required to identify as such. Forat, an aspiring theoretical physicist, explained, “I feel like it's really bringing something to the table to be considered a physicist.” He added that he hoped to generate a theorem in the future helped to advance knowledge in the field. For Jessica, taking classes in other scientific fields such as biology and chemistry made her realize that she “definitely thinks[s] more like a physicist than [she] ever imagined.”

Physicists as Problem Solvers. Fifteen students conveyed that physicists systematically solve problems in ways that advance knowledge and “improve the world.” Several described a general enjoyment of solving difficult homework and test questions. “The actual thing that has kept me in physics is that I really like problem solving,” Katherine explained. For her, the allure of problem solving stemmed in part from the “sense of accomplishment” that she feels from “finishing a problem.” Patrick similarly shared that he felt most successful in the physics program after finishing a challenging test due to the joy of seeing “really tough questions and trying to figure them out…like a really hard puzzle.” Ria also mentioned that she found it “rewarding and motivating to actually be able to solve a difficult physics problem.”

Other students highlighted an enjoyment of problem solving in the applied, experimental realm, saying that they felt more drawn to physics’ “tangible” applications such as nuclear energy, solar cell development, and quantum computing. Kevin summarized his ideal work environment as “a place where we’re always pushing the bounds of what is currently possible.” Diana stated that her undergraduate research position was largely what made her feel like a

physicist, as her data "actually kind of matters." In her future career, she hopes to work in a lab "figuring out ways to make things better." Bo, Rose, and Jessica each shared that they hope to eventually contribute to a solution that helps others and makes a difference in the world. In describing her interest in quantum computing, Rose conveyed that "it would be cool to be part of a big change in the way we view computing."

Two students framed their interest in problem solving in a physics education context. Kevin wants to develop software that utilizes augmented and virtual reality to model abstract concepts in a way that is "easier for the human brain to understand." Zach is passionate about finding ways to "make science more relatable" through science communication. Physics instructors and graduate student TAs also conveyed a love of problem solving, both in their own research and in implementing to empirically supported pedagogical strategies to better connect undergraduates with material. One instructor observed that students in the major tend to "fall into a few categories":

> Some just want to sit quietly with a piece of paper, and just solve puzzles of any sort. And then there are people who really want to change the world. And the problem is that our major is very focused on the first group of people.

She explained that she incorporated experimental lab activities into physics courses in part to provide undergraduates in the latter category with a "small experience would help them to sort of see the connection where they were trying to go. And, and then keep them more engaged [in the program]."

Physicists as Inclusive vs. Exclusive. Undergraduate, graduate TA, and instructor participants described varying perceptions of physicists as inclusive or exclusionary of different social identities, backgrounds, and perspectives. In recounting her experiences as an LGBQ+

woman in the physics program, Mari mentioned that the stereotype of physicists as "nerds…leads to more acceptance" of individuals with diverse sexual orientations, as both groups are commonly framed by society as "outcasts." Mari also described how she's found that the environment for women in the physics program improves as one moves into upper-level physics classes, as people who "really like physics" are "much nicer" than those who initially majored in an attempt to show off their intelligence. Four students emphasized that their ideal future physics work environment is one that values inclusivity and lifts up different ideas and perspectives, as they believe than such an environment is necessary for both supporting individuals' well-being and completing strong, innovative work.

Connie reiterated that a number of instructors share her values of creating a culture of inclusion in the physics program. An instructor participant emphasized that she is committed to expanding others' perceptions of what it means to be a physicist and to identifying and removing barriers that impede the recruitment and retention of physics students with diverse identities and backgrounds. She stressed that societal stereotypes about who "should" be a physics major too often limit the field to individuals who "were good at math and science in high school, [are] pretty introverted, and who are white and male" and alienate individuals who love science and problem solving but do not fit this mold. Furthermore, those in physics who do fit in with the discipline's stereotype sometimes "take advantage" of it by excluding and harassing disciplinary members who do not look like them:

> If you have internalized the idea that physics is very hard, and so you are very special because you can do it. Then oftentimes people perceive the idea of letting everybody in as decreasing their self-worth, as a direct attack on them. And so, I think it's very difficult for folks to do that. And, and I think people [in the department] are in different path place

> with respect to that. I think there are people who intellectually know that we should let everybody in who's capable, but that are still stuck in this idea that like, "You don't really look like me. So, I'm not sure maybe you shouldn't come in."

Ria recalled how stereotypical notions of physics caused her to have "serious doubts" about her decision to major in physics the summer before her first semester at Southeastern University. "Even though I had done well on my physics classes in high school, the thought of completing a physics degree just seemed like a huge challenge that I felt I would not be able to [do]," she recounted. Ria considered contacting Southeastern University's admissions office to ask to change her major, but in the end decided to give physics a try.

Jessica noted physicists can also be exclusionary when they get stuck following "old school ideas" in a way that prevents them from being open to diverse ways of thinking: "You can see it historically. Albert Einstein, for example. He stood out against the convictions of the majority of physicists at that time, and he was labeled inaccurate."

Ways of Doing Physics

In addition to isolating common ways of being in physics, participants identified several practices of doing physics that they perceived as the norm in their physics program. Participants described certain ways of doing as valued, taught, and reinforced by others in the physics program and discussed increasingly adopting them themselves. The three subthemes below characterize and elaborate upon these common ways of doing: *Doing physics requires dedication and perseverance*, *doing physics is an iterative process*, *doing physics is a collaborative endeavor*.

Doing Physics Requires Dedication & Perseverance. Undergraduate participants emphasized dedication and perseverance as some of the main things required for success in physics. In describing the physics program, Diana explained:

> You have to be driven; you have to want it. And you have to be willing to give up a lot. I don't really have a life outside of physics in school. But I like that. And I spend like all day doing studying and homework when the semester's in. And I don't really hang out with people very often outside of physics. And that's fine with me, some people that isn't going to gel with and maybe they can figure it out. I haven't. But you kind of have to be willing to do stuff you don't want to do. Because it's not fun, but it's rewarding.

Jessica highlighted that students who stick with the physics program "come out very strong and very capable of doing anything that they ever wanted." All students placed hard work and persistence are more important for achieving and remaining in physics over time than innate intelligence and skill. Rose explained:

> Some things are going to require more effort than others, and some people are going to have to put in more effort than others, but if you put enough effort, I've always felt like I would be able to do it, no matter what.

Eleven students described themselves as determined and driven people who enjoy challenges and do not give up easily once they set their mind to something. George and Tom elaborated that, while they don't consider themselves to be the "smartest" or most "naturally gifted," they feel that their "consistency" and tendency to "just chip away slowly" at a problem make them good physics students. "Everyone gets bad grades at some point," Mari added. "If you stumble, a bit, make sure this is really what you want to do and where you want to spend your time, and then

just continue." Mari's assertation aligned with James' decision to change his physics major to a minor after three years in the program:

> One of the reasons that I ultimately decided to leave is that I felt myself like not taking the extra time that I should outside of class and so I felt like it was wasting my time if I wasn't going to put in 100% effort.

Many students shared specific instances over the course of their lifetimes during which they realized their own determination and perseverance, such as attending school during the COVID-19 pandemic, distance running, being a first-generation college student from a small town, and navigating academic and personal struggles before and during college.

Most perceived that "all" of their physics instructors highly value hard work, dedication, and perseverance in physics students and mentioned that their idea future workplace does as well. "I've very consistently heard in my time here like from every professor, just like you need to devote time to this outside of class," Paul mentioned. Instructor participants reinforced this notion. One stated that "a number of faculty communicate to students that they need to put in the work and noted that "persistence and organization" are required to be successful in the major.

Importantly, while almost all student participants communicated the importance of a strong dedication to physics, six discussed needing to also find a balance between physics, outside interests, and their general well-being. Diana and Tom conveyed how they've learned that they need to "take breaks" and "get enough sleep" to succeed in the program. Rose described identifying and navigating her priorities during her first year in the program:

> I feel like I've been learning more about priorities, figuring out where my priorities are...and not always prioritizing school, even though I still have that get the job done

> mindset. It was also important to learn that sometimes school can be saved, like it you don't have to be doing that all the time. You do have to also have fun and enjoy yourself.

She added that she believes striking a balance will be "doable" as she moves forward in the program.

Doing Physics is an Iterative Process. All students described the dynamics of learning and doing physics as an iterative process that requires time, planning, strategic effort, struggle, refinement, and growth. They mentioned that this notion was frequently reiterated by their physics professors, who generally valued the process over the final answer, encouraged students to form good study habits and complete practice problems, shared that it was okay to be wrong or uncertain, provided frequent feedback, and stressed that "grades don't matter as much as [one] thinks they matter." Tom elaborated:

> A lot of professors say that it's like the ideas that count. It's not your specific answer. Because you would…most of us honestly, get like the wrong answer half the time, like the final answer, but our process was what really mattered.

Nine students admitted that they did not enter the physics program with this growth-centered mindset, and recounted feelings of "frustration", "shock", and "discouragement" upon receiving a low grade on an exam or not understanding a concept. Most succeeded academically in high school without putting in as much effort, and instances of struggle led them to question whether they had the ability required to belong and persist in the major. Rose explained:

> It was like a big smack in the face of like you need to not be putting any of your worth on like academic success. Because like, you may have been smart in high school, but there are plenty of people here who are smarter than you are. You're going to have to be

> putting in more effort than you were…This is going to be harder than everything leading up to this point.

Zach faced a similar confrontation with academic struggle as a freshman and discussed how he was spending part of his summer forming a plan for the coming academic year to turn his challenge into "something fruitful." Peter stressed that it is "really important to not get down on yourself" and to "reach out for help" as needed and keep moving forward. Tom discussed realizing that "sometimes [in physics], there's genuinely no solution to something," which helped accept the uncertainty and challenge inherent to the field. For Mari, a conversation with an upperclassman after she failed her first physics examine freshman year helped put things into perspective:

> I guess I kind of realized how much studying I needed to do with the second test that I had because the first test I had was in the 30s. I had no idea what I was doing, it was so stressful and I was like, "Oh my gosh, I'm gonna have to drop the class and I have to drop the program and I'm not going to be able to pass the class!" And so, I had one of the seniors talk to me, and she was like, "I understand I've been in the same position, I had no physics experience whenever I came." And she was like, "if you study really hard now and form these study habits, you're going to be able to get through the 400-level classes much easier because you already know how much studying you need to do." I spent a lot of time [studying], but I had like a 60-point jump in my test grades. So it was definitely a really good payoff.

Selena conveyed that, as a freshman, she sometimes found herself questioning whether she had the "intuition" required to succeed in physics. Her introductory physics instructor assured her

that “physics intuition” is simply something that “comes with work and practice.” Kevin reinforced this notion when recounting his experiences learning physics:

> Physics sense like that sixth sense you get as a physics student about how to approach and solve a problem. It is something you don't start with; you just learn it. That's where the stubbornness comes in. You have to survive until you get it. And then you’re like, “Oh!”

Nine student participants mentioned specific approaches and thought processes that help them navigate the challenging, iterative nature of physics. Peter enjoyed “breaking problems into steps” and celebrating small “victories,” while at the same time “keeping in mind [that] there are a lot of ways to solve problems that [he] might not know yet.” Patrick, Tom, Rose, and Ria regularly reminded themselves that their main goal is learning, not perfection. Patrick carefully reviewed his tests and tried “on his own time to figure out the questions.” Rose, Forat, and Diana directed their focus on the process rather than jumping to the final answer. George, Diana, and Jessica remembered that doing physics takes time and patience, given the difficulty of the subject matter. Four students mentioned that viewing learning and doing physics as an iterative process is key for belonging in the physics program. Rose stated, “I think the big thing is the mindset is that you're there to learn and you're there to grow.” Paul described his ideal future work environment as one in which “failure isn’t punished,” adding that, “in science, you want to not feel bad if something you’re working on doesn't come to fruition, because it often doesn’t.”

Instructor and graduate TA participants also stressed the iterative nature of learning, teaching, and doing physics. “Most students who see progress come to class, take notes, then go struggle,” one instructor shared. Another noted the importance of forming good study habits and said that many students in the major have been able to “coast on intelligence” until college,

which harms them eventually. A third instructor mentioned the importance of "normalizing failure" in physics. Instructor participants discussed ways in which they convey the iterative process of physics to students. One scaffolded programming skills by providing students with increasingly complex computational exercises. Another regularly incorporated demos in class, during which students first predicted what would occur (emphasizing that it was okay to be wrong), then witnessed the demo and discussed as a class what they learned. Speaking about her approach to guiding students through their experimental lab activities, Stacey described:

> I try to have a good sense of humor about experimental physics…that's how I try to approach my own research. I feel like you have to keep a good sense of humor about it, because things don't work…Sometimes it's something really silly that doesn't work and then you have to find it, but then you dig down and then you get it eventually and so like that process of failure.

When asked how students reacted to the "process of failure" in experimental physics, Stacey explained:

> A lot of them would immediately get worried. Like, "How does this affect my grade?" sort of mindset. And like, "We need the right answer for the test!" And so I would just be like, "No it doesn't matter, this is just based on your process, this is if you have an answer if you can tell me, maybe why that answer happened that's what I care about more than what the answer is."

She added that she avoided taking points off of students' activity write-ups unless they were "wildly off" and focused instead of providing them with process-oriented feedback. Connie shared a similar experience with students and said that she noticed that she found herself becoming more "adaptable" and "playful" with experiments as the semester went on.

> Reflecting on her own experiences as an experimental physicist, one instructor recounted: Most physicists I know who are experimentalists went through a period of time where they were just like, I shouldn't be an experimentalist. Because my experiment doesn't work. And then having a group of people around them go, "No, that's the way it's supposed to be that no experiment works the first time. And that's totally normal. It has nothing to do with you." I think having that cycle then enables you to be more resilient to a variety of things in your life.

Doing Physics is a Collaborative Endeavor. Thirteen students mentioned working together as an important component of learning, doing, and belonging in physics. In describing his experiences throughout the physics program, George recounted, "reading and doing the homework was not enough. I could get by with those, but I didn't gain any insight. The insight came from working with people." Five described themselves as team players who thrive most when they join forces with others. "I love working with people, I think, like more heads are, are better than one," Selena conveyed. Three others admitted that while they tend to prefer to work on things individually, they recognize the benefits of collaborating and asking their peers and instructors for help when needed and are trying to improve in this area. In providing hypothetical advice to his younger self, Paul emphasized, "Don't be afraid to ask your friends for help and don't be afraid to ask your professors for help. This is something I took embarrassingly long to internalize."

Four students described instances in which their physics courses emphasized a collaborative atmosphere. Paul and Kevin recalled particularly enjoying classes in which team projects were an important aspect of learning and assessment. Kevin wished that more classes in

the major were executed like his computational physics course, which modeled a truly collaborative learning environment:

> We were in a team the entire time and we only switch teams once. But we all worked towards one project at a time and even took tests together. I cannot speak highly enough of that strategy that was awesome.

Bo, Paul, Tom, Selena, and Mari said that they found the collaborative nature of their courses' experimental lab activities "fun." Tom emphasized how the activities made him feel like he belonged in physics due to their focus on teamwork and collaboration: "I got to meet new people and we got to work together and share ideas, it was very nice to talk to other people and learn, it was nice." Instructors mentioned that they decided to incorporate the experimental lab activities in part to "provide students with a collaborative experience." Both experimental lab TAs highlighted how they fostered student collaboration during the activity by intentionally engaging with all students and proactively creating groups in a way that prevented a woman or student of color from being in a group with all white men.

Participants also brought up collaboration as key for conducting research and developing tools that move knowledge forward and improve the world. George highlighted that engaging in meetings with his research group and attending departmental colloquiums are what make him feel most like a developing physicist. Eight students stressed that they hope to work in environments that value people with diverse perspectives, experiences, and strengths coming together to support and enhance each other's work. Many described their current undergraduate research positions in the physics department as emulating this ideal. Jessica described:

> Everybody's helping each other succeed because it's not about like, who's first or whose name gets published…It's about the fact that we're in this together and we're trying to make a difference in the world.

The Structural Domain

The structural domain organizes and institutionalizes power in a setting. Structural features of the K-12 education system shape who has access to advanced science and math courses, high-quality learning materials, experienced teachers, and extracurricular science experiences (AIP, 2015; Office for Civil Rights, 2018). On a smaller scale, the structural components of a university physics program shape the ease with which students can learn, grow, and see themselves in the discipline over time. The present study isolated three structural themes: *Unequal foundations*, *course and curricular structures*, and *out-of-class structures.*

Unequal Foundations

When asked to elaborate on their path to studying physics at Southeastern University, all undergraduate participants identified pre-university educational and professional experiences that inspired and fostered their interests and competence in the discipline. All but one took physics at a high school or community college, and many completed advanced math. Over half also described meaningful informal resources or opportunities. Many students recognized the benefits these experiences conferred and emphasized how challenging it would be to succeed in the physics program at Southeastern University without such a background. I categorized students' pre-university foundations into two subthemes: *Unequal K-14 foundations* and *unequal informal foundations*.

Unequal K-14 Foundations. Sixteen undergraduate participants completed at least one physics course before starting university. Some enrolled in regular or Advanced Placement (AP)

physics offered through their high school, while others signed up for introductory physics through a nearby community college. Students described their high school and community college physics experiences as academically preparing them for their university physics courses to varying degrees. Tom, Kevin, and George recalled that the physics courses they completed at their local high school and community college respectively as later helping them "very minimally." Others articulated that high school physics provided them with a conceptual foundation for their initial physics courses at Southeastern University. Peter mentioned that taking AP Physics I and II helped him to feel "pretty at home with everything" in his first introductory university physics course. Katherine, Selena, and James outlined how their high school physics experiences solidified their interests in the discipline. For Selena, this solidification came through interactions with course content, while for Katherine and James, interactions with others helped to confirm their enjoyment of and competence in the subject. Near the end of her high school physics course, Katherine's teacher asked her to be a teaching assistant for the course during the following school year, which she says gave her a "mentorship in physics." James connected with a high school peer who was also "super into physics," and enjoyed discussing the subject at length.

Five students also mentioned completing advanced math, statistics, and/or computer science courses in high school or community college. Three such students, Zach, Forat, and Jessica, emphasized how challenging physics courses at Southeastern University would be without a strong foundation in both physics and math. Jessica explained:

> If you don't have enough background, or enough specializations, and a strong mathematics background, a pretty good physics background, but mathematics I would

> say is the most important thing, then you might not even know how to take what [your instructors] are providing you and push it forward.

Instructors and graduate TA participants echoed that students struggle to succeed in the physics program when they did not have a solid foundation in these subjects. Connie recalled that "there was a clear distinction" between how "overwhelmed" freshmen who did and did not take physics in high school appeared when they came to her for help and advice. The one undergraduate participant, Mari, who did not take a physics course prior to coming to Southeastern University due to its lack of availability at her high school, recounted the steep learning curve that she faced in her introductory university physics courses, as her instructors assumed that course content was a "review from high school" for all students in the class. Getting through it, she emphasized, took a great deal of "perseverance" and self-reflection.

Unequal Informal Foundations. Nine students highlighted specific sources external to the K-14 classroom that promoted their knowledge, skills, and interests in physics. Peter engaged in "a bunch" of his high school's STEM clubs such as the robotics club and participated in middle school science fairs. Kevin and George discovered their interest in physics during job experiences that they had while in community college. Four students described media sources such as popular science books, YouTube, and science fiction and fostered early fascinations with physics and other STEM disciplines. Mari recalled how watching Star Wars movies with her dad inspired her interest in space, which she later supplemented by watching YouTube videos about theoretical and astrophysics "all the time." Bo became "obsessed" with a YouTube channel about organic chemistry in the fifth grade and "convinced [their] parents to buy them a glassware set so that they could make fireworks."

Several students mentioned family members who encouraged their pursuits in the discipline. Rose detailed how both her immediate and most of her extended family "have some sort of STEM degree, mostly engineering." As such "STEM was always very prevalent in [her] life." Ria grew up attending star gazing sessions at a local park with her family, which sparked her interest in astronomy. Peter's dad "taught [him] everything he knows about electrical stuff, plumbing, and fixing up the home." He acknowledged that getting to "work with his hands" gave him useful skills that women may be less likely to receive due to gender stereotypes.

Course Structures

Participants highlighted various features that characterized the structures present within and across courses and labs in the physics program at Southeastern University. Undergraduates elaborated how these structures shaped their perceived competence, recognition, and belonging in the program. Four subthemes illustrate commonly narrated organizational attributes: *Challenging course content, clear course alignment, low-stakes assignments vs. high-stakes tests*, and *active, hands-on, and applied engagement.*

Challenging Course Content. Almost all undergraduate participants heavily stressed the difficulty of courses within the physics program at Southeastern University. Phrases such as, "it's all hard," "it's pretty tough," "it's a hard major," and "nothing in physics is easy" emphasized the universally challenging nature of the program (George, Rose, Zach). Students explained that the program's difficulty stemmed from both the rigorous content and the fast pace of its courses. "You've got to be on your toes throughout," Zach conveyed. Five students and one instructor highlighted that the content of physics courses gets progressively harder over time, particularly when one advances out of introductory courses which, for many students, cover content that they've seen in high school or community college courses. For three students, the

difficulty of the program was intensified because they learn differently from the "norm." Kevin and Diana described how ADHD makes it particularly challenging to follow and learn from lectures and can make concepts take longer to understand. "The problem is now there just doesn't exist tools for people like me," Kevin stressed. Selena mentioned that she feels behind when instructors have students quickly work through examples in class, as she needs time and space to work through and "process information." The challenging nature of the program was also magnified for students with jobs, minors, and double majors. Kevin calculated that, between physics, computer science, and two jobs, he often worked 80 hours a week and still struggled with feeling behind. "My biggest concern is that there's nothing I can do about it," he underscored.

Three students stated how "a number" of students drop the major due in part to its difficulty. Speaking about his freshman year cohort, Zach stated, "We had like four or five people just [change majors]. At least two of them, I know they're actually very passionate about physics and it's very sad for me to see that." Seven participants admitted that the challenging nature of the major has made them at times question whether they belong in physics. Tom recounted:

> When I'm working on homework late at night. I'm struggling really, really hard. I'm like, "Dang, do I really have what I need to be able to do this?" Yeah, it's just it's difficult, and so this happens pretty often.

Clear Course Alignment. Students emphasized the importance of clear curricular alignment, both between and within their physics courses. Four stressed that, while courses in the physics major are quite challenging, their sequence within the major allows content to build on itself in a manner that is conducive to learning and enjoyable. "[My courses over the past year]

highlighted the coolest parts of physics," Bo exclaimed. Others appreciated the clear and "simple" structure within their physics courses, which made expectations and due dates easier to follow.

When asked about their experiences in their classes' experimental lab activity, thirteen mentioned that its benefits related to its alignment and incorporation into the rest of a class. Paul detailed, "I always enjoy learning about something in a book and then being able to do it physically within like an hour and see the same effects arise that's legitimately awesome." Ria explained how her instructor's placement of the activity, "helped to expand [her] understanding of entropy in the class." Seven students described instances in which the experimental activity did not fit in well with a course's structure and as a result "seemed like a side thing," was "stressful," or "felt a bit tacked on." "It related [to the class], but you really had to think about how it related," Jessica said. Some conveyed that their instructor did not provide prior context before or follow-up after the experimental activity, which further made it seem disconnected from the class. James stated:

> After we did it, we never heard anything about the activity ever again, like we never talked about it as a class. I feel like maybe if we'd gone over it like as a class that could have been more helpful.

All instructor and graduate TA participants brought up that they want students to see students "really engage" with the activities as opposed to viewing them as an "extra" assignment and conveyed that value coordinating them with the class to help "meeting the needs" of students.

Low-Stakes Assignments vs. High-Stakes Tests. In describing the structure of their physics courses, students mentioned that most were a mixture of low-stakes homework assignments, in-class review questions, an experimental lab activity, and high-stakes tests.

Homework typically took the form of 6-12 challenging problems assigned at the start of the week that some, but not all, instructors later went over in class. Peter emphasized that, in his experience, "homework was actually a lot harder than [tests]" as his instructors wanted students to "stretch ourselves a little bit." George added, "homework for the last year is what really taught me physics. And discussing the homework has helped me understand what's actually going on." In addition to completing homework problems, instructors commonly encouraged students to attempt practice problems in their textbook. Paul shared in a "number of classes, reading the textbook and then writing a little bit about it before class was a graded thing." At the start of class, instructors often asked several review questions to "get [students'] brains warmed up" and address "misunderstandings" prior to moving into the day's material.

Students clarified that a course's experimental lab activity generally counted as a homework grade, which contributed to it being "a lot less stressful than regular labs." Fourteen used qualifiers such as "fun," "cool," and "awesome" to describe the activities. Bo summed up their experimental lab TAs approach as, "figure it out and have fun!" Selena conveyed that there was a "comfort in that we [couldn't] mess it up." Patrick elaborated:

> There was no stress really because…you weren't trying to get anything exactly right. You were just trying to…mess around and just get a feel for what it would actually be like, if you were actually doing an experiment.

Jessica and Tom mentioned that the activities' short duration and straightforward structure further added to their low-stress nature. Both graduate TAs stressed that they intentionally tried to create a "relaxed" and "lighthearted" learning environment as students completed the experimental lab activities.

While all physics courses included frequent low-stakes, formative assignments, nine students stressed that "tests are what make or break your grade." Five emphasized that they were "really thankful" for the short-answer format of their physics tests, and for the fact that instructors give partial credit when grading. Patrick recalled an instance when he "got so much partial credit that it was almost like [he] got the whole question right, even though [he] didn't get the right answer." James compared this to his testing experiences in physics courses for engineering majors, which do not give partial credit and thus don't give students the "opportunity to actually learn from [their] mistakes." Though even with partial credit, multiple students conveyed that the weight of tests made it so that one could fail a class if they were "just having a bad day." Kevin, George, and Diana described how being neurodivergent sometimes made physics tests quite challenging even with accommodations, particularly when they were timed. Kevin explained that going back to review his test mistakes, a common practice in the program, does not work for him, as it leads him to get "further and further behind" while instructors move on to new material. "Tests are too final in how they teach students," Kevin stressed. He described feeling "stunned" and demoralized after failing a final exam caused him to fail a class, even though he obtained full credit on the homework portion of the course. Kevin added that he wished exams were more project-based and formative so that he and his peers could "pull from [their respective] expertise" and "adapt actively" to learn from their mistakes before "it's in the gradebook." One instructor participant noted that he hopes to move away from employing standard tests in the future based on student feedback.

Active, Applied, & Hands-On Engagement. All participants highlighted various ways in which their physics courses and labs promoted active engagement, demonstrated tangible applications of abstract concepts, and involved students in hands-on activities. Katherine

emphasized that instructors in the program, “really want you to be an active learner.” James described how his physics instructors over the past academic year regularly incorporated interactive activities, sometimes using instructional technology, in which students discussed and answered questions relevant to the day’s topic. Rose added that her introductory physics instructor “really, really liked when students asked questions” in class. For Peter, instructors’ encouragement of active engagement made him feel a sense of connection and belonging in the physics classroom. Others appreciated how their instructors illuminated real-world applications of course concepts by utilizing demos and mentioning career connections. “I love it when teachers show how it’s relevant to us, or show a demo, because I think it’s the best way to keep students engaged,” Bo stated. Kevin and Katherine mentioned particularly enjoying physics courses focused on developing computational and lab skills, both for their content and delivery. “I think that [our] physics program is really well-tailored to really doing physics and not just learning it,” Katherine stressed. Kevin added that the team and project-based nature of his physics computing skills class made it, “the most effective way [he’s] learned Python and computational science.” He described how he and his team members regularly took a trial-and-error approach to write and troubleshoot functions and built on each other’s strengths to ultimately succeed.

Two instructor participants included how they regularly incorporate active learning strategies such as think-pair-share and just-in-time teaching into their classes to keep things “lively and interactive.” They also emphasized helping students make connections to real-world applications in their classes and stressed that this was one reason that they decided to incorporate an experimental lab activity into their courses. One recalled that, as a student, he had to make such connections himself:

> When you get focused on equations and just a formal way of teaching where you have to you know solve problems which are really abstract and are unrelated to life, I think it gets a bit frustrating for students to really see the connections. And so my approach has been for any topic we do… just make sure that the students understand how you know it's related to something that they do encounter on a daily basis.

In describing their experiences completing their physics courses' experimental lab activity, 13 students brought up that the activity was most beneficial when it provided a tangible application to what they were learning in the course. Jessica described this as "really exciting." Tom conveyed:

> It was really interesting and kind of thought provoking because when you're working in class it's just all kind of numbers and equations. That's tough. You're like, how does it work in your life? But [during the activity] you can actually see it. I thought that was really cool.

Several students mentioned that they enjoyed getting to learn about and use equipment in the physics department's shared user facility. "We used a lot of the actual instruments to measure stuff like the wavelength of light. That really excited me," Zach stated. Bo appreciated that their experimental activity TA encouraged students to "play around with the setup" of their experiment, which allowed for a less structured atmosphere than a traditional physics lab. This dynamic made Patrick feel "more energetic about learning," as he got a "feel for what it would be like to do an actual experiment." Rose added:

> The TA was just right off the bat like, "Okay figure it out, have fun!" But…you don't know the answer you're necessarily supposed to really be getting. Like you kind of do

> because it's not a very complicated experiment, but like you don't have it written out in the lab report.

Both graduate TAs enjoyed "teaching students to use real equipment." They stated that they hope students view the experimental lab activities as an "empowering thing that is giving them more tools" that they can later use in their academic and professional careers. An instructor explained that, prior to the development and incorporation of the experimental lab activities into courses, the physics major had an "experimental desert" in which students completed traditional cookie-cutter labs in introductory courses, they had no lab requirement until a required, independent senior research experience. As a result, students often felt unprepared to complete the senior research experience and frustrated and "disheartened" by the process of experimental physics. In addition, students more drawn to experimental than theoretical physics grew to believe that the physics major was not for them. Given that many physics-related jobs require experimental and technical skills, the physics program was not adequately training students to thrive in a professional setting. She hopes that the experimental lab activities help to better scaffold research skills, teach students about the dynamics of experimental physics, and "prepare them for their ultimate career."

While student participants enjoyed the experimental lab activities, 9 students, mostly upperclassmen, wished that they were less structured and more adjacent to the actual physics research process. They suggested explicitly adding a more open-ended, design component to the activity to provide students with an opportunity to think critically about how they could hypothetically investigate a particular problem. "Obviously you can't actually go out and make everyone's experiment happen," Kevin stressed, "but the professor can like just talk about these proposals because that's a real thing for physics students, making proposals and designing

experiments." Kevin, Diana, George all envisioned a modified assessment for the activity that was less "fill in the blank" and more of a reflection of what students learned and took away from the experience.

One underclassman, Zach, wished that students within groups were given more defined roles and tasks during the experimental activities. When asked to describe the typical dynamics of their group during an experimental activity, five undergraduates (Ria, Selena, Mari, Rose, and Tom) stated that their group rotated tasks equally. Four others (Diana, Bo, Patrick, and Paul) mentioned that their group tended to fall into roles "organically." Bo detailed that group members "naturally fell into their role" while Patrick said that his group "figured out who does what best." Forat described how he "took the lead" in his group, who in turn "just went along with it."

Out-of-Class Structures

Participants also isolated multiple physics program and university structures that played a role in their physics identity development and over-arching experiences in the discipline. Three subthemes characterize these structures: *Undergraduate research and internships*, *diversity, equity, inclusion, and justice (DEIJ) and affinity groups*, and *departmental and university engagement opportunities*.

Undergraduate Research & Internships. Eight student participants highlighted their involvement in undergraduate research within the physics program as an important source of interest exploration and confirmation, recognition, belonging, and disciplinary identity development. They described initially connecting with their mentors in a variety of ways, from peer recommendations to reaching out to faculty after a required 1-credit freshman seminar in which departmental researchers took turns introducing their work. Peter appreciated how his

research mentor gave students "freedom to explore [their] interests" and conveyed that his position has helped to clarify his "role" in the department. James shared how he first "fell in love" with coding during his two years in a departmental lab and emphasized that his research experience is "another big reason [that he] loves the community of the physics department." For Ria, engaging in undergraduate research helped her realize that she enjoyed "coding, data visualization, and just working with…data" more than the "research process itself." As a result, she pivoted her career interests from astronomy researcher to statistician and spent the past summer interning at an analytics software company. Even though she does not plan to pursue a career in research, Ria stressed that the supportive relationship she has with her mentor "has been really beneficial in helping [her] grow as a scientist and as an individual." She added that her peers and instructors have commented that they find the fact that she is working on a publication "cool" and "interesting," which helps make her feel like a "qualified physics student." Forat and Paul highlighted their undergraduate research positions as making them feel like they belong in physics. Paul specified that this feeling arose both from getting his code to work with "moderate consistency" and from conversing with lab mates who "legitimately" want to learn about each other's work. George and Diana conveyed that contributing to actual scientific research and participating in lab meetings and physics colloquiums is largely what makes them feel like a developing physicist. Five students stated that their ideal future work environment closely mirrors the dynamics that they know from their undergraduate research and internship positions.

Four other students mentioned that, while they have not yet engaged in undergraduate research, they hope to in the future. Bo conveyed that their imposter syndrome prevents them from seeking out opportunities, as they worry that they do not possess the needed skills. Jessica suggested that the physics department create ways to help women connect with research

opportunities, as it "may be a lot more intimidating for a woman to reach out to a professor, especially because most professors are men."

DEIJ & Affinity Groups. Six students mentioned an involvement or awareness of departmental groups centered on increasing diversity, equity, inclusion, and justice in physics. Paul described the existence of a departmental DEI committee as "reassuring." Forat shared that his involvement in the department's organization for Black physics student has "definitely" been positive, though he wishes that the group had more members.

Four women brought up the department's group dedicated to building community and career development for women in physics. Ria, an officer, described how the group hosts social events, "provides lunches or dinners for study sessions," and brings in speakers who have done "really unique, interesting" things with their physics degrees "to emphasize to people that there are so many different things that you can do with a bachelor's in physics." Ria recounted co-organizing a campuswide "diversity in STEM club showcase" that entailed watching Hidden Figures in the campus cinema followed by a discussion about "what it's like to be a woman in STEM today, and how that experience may have evolved over time." Selena described the group as a "nice community," while Jessica stated that she wished the group was more focused on women creating together as opposed to social events.

Departmental & University Engagement Opportunities. Undergraduate participants mentioned specific departmental and university structures that supported their academic success and sense of belonging at the institution. Six students highlighted structures and practices that allowed students to interact with departmental members in an informal context. Four described the department's student lounge as a "good way to study" together and to "build a community" with students at different academic levels. Paul appreciated being included in "fun" celebratory

meals with his research group and said that he doesn't feel "that out of place" even though the group is mostly graduate students. Katherine stressed that informal engagement opportunities such an instructor conversing with students over cookies helped her feel like she belongs in the program:

> I think those are very, very cool. It kind of de-formalizes your relationship with other people, because I, in general, do treat peers I don't know or really all my professors with a very formal level of respect. I think that, to really feel like you belong, you might need to deconstruct that.

Six students brought up university resources that supported them in their academic success and sense of belonging, both in the department and in college at large. James described how being part of a university program for first-generation college students has "helped [him] a lot because [it's] given [him] access to so many resources." Diana similarly mentioned that a scholarship program for transfer students was a main reason that she decided to attend Southeastern University. Zach and Selena included the university's academic support and tutoring center as a solid resource for success that they learned about from their physics academic advisor. Ria discussed how conversations with a university career counselor made her feel confident that changing one's career goals over time is normal. Bo emphasized that they spend a lot of time at the university' LGBTQ center, through which they've found a community who is "accepting of who [they are]."

The Disciplining Domain

The disciplining domain relates to how policies and practices are differentially implemented and enforced, often to protect and uphold those in power. Discipling dynamics in

postsecondary physics educational environments impact how structures are implemented and how students with various identities and backgrounds are recognized, supported, and valued. I identified two major disciplining themes that shaped students' disciplinary development and overarching well-being and safety in the program: *Importance of flexibility and accommodations* and *importance of awareness, acknowledgement, and intervention that supports diversity, equity, inclusion, and justice (DEIJ).*

Importance of Flexibility & Accommodations

Ten student participants highlighted flexibility and accommodations in their classroom and research environments as essential for their success and belonging in the major. For some students, flexibility took the form of instructors adapting the pacing of their courses to ensure understanding and engagement. "[My introductory] class wasn't insanely structured," Peter described. "I'd say being able to interject whenever there's something going on that's confusing or maybe not totally clear is the most important thing in physics." Bo recounted how some of their favorite courses welcomed student questions even if they weren't totally relevant to the content at hand. In Diana's experience, instructors became more flexible as one moves from introductory to upper-level physics courses: "A lot of the higher up classes, professors will give you much more lenient extensions, whereas others won't early on, because they want you to realize how tough it is."

For other students, flexibility entailed instructors working with them when they encountered external events such as illness or family issues that prevented them from being present in the classroom. "Our professors work with us. The department works with us, especially me. I had much stuff going on the past year," Zach explained. Katherine detailed how her instructors employed some of the "leftover elements of COVID" such as recorded lectures

and optional attendance in a manner that was “super helpful” when she dealt with external matters. In such situations, instructor flexibility allowed for “breathing space” and made students feel that they could still succeed in the course. Two students, Ria and Jessica, recalled instances in which an instructor’s lack of flexibility during an external event reduced their sense of belonging and support in the program.

George, Kevin, and Diana emphasized the need for flexibility and accommodations as they navigated the physics program as neurodivergent students. Diana stressed the importance of instructors extending time on tests, posting notes online, and having some flexibility with due dates:

> I had a professor this year who would not extend anything ever. So, there was a lot of stress and sleepless nights working on stuff and prioritizing, just getting it done versus really learning anything, which you kind of have to do to get it done. But it was it was kind of…I can't really say toxic because it's within the allowed rules, but it was very painful. It was very painful.

Kevin emphasized that as physics and computer science student who works, has ADHD, and who completed all of his easier classes before transferring from a community college, the inflexible 12 credit-hour minimum to receive many types of financial aid acts as a barrier to his well-being and success: “The biggest thing I would view as help would be just the lowering of what would be considered a full-time student.”

Importance of Awareness, Acknowledgement, and Intervention That Supports DEIJ

Multiple undergraduates emphasized the need for physics program members to develop and maintain a critical awareness of the dynamics of marginalization, to explicitly acknowledge the ongoing existence of oppression, and to intervene to inhibit the perpetuation of exclusionary

and/or inequitable interactions, cultures, and structures. In describing her experiences as a queer woman of color in the physics program, Selena emphasized the importance of physics community members recognizing the on-going existence of oppression in physics spaces. Selena explained that, for her, such an acknowledgement helped to reassure that "the issue is not [her], but a greater issue that society itself needs to work on." In addition, it made her feel more comfortable with reporting instances of bias, discrimination, or harassment:

> It kind of creates a support system in a way. Just to know that someone is there in case anything happens…Because it's kind of unavoidable, misogyny and racism, whether it's unconscious or like, direct. But the simple acknowledgement that like, we're going through it, and it's going to happen, whether we like it or not, is enough for me.

Selena's recommendations were echoed by Katherine and Mari, who both shared that their instructor and peers generally did not seem to notice instances of gender-based harassment in the classroom. "Pay attention," Katherine stressed. "If you see something like that happen, try to intervene." In describing his experiences with financial hardship, Kevin conveyed, "There're definitely others like me but it's not something that's talked about at all…which I think is a shame." Ria wished that the department held workshops for students on the dynamics of imposter syndrome to help legitimize and navigate such feelings in physics.

Students shared varying experiences with the physics program responding to known instances of oppression. Katherine reported her experience of gender-based harassment to the department and university but remains unsure of their response. "It's a little bit worrisome moving forward," she stressed. Mari and Ria each brought up situations in which the physics department took explicit action against bias, discrimination, and harassment in the program. As previously introduced, Mari described how she and a friend reported gender-based harassment

that occurred in the physics student lounge. Due to this and the reporting of a "racist comment" made in the space, all students were locked out of the lounge until they participated in a university DEI focused training. Ria remembered completing this training as a freshman. It provided evidence to her that the physics program is "a community that cares about diversity and inclusion." Mari also recalled an instance during her freshman year in which a physics instructor was fired for making sexist comments while teaching. "You can't say that to people and expect to still have a job [here]," she stated. "So, I think that helped a bit."

Four students acknowledged how their own privileges might have shaped their experiences in the physics program. Paul conveyed that "just because [he] hasn't noticed [issues] doesn't mean [they're] not there." Peter shared that his childhood experiences helping his dad might have given him hands-on skills that women are less likely to receive. Rose admitted that growing up surrounded by female family members working in STEM most likely gave her a "different perspective coming in." Katherine expressed that while she has felt excluded from her physics peers due to her gender identity and presentation, students who are not white and/or who are visibly queer most likely experience even "more extreme" assaults on their belonging. Such remarks speak to the potential for undergraduate physics programs to foster norms and structures through which individuals with a diversity of social identities and backgrounds actively acknowledge and dismantle the legacy of oppressive interactions, cultures, and structures in the discipline.

Discussion

This study contributes insight into the lived experiences and disciplinary identity development of undergraduate physics students with marginalized and multiple marginalized social identities who engaged in major-specific physics courses that incorporated an interactive

experimental lab activity at a large PWI in the Southeastern United States. Situating a conceptual model of physics identity development in Collins' (2009) Domains-of-Power-Framework allowed for a critical exploration of how marginalized students in the program perceive that the interpersonal, cultural, structural, and disciplining components of their physics learning environments support or deter their disciplinary interests, competence, recognition, and sense of belonging and hence, their physics identity (Hazari et al., 2020; Johnson et al., 2020). Narratives gathered from individuals with a diversity of roles, backgrounds, and social identities convey a complex portrayal of a physics program that both actively disrupts and reproduces stereotypical conceptions of the discipline. This discussion synthesizes major findings and provides practical implications for undergraduate physics program members. It ends by offering directions for future research.

Physics Identity Negotiations

The present study frames physics identity development as the process of being recognized by the self and others as the *kind of person* deemed valuable and legitimate in physics spaces (Avraamidou, 2022; Gee, 2000; Carlone & Johnson, 2007). Given the interpersonal, cultural, structural, and disciplining power dynamics of what Johnson (2020) describes as the "prototypical physics department," physics students who do not embody a white, masculine, heteronormative, able-bodied, middle- and upper-class disciplinary standard are often excluded developing a physics identity to the same extent as their non-marginalized peers (Avraamidou, 2022; Gonsalves & Danielsson, 2020; Traxler et al., 2016). Interestingly, in the present study, 5 out of the 8 women and non-binary undergraduates (including women of color, women from lower social classes, queer, and neurodivergent students) and only 1 out of 9 men proclaimed that they currently identify as a physicist given their existing level of interest, investment,

knowledge, and skill in the field. As expanded upon below, this finding stemmed largely from a combination of inclusive programmatic practices, cultures, and structures, and from agency on behalf of marginalized students and instructors to reframe what it means to be a physicist (Johnson, 2020; Carlone & Johnson, 2007; Ko et al., 2014). The range of perspectives presented by participants within and across various social identities substantiate that the processes through which students construct and negotiate their position in physics in relation to their gender, racial, ethnic, sexual orientation, socioeconomic status, and disability identities are heterogenous, dynamic, and intersectional (Avraamidou, 2022; Gonsalves, 2016). The subsequent sections discuss the overlapping and divergent ways in which physics students with a diversity of social identities defined and negotiated their disciplinary competence, recognition, interests, and belonging in the context of the power dynamics of their university physics learning environments.

Dynamics of Competence, Interest, & Recognition

All participants perceived that competence in physics requires connecting with conceptually and quantitatively challenging material in a manner that promotes deep engagement and understanding. This description aligns with dominant notions of physics as among the most intellectually rigorous STEM and non-STEM disciplines (Hughes, 2001; Gonsalves, 2014; Traweek, 1988). Undergraduates who stated that they did not yet feel qualified to identify as a physicist expressed that they did not possess the level of understanding and/or record of accomplishments required to assume this title, a finding that has been observed by others (Irving & Sayre, 2015; Quichocho et al., 2019). Though unlike common portrayals of the field, participants conveyed that obtaining a deep level of understanding in physics is an iterative process that requires struggle, strategic, concerted effort, perseverance, support, and

collaboration far more than a high innate intelligence. In other words, the lone, "effortlessly clever physicist," an archetype stereotypically tied to white masculinity, did not appear as a reality in this setting (Archer et al., 2020a).

Numerous students emphasized that they did not enter the physics program at Southeastern University with this growth-oriented perspective, but instead acquired it through their experiences with challenge in and outside of the physics classroom and through interactions with their peers and instructors. Undergraduates, physics instructors, and graduate TAs each brought up that hard work, active engagement, and dedication were recognized by the program as qualities of a good physics student and a physicist. Assignments such as problem sets, interactive in-class activities, and experimental labs provided students with the opportunity to engage and struggle with material in a low-stakes manner, while open-ended tests with partial credit placed the primary focus on the process rather than the final answer. Coming together to study, complete assignments, and commiserate over the difficulty of physics acted as an important source of recognition for students with a diversity of identities, as peers valued each other's contributions and affirmed that they were not alone in their academic challenges (Fries-Britt, Younger, & Hall, 2010; Johnson, 2020; Schipull et al., 2019). Instructors with readily available office hours were a reliable resource for personalized guidance when students encountered struggle (Fries-Britt et al., 2010; Seymour & Hunter, 2019). In addition, many instructors offered a degree of individualized flexibility and accommodations that supported students with disabilities and external life events in their academic success and well-being. Outside of the classroom, participants discussed how undergraduate research experiences taught them that failure is an important part of science (Corwin, Charkoudian, & Heemstra, 2022). Taken together, such findings emphasize the vital role that programmatic norms, structures, and

interpersonal interactions play in shaping students' beliefs and perceptions about their abilities and potential in a subject (Binning et al., 2020; Murphy & Dweck, 2010).

Students with a range of social identities shared the benefits of collaborative, growth-oriented interpersonal interactions, cultural norms, and classroom structures to their recognition as competent physics students. At the same time, literature documents that this divergence from physics' prototypical elevation of innately high intelligence is particularly important for the disciplinary identity development of those with marginalized gender, racial, and ethnic identities (Johnson, 2020; Ong et al., 2018; Schipull et al., 2019). As previously discussed, women, Black, Latine, and Indigenous physics students are systematically excluded from occupying positions of inherent brilliance in science and society due to negative intelligence stereotypes (Johnson, 2020; Keller, 1985; Prescod-Weinstein, 2021). Such stereotypes contribute to the marginalization and underrepresentation of individuals with these social identities in traditionally brilliance-focused fields such as physics (Leslie et al., 2015). Reframing effort and struggle as normal components of learning and doing physics (as opposed to indications that one is lacking an essential quality needed to succeed) has the potential to reduce the impact of oppressive negative intelligence stereotypes and allow all students to gain a greater sense of competence in the discipline (Binning et al., 2020).

In addition to positioning competent physicists as engaged in an iterative process of deep understanding, participants described physicists as individuals who work together in both academic and industry settings to systematically solve problems that both contribute knowledge and improve the world around them. Many mentioned that their ideal future work environment consists of individuals with diverse strengths and perspectives coming together to contribute towards a common larger goal. Stereotypical representations frame physicists as concerned

primarily with individually working to uncover the complex laws of the universe (Gonsalves, 2014; Traweek, 1988). Expanding conceptions of physicists to include individuals who apply diverse epistemological perspectives to experimentally ameliorate societal concerns like energy use and disease detection allows individuals interested in physics' real-world applications to be recognized as competent members of the field (Carlone & Johnson, 2007; Johnson, 2020). Empirical work supports that students with traditionally marginalized identities are more likely to be motivated to pursue scientific careers that benefit their communities, though importantly this was not uniformly the case in the present study (Allen et al., 2015; Allen et al., 2021; Hyater-Adams et al., 2019; Smith et al., 2014; Thoman et al., 2015). Embracing multiple ways of thinking and doing in physics also works to uplift the perspectives of disciplinary members with traditionally marginalized identities and backgrounds (McNeill et al., 2022; Ong et al., 2018). Findings once again suggest that undergraduates' perceptions that physicists systematically yet creatively address applied, real-world problems arose in part from their experiences in the physics program at Southeastern University. Selena, a queer Latina sophomore, discussed how she appreciated that her instructors welcomed students approaching problems differently, as it showed her that there are often many ways to solve any one problem. Most students enjoyed when their experimental lab activities explicitly applied to course material and found it interesting and helpful to visualize abstract concepts in real life. Physics instructors and graduate TAs highlighted ways in which they support undergraduates in making applied and experimental connections to the material that they are learning in class, from demos, to guest speakers, to experimental activities, as they recalled that these strategies supported them in their own development as physicists.

Providing low-stakes, low-stress opportunities for women and marginalized students of color to playfully engage in experimental physics activities also addresses the reality that students with these identities are less likely to been afforded the capacity to do so that white men in pre-college and university experiences (Due, 2012; Hasse, 2002). Neurodivergent students who struggle to learn from traditional lectures can too particularly benefit from low-stakes, interactive learning activities (Pfeifer et al., 2023; Salty et al., 2022). Undergraduates with traditionally marginalized identities commonly remarked that the structures and interpersonal dynamics of the experimental lab activities were more conducive to collaborative, hands-on inquiry than their standard physics labs. At the same time, many participants shared that their activity groups divided up experimental tasks by organically falling into different roles as opposed to rotating through tasks equally. Literature documents that women and marginalized students of color are often implicitly or explicitly relegated to more passive roles in physics lab settings than their white male peers (Akudo et al., 2022; Day et al., 2016; Doucette et al., 2020b; Quinn et al., 2020). Ongoing research and practice should attend closely to experimental lab activity group dynamics to ensure that all group members can directly engage with experimental tasks.

The findings discussed above illuminate interpersonal interactions, cultural norms, and structures within the physics program at Southeastern University that disrupt prototypical physics practices in ways that support marginalized students in gaining competence and recognition in the field (Johnson, 2020). Simultaneously, undergraduates in the program with marginalized and multiple marginalized identities described navigating both internal and external assaults to their competence and a lack of recognition from others that stemmed from oppressive notions about who can legitimately exist in physics learning spaces (Gonsalves, 2014; Keller,

1985; Prescod-Weinstein, 2020). While all undergraduate participants conveyed that they questioned their physics abilities at times, four women and one non-binary student regularly experienced feelings of self-doubt and imposter syndrome that arose from an awareness of negative gender and, for women of color, racial and ethnic intelligence stereotypes. They confided that they often felt hesitant to actively engage in physics classes for fear of being wrong and confirming to others that people with their social identities are not competent in STEM, a phenomenon that is well-documented in the literature (Archer et al., 2020a; Bian et al., 2018; Dar-Nimrod & Heine, 2006; Herrera, Mohamed, & Daane, 2020; Murphy & Zirkel, 2015; Steele et al., 2002). One woman recalled how her awareness disciplinary stereotypes nearly caused her to change her major before she even walked into her first university physics course.

On top of this internal self-doubt, two white women and one woman of color recounted instances of microaggressions, overt exclusion, and/or gender-based harassment from male peers in introductory physics courses and labs that dismissed their competence and presence and reduced their sense of safety in the program. In addition to negative peer interactions, several women shared interactions with instructors who implicitly or explicitly questioned their competence in the field. One noted that women physics faculty often appeared less relaxed than their male counterparts in the classroom, which she gathered arose as a response to their own contentions with negative gender stereotypes. For Selena, experiences of self-doubt and exclusion were intensified as she contended with the "cumulative disadvantage" of both negative intelligence stereotypes about her gender and ethnicity and faced immense isolation from being the only woman of color in her physics classes (Kachchaf, 2015; p. 175). Throughout her postsecondary physics experiences, Selena remained hyper aware of cues that threatened or affirmed her legitimacy her physics learning environments perceived her (Ong, 2005). Together,

these findings emphasize that both white women and women of color are still commonly relegated to the margins of physics (AIP, 2020; Aycock et al., 2019; Barthelemy et al., 2016; Bjorkquist et al., 2019; Crenshaw, 1991; Fries-Britt & Holmes., 2012; Gonsalves et al., 2016; Johnson et al., 2017; Keller, 1985; Ko et al., 2014; Lavender, 2013; Prescod-Weinstein, 2020; Settles et al., 2006). Even though participants described effort as more important for success and membership in physics than inherently high intelligence, oppressive associations between white masculinity, intelligence, and objectivity continue to shape who is seen as legitimate scholars and practitioners of the discipline (Archer et al., 2020a; Bian et al., 2018; Cheryan et al., 2017; Gonsalves & Danielsson, 2020). Contending with negative, oppressive internal and external identity-based assaults on competence and recognition inhibited participants' capacity to fully engage in the process of learning and doing physics (Hazari et al., 2017; Ko et al., 2014; Prescod-Weinstein, 2021).

The five white, Latina, and Asian women undergraduates who explicitly highlighted ways in which negative associations between their gender and/or race and ethnicity and physics competence influenced their experiences in the program each employed strategies to develop competence and obtain recognition as physicists despite these barriers. In line with literature on persistence strategies for marginalized STEM students, all described how their strong interests in physics helped to sustain them through instances of self-doubt, exclusion, and harassment (Ko et al., 2014). Ria, Mari, and Selena discussed their feelings of imposter syndrome with peers who shared their identities, which helped them to frame their feelings not as individual shortcomings but as artifacts of oppression in the field (Ong, Smith, & Ko, 2014). Selena also drew on her logical mind to systematically disprove her feelings of inferiority in the field, and thus applied a stereotypically white masculine trait (rationality) to affirm her own competence. Katherine and

Jessica revised dominant narratives regarding gender and physics to create a "new ideal that consolidates seemingly conflicting…identities" (Ong, 2005; 0. 600). In analyzing the narratives of 15 undergraduate and graduate women of color in STEM, Carlone and Johnson (2007) similarly found that participants persisted in part through creating alternate conceptions of what it means to identify as a scientist that contested their fields' white, masculine stereotypes.

As they moved through their classes, specific instructor and programmatic interpersonal, cultural, structural, and disciplining practices supported these women in their agency and persistence. Recognition from instructors, mentors, and peers helped to confirm the women's competence (Carlone & Johnson, 2007; Hazari et al., 2017; Hazari et al., 2020; Kalender et al., 2019a; Li & Singh, 2022). Structures such as the experimental lab activities and the department's group for women in physics provided a space for more inclusive collaboration (Ong et al., 2018; Schipull et al., 2019). Instructors' acknowledgement of imposter syndrome and concrete action upon learning about instances of sexism, racism, and harassment affirmed that such situations were taken seriously by the department (Johnson et al., 2020; Ong et al., 2018). At the same time, Katherine, Mia, and Selena each brought up situations in which departmental practices, namely the fast past of courses, and a lack of awareness or intervention during instances of marginalization and a lack of acknowledgement of the permeance of sexism and racism in physics, inhibited their competence, recognition, and identity development in the program. Such findings stress the need for physics program members to critically reflect upon the dynamics of power and oppression in the department and to proactively disrupt interpersonal interactions, cultures, and structures that inhibit individuals from developing a physics identity (Collins, 2009; Watts, Diemer, & Voight, 2011).

Four undergraduate participants with gender and/or racial and ethnic identities traditionally marginalized in physics spaces did not perceive that their social identities had a direct impact on their internal or external recognition as competent physics students in the program. Rose, a Latina sophomore, came from a family in which both men and women commonly worked in STEM. Her immediate family members all studied engineering at Southeastern University. As such, Rose possessed a strong STEM-related social and cultural capital (Gonsalves et al., 2021). As a result of her many familial role models, she was raised to view being a Latina woman as compatible with being competent in STEM (London et al., 2011). Rose did actively contest the stereotype that people in physics devote all of their time to the discipline in her commitment to both work hard and maintain a balance that allowed time for friends and family (Fries-Britt & Holmes, 2012; Ko et al., 2012). Diana described that preferred to not interact with her classmates beyond her neurodivergent friend group. She aligned herself strongly with departmental values of hard work and dedication, discussed receiving recognition for her analytical and academic competence from her friends and an instructor, and conveyed a strong identity as physicist (Gonsalves, 2014). In addition, Diana recognized ways in which the physics program at Southeastern University actively supports women, which provided evidence for the program's commitment to her persistence (Johnson, 2020; Ong et al., 2018).

No Black or Latino men in the study perceived that their race or ethnicity negatively influenced their disciplinary identity development in the program. Forat, a Black male sophomore, described that while he was aware of the lack of Black students in the program, he did not perceive that his race negatively shaped his interactions with others. Forat entered the program with a strong K-12 foundation in physics and math and personally aligned with departmental and stereotypical physics values such as deep thinking and dedication. In addition,

he valued his experiences in departmental undergraduate research and the Black physics student organization. Tom, a Latino sophomore, described how close collaborations with physics peers provided a sense of both recognition and competence. Though they did not explicitly mention this, it possible that the gender privilege experienced by Forat and Tom made it easier to be recognized in their male-dominated physics spaces (Hyater-Adams et al., 2019; Womble, 2018). The heterogenous experiences and perceptions of undergraduates with traditionally marginalized gender, racial, and ethnic identities underscore that the dynamics through which students develop a disciplinary identity in relation to their developing gender, racial, and ethnic identities are influenced by a complex combination of individual and contextual factors (Hyater-Adams et al., 2019; London et al., 2011; Williams et al., 2020).

Three undergraduate participants navigated threats to their physics competence that stemmed not from their gender, race, or ethnicity, but from their disability and/or social class. They described how the fast pace of course material, the lecture-based format of many classes, the intensity of low- and high-stakes work, and the structure and timing of tests made succeeding and staying on top of things extremely challenging and exhausting. In line with recent literature, being neurodivergent in the program was particularly difficult when instructors strictly enforced inflexible deadlines and test times (Chini & Scanlon, 2022). For Kevin, the challenges of having ADHD in physics were compounded by his needing to work to support himself through college, a combination that caused him to feel perpetually overworked, behind, and not as competent as his physics peers. Kevin's experiences echo reports from the UK, which document that individuals from lower and working class backgrounds, particularly those with multiple marginalized identities, are commonly excluded from STEM careers due in part to class biases (Archer et al., 2013; Follows, 2022).

It is important to highlight that most undergraduate participants described that their competence in the physics program was greatly supported by pre-university experiences, from advanced STEM courses in high school and community college, to positive family support, to informal learning experiences such as YouTube. Exposure to such experiences, particularly advanced physics and math courses, allowed undergraduates to better navigate the difficulty of the program, and provided an important source of recognition from instructors and peers (Archer et al., 2015; Gonsalves et al., 2021). The few students who entered with little to no formal pre-university experiences in physics and math faced substantial learning curves and failures that caused them to question their place in the discipline. Given that national data documents that women, Black, Latine, Indigenous, and lower socioeconomic students are less likely to have access to formal and informal educational pre-university opportunities in STEM than their peers, students in such groups are less likely to enter postsecondary education with a baseline level of competence and recognition to support them in their university pursuits (AIP, 2015; APS, 2011; Hasse, 2002). Efforts to increase diversity, equity, inclusion, and justice in postsecondary physics programs must include critically evaluating and disrupting the assumption that all undergraduate physics majors come to college with a uniformly strong foundation in STEM.

Pathways to Belonging

Undergraduate participants conceptualized belonging in physics in several ways. All described that belonging includes authentically connecting with disciplinary members such as peers, instructors, and research mentors. Seven students with a variety of social identities added that belonging also entails enjoying the subject. Three conveyed that it requires academic competence, two mentioned that it necessitates thinking like a physicist, and three included that it means seeing one's future in the field. Students' multiple definitions support Hazari et al.'s

(2020) conceptual model of disciplinary identity development for physics majors, which positions belonging as relating to interest, competence, recognition, and, for upper-level students, physics identity. Their conceptions of belonging in physics also align with Lewis and Hodge's (2015) model of academic belonging, which distinguishes between *ability belonging*, or the extent to which one 'fits' intellectually in a field and *social belonging*, or feeling accepted and valued by other members of a learning environment. Many undergraduates described instances in which they questioned whether they belonged in physics as a result of struggling with a test, course assignment, or research problem. Several mentioned that some of their peers left the major as they perceived that they did not belong academically due to feeling behind, often due to their lack of pre-university coursework in physics and math. A great deal of overlap existed between the norms, practices, and structures that students shared promoted their ability belonging in the program and those described above that promoted competence and recognition. Normalizing learning and doing physics as an iterative process that involves struggle helped to frame failure not as an individual shortcoming but as a regular component of the field. Students recalled instances in which an instructor or peer emphasized this iterative dynamic in a way that reassured them that they belonged despite their struggles. Structures and practices such as low-stakes, active in-class engagement, demos and experimental lab activities, process-oriented grading, and undergraduate research experiences helped to legitimize trial-and-error, play, and failure as part of learning (Corwin et al. 2022; Seymour & Hunt, 2019). Welcoming more diverse epistemologies and practices that broaden ways of thinking and doing in physics allows students with a range of interests and perspectives to see themselves as members of the field (McNeill et al., 2022). For most undergraduates, the dynamics of ability belonging were closely tied to those of social belonging. Students with both marginalized and privileged social identities described

how physics peers came together to study for tests, work through difficult problems, and bond over the difficulty of the material. Connecting with instructors in and outside of class to ask questions and discuss physics served as a further source of social belonging. Multiple students also mentioned that collaborating with others during the experimental lab activities and undergraduate research experiences made them feel like a valued member of the program. Each of these norms and structures appear in the literature as strategies for creating community and increasing retention of students undergraduate STEM programs (AIP, 2020; Binning et al., 2020; Corwin et al. 2022; Espinosa, 2011; Fries-Britt et al., 2010; Johnson, 2020; McNeill et al., 2022; Ong et al., 2018; Rainey et al., 2018; Seymour & Hunter, 2019). Together, they describe features of a disciplinary setting that replaces prototypical physics conceptions of inherent, solitary brilliance with traditions of growth and collaboration (Gonsalves, 2014; Johnson, 2020).

At the same time, numerous undergraduates with traditionally marginalized, gender, racial, ethnic, disability, and social class identities faced exclusion, isolation, harassment, imposter syndrome, and rigid, intense course structures that inhibited their capacity to belong in the physics major to the same extent as their non-marginalized peers (Banchefsky et al., 2019; Lewis et al., 2016; Lewis et al., 2017; Rainey et al., 2018; Seyranian et al., 2018). In addition, several undergraduates and one graduate TA shared that, while they had not explicitly experienced negative interpersonal interactions with students or instructors due to their social identities, they were nonetheless reminded of their underrepresented status simply by the lack of women and people of color in the physics program. Literature supports that this perennial awareness of underrepresentation in itself erodes one’s sense of belonging in a discipline (Herrera et al., 2020).

Several white women and women of color detailed internal and external strategies to gain a sense of belonging in the physics program despite the abovementioned assaults and threats. Katherine expressed that while she does not feel that she belongs socially among her peers, she is confident of her ability belonging in physics. Selena also reminded herself of her physics ability belonging to verify that she is a legitimate member of the discipline during instances of peer exclusion. Mari explained that while she struggled to belong socially in her introductory physics courses, instances of exclusion and harassment diminished over time, as men who were only in the major to display their intelligence eventually left. Those who remained (individuals who truly enjoy physics) are far more welcoming and inclusive of women in the major. Ria became actively involved in the program's affinity group for women in physics. Katherine, Selena, Mari, Ria, and Jessica each connected with physics faculty who affirmed and supported their place in the program. These internal and external strategies supported the students in developing a sense of belonging in the face of marginalization. At the same time, attention to verifying that they belonged in the discipline took time and energy away from learning and doing physics (Ko et al., 2014).

Findings suggest that the interpersonal, cultural, structural, and disciplining dynamics of the physics program at Southeastern University are in many ways welcoming and supportive of belonging of LGBQ+ individuals. Most LGBQ+-identified students described that they could openly be out among their peers, and all described their instructors as very accepting. As an older student, Diana posited that this openness seemed in part generational, as her younger peers are prouder of their sexual orientations than she experienced in her youth. Mari observed that many individuals in the program are LGBQ+, which provided the opportunity to make physics friends who were also LGBQ+-identified. She attributed physics members' welcoming of LGBQ+

individuals to the fact that both groups are traditionally labeled as ‘outsiders’ in society, which can make them more accepting of difference. At the same time, Bo, a non-binary, gay sophomore described that, while the physics program was more accepting than Southeastern University as a whole, they tended to stick to academic and professional related topics when conversing with physics peers outside of their friend group, as some men in the program were not supportive of their identities. Bo’s experiences align with recent findings that gender non-conforming and transgender individuals are less likely to feel comfortable in physics spaces than women or men LGBQ+ physicists (Barthelemy, 2020; Barthelemy et al., 2022). Given the documented importance of fostering physics environments in which all students can authentically be themselves, it is important to foster practices, norms, and structures that value the authenticity of LGBTQ+ students with a range of identities (Feder, 2022; Barthelemy et al., 2022; Leyva, 2022).

The lived experiences of undergraduates as they navigated a sense of belonging in physics emphasize the importance affirming students’ value and legitimacy not just as physicists, but as humans (Prescod-Weinstein, 2021). Students with a diversity of social identities valued forming friendships with physics peers and stressed how they appreciated instructors who took time to get to know them as individuals and provided flexibility and understanding during instances of illness or crisis (Seymour & Hunter, 2019). Several women and one man highlighted the importance of informal engagement opportunities for building community with peers and instructors. Affinity groups for women and Black students in physics provided counterspaces for students to bring their full selves (Ong et al., 2018). At the same time, white and male participants were overall more likely to proclaim that they felt completely comfortable in the physics program than women and people of color. Physicists’ history of disguising white,

masculine, heteronormative, ablest, and classist traditions, values, and practices as neutral and objective excludes individuals who do not align or assimilate with these norms from confidently existing in physics spaces not only as legitimate scientists, but as valued, authentic humans (Leyva, 2022; Prescod-Weinstein, 2021). Expanding who belongs in physics spaces requires acknowledging and understanding the oppressive nature of these norms and recognizing the value that diverse epistemologies, perspectives, and cultures bring to the practice of physics (McNeill et al., 2022). Actively intervening in instances of exclusion and harassment not only disrupts oppressive interactions and cultures but legitimizes the right students with traditionally marginalized social identities to comfortably take up space as scientists and as humans (Johnson, 2020).

Conclusions

As suggested by Johnson (2020), Collin's (2009) Domains-of-Power Framework provided an ideal tool for exploring how the dynamics of marginalized physics students' disciplinary identity development are rooted in the interpersonal, cultural, structural, and disciplining domains of power of their physics learning environments. Focusing on not only dynamics of gender, race, and ethnicity but also sexual orientation, disability, and social class allowed for a more complex, holistic exploration that is often missing from the literature. Narratives collected from physics program members with a variety of social identities and roles revealed common classroom and departmental norms and practices, some of which contested the discipline's white, masculine, heteronormative, able-bodied, middle- and upper-class traditions in ways that supported students with both marginalized and privileged social identities. Participants framed learning and doing physics as an iterative, collaborative process that can be applied to both generate new knowledge and improve the world. Open, caring, and inclusive

instructors supported students in this process, recognized them as physicists and as people, offered a degree of flexibility when needed, and intervened in instances of harassment. Structures such as active in-class learning, the experimental lab activities, undergraduate research opportunities, and departmental affinity groups provided spaces for students to engage as learners, physicists, and humans. At the same time, narratives from white women and women of color highlighted the permanence of sexism and racism in physics spaces, which took the form of imposter syndrome, negative intelligence stereotypes, implicitly and explicitly exclusionary behavior, and gender-based harassment. In addition, programmatic and university structures and practices at times disproportionately harmed neurodivergent and lower socio-economic students. Most undergraduate participants entered the physics program with a strong formal and informal foundation in STEM, which greatly supported their success and belonging. And while male and female LGBQ+-identified students saw the physics program as an inclusive space for LGBTQ+ individuals, the one non-binary participant described unsupportive interactions with male peers. Findings emphasize the importance of physics program members, particularly those in positions of power, to remain knowledgeable and aware of the dynamics of marginalization in physics learning spaces and to intervene in ways that continuously support and improve diversity, inclusion, equity, and justice in the program.

Directions for Future Research

This study contains multiple limitations and opportunities for further inquiry. First, while dynamic narrative inquiry allowed for an exploration of the experiences and perspectives of individuals with a diverse range of social identities, backgrounds, and roles, it prevented me from focusing deeply on the lived experiences of individuals with a particular identity or intersection of identities. Findings emphasize that the situated experiences of any one group,

such as Latina undergraduates, are heterogenous and dynamic. Future research might narrow and deepen its scope to one such group. Second, this study was limited by the overarching lack of diversity in the physics program, particularly the low number of Black, Latine, and Indigenous members. My recruitment messages stressed that I was interested in the lived experiences of individuals with gender, racial, ethnic, sexual orientation, disability, and/or social class identities traditionally underrepresented and marginalized in physics, though I did have any Black women or Indigenous participants in my study. Future work might expand to multiple institutions and/or collaborate with individuals and organizations centered on Black, Latine, and Indigenous physicists. In addition, it should focus on actively recruiting more non-binary individuals. Third, the individuals who responded to my recruitment emails sometimes conveyed in interviews that they felt personally drawn to my research topic. As such, my participants may have somewhat different experiences and perceptions than their peers. Fourth, my research methods did not include directly observing the interpersonal, cultural, structural, and disciplining dynamics of physics program spaces. Further work might employ ethnographic methods for observing and analyzing these power domains.

Practical Implications: Humanizing Physics Education

In her presidential address at the 47th annual conference of the Association for the Study of Higher Education last November, Dr. Joy Gaston Gayles called for a *humanization* of the policies, practices, and places of postsecondary education. Humanizing higher education, she stressed, necessitates disrupting hypercompetitive, individualistic norms, acknowledging and opposing systemic oppression, and fostering communities built on care, empathy, authenticity, and respect (Gayles, 2022). As articulated throughout this paper, the discipline of physics is traditionally framed as an intellectually rigorous and elite subject focused on uncovering the laws

of the universe in ways that are removed from the cultural subjectivities that infiltrate other fields (Hughes, 2001; Traweek, 1988). But, as Dr. Chanda Prescod-Weinstein explains, "There's the universe and then there's the process of developing a mathematical understanding of it. This is physics, and physics is a human process" (p. 147). Recognizing physics as a human activity involves proactively and intentionally acknowledging, understanding, and disrupting ways of teaching, learning, thinking, and doing that marginalize and reject individuals who do not fit physics' traditional mold. Humanizing physics education requires expanding who and what is considered legitimate in physics learning spaces so that students with a diversity of social identities, backgrounds, and interests can be recognized as valued members of the field as their authentic selves. Participants' narratives reveal humanizing practices currently present in the physics program at Southeastern University such as the normalization of trial-and-error, struggle, and collaboration, open, caring, and personalized instructor interactions, low-stakes opportunities to engage with material, a degree of flexibility, the broadening of physics career options, and tangible intervention during instances of sexism and racism. These practices support the success, well-being, persistence of physics students with a diversity of social identities and backgrounds.

Findings also point to the need for additional practices that further humanize physics education at Southeastern University. First, undergraduates shared that they would benefit from more low-stress opportunities to authentically engage with the process of science and to interact with their instructors and peers in informal contexts. Many conveyed that heavily weighted exams largely dictate one's grade in a course. The structure and weight of such exams were particularly challenging for neurodivergent students, even with university accommodations. One student, Kevin, wished that exams were more project-based and formative so that students had a greater opportunity to actively learn from their mistakes before an exam grade was finalized. His

recommendation mirrored the structure of two-stage collaborative exams, an increasingly used testing format in which students answer questions both individually and with a group as part of their exam grade (Macpherson, Lee, & Steeples, 2011; Miller, Kestin, & Miller, 2022).

Undergraduate participants also mentioned that the experimental lab activities could as a whole be better integrated into the structure and content of their physics courses. This recommendation stemmed from both the stress that the activities added when they were implemented on top of other weekly course assignments and from a desire to engage with the experiments at a greater depth. Future implementations of the experimental lab activities could brainstorm ways to incorporate these recommendations while still maintaining their simple, low-stakes structure.

Second, the fast-paced, rigorous nature of the undergraduate physics curriculum presented particular challenges for neurodivergent students, working students, and students who entered Southeastern University with little pre-college preparation in math and physics. Several participants shared that introductory course instructors assumed that students completed advanced math and physics courses in high school, which created a very steep learning curve for those without this foundation. In addition, students perceived that introductory physics courses were often more rigidly structured than advanced courses in order to acclimate students to the rigors of the major. Participants conveyed that this resulted in a high attrition freshman year, as students with varying learning needs and backgrounds felt that they could not succeed or belong in the program. Physics course instructors should reflect on how the assumptions and practices that they bring to their courses could disproportionately harm students with different learning needs, backgrounds, and life situations. Instructors might also draw upon the universal design for learning framework to create and implement classroom structures and practices that support the

learning needs of all students (CAST, 2018; Pfeifer et al., 2023; Scanlon et al., 2018; Schreffler et al., 2019). Universal design considers students' needs, strengths, and interests to develop flexible curricula that increases access, inclusion, and equity in the classroom (CAST, 2018). The universal design framework contains three guiding principles: multiple means of representation, multiple means of action and expression, and multiple means of engagement (CAST, 2018). Multiple means of representation includes providing information through multiple modes, such as text, videos, and demos. Multiple means of action and expression includes scaffolding activities and providing students with more than one way for interacting with content and conveying understanding. Multiple means of engagement includes supporting students' motivation, self-regulation, and persistence in learning (CAST, 2018). While universal design was first conceptualized to support students with disabilities in K-12 settings, its guiding principles have the potential to support students' learning needs in a variety of contexts (CAST, 2018; Pfeifer, 2023; Scanlon et al., 2018). Scanlon et al. (2018) offer concrete recommendations for implementing the universal design for learning framework in postsecondary physics courses.

Third, participants' lived experiences illustrate that white women, women of color, and non-binary individuals remain marginalized in the physics program by oppressive intelligence stereotypes, negative peer and instructor interactions, and their underrepresentation in itself. Together, these factors inhibit individuals with these social identities from existing in physics spaces with the same level of comfort and well-being as their non-marginalized peers. It is vital that physics instructors pay close attention to the peer dynamics of their classrooms, labs, and other departmental settings and implement structures that prevent students from being excluded from engaging in course and lab activities (Doucette & Singh, 2022). In addition, instructors should regularly incorporate culturally responsive teaching practices that welcome diverse ways

of thinking and doing and relate physics concepts to students' lived experiences (Gay, 2018; Joshi, 2023). On top of this, the program should continue to create structures (such as scholarships for low-income students and paid undergraduate research an internship opportunities) that support students with marginalized social identities in their professional development as physicists.

The physics program at Southeastern University would also benefit from incorporating programmatic and curricular lessons and activities that support students and instructors with a diversity of social identities and backgrounds in developing an awareness, understanding, and commitment to ameliorate inequities in the discipline (Byrd, 2022; Byrd, 2023; Arielle-Evans et al., 2019; Dalton & Hudging, 2020; Decker & Daane, 2017; Lock & Hazari, 2016; Watts et al., 2011). Given that physics is stereotypically depicted as objective and neutral, individuals whose social identities align with the prototypical physicist may not otherwise be challenged to recognize their privileges, learn about dynamics of oppression in physics, or be motivated to act in ways that promote diversity, equity, inclusion, and justice in the field (Dalton & Hudging, 2020; Decker & Daane, 2017). Explicitly incorporating equity-focused lessons and activities can also provide students with traditionally marginalized identities with the space to both learn about their own social identities and the dynamics of oppression in physics and to develop an agency to take critical action (Byrd, 2023; Dalton & Hudging, 2020; Doucette et al., 2021; Lock & Hazari, 2016). In recent years, several physics and STEM education research teams have developed and implemented curricular units focused on introducing high school and college students to the historical and current dynamics of inequity in physics (Dalton & Hudgings, 2020; Decker & Daane, 2017; Arielle-Evans et al., 2019; Lock & Hazari, 2016). When adopting such equity-focused lessons, it is extremely important that physics program members first critically consider

both their own positionality and how the positionality of students in a course might shape their responses to their content and activities (Doucette, Park, & Rifkin, 2022). In addition, it is vital to establish inclusive classroom norms that prevent equity-focused lessons from further marginalizing students with social identities that are drastically underrepresented in postsecondary physics spaces. Byrd (2023) provides a model that outlines the stages and cycles through which individuals develop cultural competence, or an awareness and understanding of social identity groups, and critical consciousness, or an intentional commitment to analyze and disrupt inequity in a manner that promotes social change (Watts et al., 2011). Her model provides important considerations that physics program members should use as a source of guidance when planning and implementing DEIJ-focused content (Byrd, 2023).

Beyond the discipline itself, humanizing physics education involves recognizing program members not only as competent, valuable students and physicists, but as humans. In the last three years, students, faculty, and staff have navigated a global pandemic, domestic and international instability and unrest, and increased violence against people of color (Gayles, 2022). Due in part to the stress and isolation brought on by these happenings, the mental health of college students has plummeted (Lipson et al., 2022). Many instructors have adopted greater flexibility to their course structures, though such flexibility is admittedly easier to manage in small than large academic programs (Supiano, 2023). Humanizing physics education requires acknowledging the lasting and often disproportionate impact of the events of the past three years on individuals' lives and adapting practices that center the needs of physics community members. By fostering and equitably enforcing humanizing interactions, cultures, and structures, we give individuals room to cultivate the love of STEM that brought them to the discipline in the first place (Prescod-Weinstein, 2021).

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CONCLUSION

Together, results from these three studies add important empirical understanding into the experiences, beliefs, and perceptions of undergraduate physics students who engaged in major-specific physics courses that incorporated an interactive instructional approach (NRC, 2013). From a scholarly perspective, my findings substantiate that students' domain-specific intellectual ability beliefs shift and change over in accordance with both individual and environmental factors, and that such shifts carry important consequences (Dweck & Yeager, 2019; Dweck, 2012; Kinlaw & Kurtz-Costes, 2003; Little et al., 2019; Limeri et al., 2020; Malespina et al., 2022; Shively & Ryan, 2013). In the short term, variations in the malleability of students' physics ability beliefs related to the extent to which they felt recognized by others as an exemplary physics student. Over a longer time period, students with incremental physics ability beliefs conveyed a greater sense of belonging and intent to persist in the physics major. While incremental physics ability beliefs benefited all students, they particularly supported the extent to which women felt that they fit intellectually and could persist in the physics major. Qualitative findings provided a richer context for these trends. Believing one's physics abilities to be malleable with time and effort provided students with a sense of reassurance that they could belong and remain in the major despite its difficulty. Certain instructors, peers, and structures helped to foster a programmatic culture that framed learning and doing physics as an iterative process of trial-and-error and legitimized the malleability of an individual's physics abilities. Women in the major often faced heightened levels of self-doubt that stemmed from exclusionary interactions and an acute awareness of both their underrepresentation in physics and of negative stereotypes about women's innate abilities in STEM. Framing physics ability as something that

grows over time with experience and struggle helped to reassure women in the program that they were not lacking in an essential intellectual ability needed to be part of the major.

At the same time, these studies' findings emphasize that dismantling physics' culture of brilliance extends beyond supporting students in viewing their physics abilities as malleable. Participants were on average more likely to ascribe to incremental beliefs about own physics abilities than they were to agree that ultimate success as a physicist can be realized without high, innate intelligence. Such results suggest that disciplinary-level brilliance beliefs can persist even when individuals do not hold particularly fixed beliefs about their abilities in a subject. In both surveys and interviews, students with a range of social identities were reluctant to describe themselves (or to perceive that others viewed them) as an exemplary physics student. Open and caring instructors and low-stakes, collaborative active learning opportunities such as the experimental labs largely supported undergraduates in their learning and engagement. Simultaneously, the challenging, exam-heavy nature of the physics program nonetheless spurred many students to question whether they belonged on a regular basis. The fast-paced, rigorous nature of physics courses was particularly challenging for neurodivergent students, students who juggled jobs, and students who entered without a strong K-12 foundation in math and science.

On top of this, women, non-binary, Black, and Latine students contended with negative interpersonal interactions that explicitly and implicitly challenged their right to take up space in their physics learning environments, particularly those at the introductory level. Quantitative findings documented that students with these social identities were less likely to feel that they belonged social or intellectually in the physics major than their male, white, and Asian peers. Overall, these results substantiate that expanding who and what is deemed deserving of recognition, belonging, and disciplinary identification in undergraduate physics programs

requires ongoing, intentional, multifaceted work on behalf of those in positions of power to deconstruct exclusive interpersonal dynamics, cultures, and structures that traditionally characterize the field.

Quantitative and qualitative findings also illuminated the strong determination and resilience of physics students and faculty with traditionally marginalized social identities. Multilevel models showed that women, Black, and Latine students often reported that they intended to persist in the major despite experiencing lower levels of academic belonging. Narratives illustrated numerous persistence strategies employed by white women and women of color, from building community with supportive peers and instructors, to courageously sharing their experiences with imposter syndrome, exclusion, and harassment, to actively reframing what it means to be a physicist. LGBQ+ students collectively fostered an environment in which being out was largely accepted by program members. Faculty and graduate TAs conveyed a high commitment to provide undergraduates with a level of inclusion and engagement that they themselves did not receive as college physics students. Together, these results speak to the bravery of physicists with marginalized identities to carve out and reshape spaces for themselves and others, even in the face of ongoing interpersonal, cultural, and structural exclusion.

Methodological Implications

My studies contribute important methodological implications. First, a time series approach to quantitative data collection in which variables of interest are measured in a sample at more than two intervals confers multiple benefits. Such an approach permits a detailed examination of the contextual dynamics by which constructs of interest shift and change over time (Velicer, Hoeppner, & Goodwin, 2010). Time series studies can be particularly useful when one is interested patterns of variation and change in a small population, such as undergraduate

physics majors at a single institution, or when standard experimental designs are not feasible due to ethical and/or logistical constraints (Kratochwill & Levin, 1978). This is not to imply that a time series approach allows a researcher to derive causal conclusions from correlational designs. At the same time, time series and other longitudinal approaches that measure sample units repeatedly allow for richer insight into dynamic patterns and relationships between variables than can be gleaned from correlational studies that employ cross-sectional or pre/post data collection approaches (White & Arzi, 2005). Such insight can then inform pedagogical and policy decisions as well as directions for future experimental and quasi-experimental inquiries. When designed and implemented using a critical quantitative framework, a time series approach can illuminate how disciplinary spaces support or further oppress students with traditionally marginalized social identities through an examination of how such students' experiences and perceptions vary and change in relation to specific aspects of their learning environments.

In planning time series studies, it is important to first consider the rate at which a construct is known or proposed to vary and change. This information should inform the time interval and duration of data collection. For example, my second study measured students' perceived recognition and physics ability beliefs on a weekly basis throughout a semester, as recent literature suggests that such constructs are quite dynamic in nature (Avraamidou, 2022; Little et al., 2019). It is also important to employ measurement tools that are straightforward for participants to complete in order to reduce study attrition. Multilevel modeling is an ideal tool for time series studies in which there are at least 30 units at the highest level of analysis (in my case, students). Using this tool, the research can model how temporal-, person-, and environmental-level factors contribute to interindividual differences in intraindividual change (Raudenbush & Bryk, 2002). Multilevel modeling accounts for dependency of observations and allows sample

units to both start out and change differently. In addition, it permits unbalanced data, meaning that an individual can be included in analyses even if they do not have a data point at every time interval (Raudenbush & Bryk, 2002). By employing multilevel modeling to analyze time series data, the researcher can thus both utilize a more complete dataset and develop and run models that account for complexities present in intra- and inter-subject variation and change.

Secondly, results from my studies emphasize the importance of focusing not only on undergraduates at the introductory level when studying the beliefs, perceptions, experiences, and intentions of students in college physics courses. Most existing empirical work in postsecondary physics education research samples undergraduates enrolled in calculus- and algebra-based introductory physics courses meant for students majoring in a range of STEM fields due in part to the large number of students who enroll in such courses. My quantitative findings indicate that undergraduates majoring in physics possess beliefs, perceptions, and intentions about their ability, place, and future in the discipline that differ from those of undergraduates taking college physics courses for a different STEM or non-STEM major. In addition, the disciplinary beliefs, perceptions, and intentions of undergraduate physics students are not uniform across different academic levels. Sampling undergraduates in courses meant for physics majors, as well as undergraduates across academic levels, is essential for understanding the dynamics through which students' beliefs, perceptions, and intentions shift and change as they advance through their postsecondary studies.

Lastly, findings from my qualitative study highlight the importance of empirical work that takes an intersectional approach to better understand the complex ways in which power in a particular physics learning environment exists "as an intangible entity that circulates within a matrix of domination" (Collins, 2009; p. 292). Exploring how power functions at the

interpersonal, cultural, structural, and disciplining level to reproduce and disrupt the status quo is necessary for building a more nuanced portrait of the dynamics of oppression and resistance in a given setting. In addition, studying how power dynamics shape the lived experiences of individuals with a range of traditionally marginalized social identities allows for greater insight into how the matrix of domination functions in a disciplinary environment. As detailed below, ongoing quantitative, qualitative, and mixed methods work in physics education research should employ intersectional methodologies that support the empowerment of physics students and instructors in the margins.

Recommendations for Future Research

These studies point to the importance and complexity of exploring the experiences, beliefs, perceptions, intentions of undergraduate physics majors with a diversity of social identities. Future work should continue to discern the situated dynamics of these complexities through quantitative, qualitative, and mixed methods research techniques. Quantitatively sampling physics majors across multiple postsecondary institutions and institution types would be beneficial for increasing both the total number of participants and the number of participants with various marginalized social identities. A greater pool of participants would open the door for intersectional analyses, multilevel structural equation modeling, and quasi-experiment and experimental methods that allow for an understanding of the causal effects of specific interactive instructional approaches. Ongoing quantitative work should also continue to refine survey measures to best capture the ability beliefs and perceptions of undergraduate physics majors. Given the important role that both undergraduate research and a strong interest in STEM played in supporting the belonging, disciplinary identification, and persistence of undergraduate participants in the qualitative study (particularly those with marginalized social identities), it

could be beneficial to include survey items that ask about research experiences and interest in physics in future survey inquiries. Lastly, future quantitative research should expand to capture the dynamics of physics students' disciplinary beliefs, perceptions, and intentions at the secondary and graduate levels, as such factors undoubtably also vary and change in important ways as individuals interact with various aspects of these disciplinary learning environments.

Future qualitative and mixed methods research should continue to explore the contextually situated, lived experiences of physics students with marginalized and multiple marginalized social identities. A great need exists for work that examines the experiences and perceptions of physics students marginalized not only by their gender, race, and ethnicity, but by their sexual orientation, disability, and/or socioeconomic status. Taking into account these identities and their intersections allows for more holistic insight into the dynamics of oppression in physics learning spaces. Future qualitative work should also incorporate both direct observations of students in their classroom and lab spaces and document analysis of instructional materials to better understand the interpersonal, cultural, structural, and disciplining dynamics of interactive instructional implementations.

Practical Implications

Literature documents that the capacity of interactive instructional approaches to support students' success, engagement, well-being, and disciplinary development is dependent on the inclusivity and equity of their classroom, lab, and programmatic contexts (Theobald et al., 2020; Maries et al., 2020; Pollock et al., 2007). Results from my three studies corroborate this insight and offer five overarching implications and corresponding recommendations for physics programs and instructors who design and carry out interactional instructional activities in physics courses.

First, all qualitative participants expressed that the experimental lab activities provided a low-stakes, straightforward experience to engage with tangible applications of abstract concepts. Given the discipline's challenging and intellectually rigorous reputation, the opportunity to have a low-pressure, light-hearted physics learning experience was in itself quite meaningful. Providing low-stress spaces for physics students to connect with both the discipline and its members in informal contexts has the potential to help to humanize the field and bring undergraduates a greater sense of belonging. Indeed, qualitative participants shared that they would benefit from more low-stress opportunities to authentically engage with the process of science and to interact with their instructors and peers in informal contexts. At the same time, the benefits of the experimental activities corresponded largely to the extent to which they aligned and integrated well with the course. In addition, many undergraduate participants wished that the activities offered a greater opportunity to authentically engage with the process of experimental physics. Ongoing collaborations between experimental lab activity support staff and course instructors should focus in part on better embedding and contextualizing the experimental activities into course content and structures.

Second, it is vital that undergraduate physics programs and instructors proactively implement structures and practices that help to both disrupt physics' disciplinary culture of brilliance and support students in viewing their physics abilities as malleable with strategic effort. Such a disruption first requires administrators and instructors to intentionally reflect on their own beliefs about the role that innate, high intelligence plays in the field, as such beliefs undoubtably influence the culture that they build and maintain in their disciplinary spaces. Instructors might then incorporate lessons into interactive physics courses about the academic and professional journeys of historical and current physicists to illustrate that the actual process

of learning and doing STEM requires collaborative dedication and perseverance over innate giftedness. Physics programs could also host seminar speakers that expose students to the range of skills, approaches, and applications valued by professional physicists. In addition, programs and instructors should actively involve students in fostering programmatic and classroom norms that elevate effort over innate, high intelligence.

On top of dismantling a culture of brilliance in physics learning spaces, instructors and TAs should implement practices that aid students in perceiving their own abilities in the discipline as capable of growth and change, particularly when they are faced with academic challenges. Binning et al. (2020) a classroom activity with documented efficacy in increasing the malleability of students' ability beliefs in college physics contexts. Alongside such student-focused activities, instructors play an important role in establishing and reinforcing norms and structures that foster classroom cultures of learning, challenge-seeking, and growth as opposed to competition for high grades (Yeager et al., 2019; Zeeb, Ostertag, & Renkl, 2020). Qualitative participants, for example, shared that heavily weighted exams largely determined one's grade in a physics course. Instructors should consider examination and grading techniques that prioritize students' process over the final answer, as well as those that are more project-based and formative in nature (Macpherson, Lee, & Steeples, 2011; Miller, Kestin, & Miller, 2022; Zeeb et al., 2020). Such techniques allow students a greater opportunity to actively learn from their mistakes and to make concrete plans for improvement (Dweck, 2012; Miller, et al., 2022; Zeeb et al., 2020). When embedded effectively (as described above), low-stakes course experiences such as the experimental lab activities can further foster classroom cultures of growth and engagement by providing students with the opportunity to engage with the trial-and-error process of learning and doing physics. Experimental lab TAs can support such efforts by offering

process-oriented feedback that praised students' strategies and provided constructive, targeted suggestions for growth (Zeeb et al., 2020).

Third, it is important for interactive instructional approaches to be designed and implemented in ways that expand students' conceptions of what it means to be an exemplary physics student and a physicist. Qualitative participants conveyed that the fast-paced, rigorous nature of introductory physics courses in particular inhibited the capacity of students with varying learning needs and backgrounds to succeed or belong in the program. Physics course instructors should reflect on how the assumptions and practices that they bring to their courses could restrict who and what is deemed exemplary in the discipline. Instructors might also draw upon the universal design for learning framework to create and implement classroom structures and practices that support the learning needs of all students (CAST, 2018; Pfeifer et al., 2023; Scanlon et al., 2018; Schreffler et al., 2019). Interactive instructional activities and labs have the potential to expose students to a diversity of physics topics, skills, approaches, and applications. Many undergraduate participants in the qualitative study, for example, were interested in careers that applied experimental physics to ameliorate societal concerns. Embracing multiple ways of thinking, doing, and being in physics allows students with a variety of social identities, backgrounds, perspectives, learning needs, and interests to be recognized by themselves and others as valued, competent disciplinary members (Hyater-Adams et al., 2019; McNeill et al., 2022; Ong et al., 2018).

Fourth, it is essential that interactive classroom and lab activities be accompanied by structures and practices that keep them from disproportionately benefiting white, male, cisgender, heterosexual, neurotypical, middle and upper-class students. For example, women in the qualitative study shared that often felt hesitant to participate in class during interactive

instructional activities due to the increased self-doubt and peer exclusion, a finding that is well-documented in the literature (Bando et al., 2019; Eddy et al., 2015; Ernest et al., 2019; Reinholz et al. 2022; Setren et al., 2021). Instructors and TAs should structure both in-class and lab groups and tasks so that students with marginalized social identities are not singled out or left out of actively engaging in discussions and activities (Doucette & Singh, 2022). In addition, instructors should critically reflect on how their own implicit biases potentially impact their interactions with their students and ensure that all students are being inclusively and equitably recognized for their contributions (Guzzetti & Williams, 1996a). Guzzetti & Williams (1996b) encourage instructors to actively involve students in creating and maintaining classroom norms that disrupt oppressive dynamics. Alongside this, it is important to ensure that the structure of interactive instructional approaches do not cause inequitable stress for neurodivergent and working students. Several sources provide excellent recommendations for supporting students with disabilities in interactive learning contexts (Pfeifer et al., 2023; Scanlon et al., 2018). Given the deeply embedded nature of oppression in physics, continual, proactive, critical, and intentional action is necessary for fostering diversity, inclusion, equity, and justice in interactive physics learning spaces.

Fifth, as detailed in the implications section of my third study, undergraduate physics programs should widely implement programmatic and curricular lessons and activities that support students and instructors with a diversity of social identities and backgrounds in developing an awareness, understanding, and commitment to ameliorate inequities in the discipline (Byrd, 2022; Byrd, 2023; Arielle-Evans et al., 2019; Dalton & Hudging, 2020; Decker & Daane, 2017; Lock & Hazari, 2016; Watts et al., 2011). Without such curricula, individuals whose social identities align with the prototypical physicist may not otherwise be challenged to

recognize their privileges, learn about dynamics of oppression in physics, or be motivated to act in ways that promote diversity, equity, inclusion, and justice in the field (Dalton & Hudging, 2020; Decker & Daane, 2017). Explicitly incorporating equity-focused lessons and activities can also provide students with traditionally marginalized identities with the space to both learn about their own social identities and the dynamics of oppression in physics and to develop increased agency to take critical action (Byrd, 2023; Dalton & Hudging, 2020; Doucette et al., 2021; Lock & Hazari, 2016). Several STEM and physics education research teams have developed curricular resources focused on introducing high school and college students to the historical and current dynamics of inequity in physics (Dalton & Hudgings, 2020; Decker & Daane, 2017; Arielle-Evans et al., 2019; Lock & Hazari, 2016).

While each of these implications stem from postsecondary contexts, they are equally pertinent to secondary physics settings. Indeed, fostering inclusive and equitable physics learning environments long before individuals arrive to college is essential for broadening the diversity of students who select physics as their undergraduate program of study (Maltese & Tai, 2010). Proactively disrupting oppressive dynamics and reshaping the qualities deemed important for success, belonging, identification, and persistence across all levels of physics education will support students with a range of social identities and backgrounds as they learn and grow in the field.

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APPENDICES

Appendix A

Article 1 Survey Scales

Physics Ability Beliefs Scale (Modified from van Aalderen-Smeets et al., 2019)

6-point Likert items (6 = *strongly agree* to 1 = *strongly disagree)*

I don't think I personally can do much to increase my physics ability. (r)

My physics ability is something about me that I personally can't change very much. (r)

To be honest, I don't think I can really change my physics aptitude. (r)

With enough time and effort, I think I could significantly improve my physics ability level.

I believe I can always substantially improve on my physics aptitude.

Regardless of my current physics ability level, I think I have the capacity to change it quite a bit.

I believe I have the ability to change my basic physics aptitude level considerably over time.

Field-Specific Ability Beliefs Scale (Leslie et al., 2015)

6-point Likert items (6 = *strongly agree* to 1 = *strongly disagree)*

Being a top scholar of [discipline] requires a special aptitude that just can't be taught

If you want to succeed in [discipline], hard work alone just won't cut it; you need to have an innate gift or talent

With the right amount of effort and dedication, anyone can become a top scholar in [discipline] (r)

When it comes to [discipline], the most important factors for success are motivation and sustained effort; raw ability is secondary (r)

Ability Uncertainty Scale (Lewis & Hodges, 2015)

6-point Likert items (6 = *strongly agree* to 1 = *strongly disagree)*

I worry my abilities aren't good enough to do well in my major.

I often wonder if I have what it takes to succeed in my major.

I feel confident about my abilities in my major.

I sometimes feel like other students in my major have skills that I don't.

When I'm doing work in my major, I feel a sense of competence.

My major requires some abilities that I'm not sure I possess.

I worry that no matter how hard I try, I won't be able to perform successfully in my major.

When I'm doing work in my major, I feel I have the skills that I need.

I'm not sure that I'm cut out for my major.

I have no doubts that I possess or can acquire the abilities my major requires.

I feel similar to the kinds of people who have what it takes to succeed in my major.

I'm not certain I "fit in" intellectually in my major.

Social Belonging Scale (Good et al., 2012)

6-point Likert items (6 = *strongly agree* to 1 = *strongly disagree)*

When I am in a physics setting,

I feel that I belong to the physics community.

I consider myself a member of the physics world.

I feel like I am part of the physics community.

I feel a connection with the physics community.

Intent to Persist Scale (Lewis & Hodges, 2015)

6-point Likert items (1 = *strongly agree* to 6 = *strongly disagree)*

I have seriously considered changing my major. (r)

I often wonder if I really want to have a career in my major. (r)

It is important to me to finish my program of study in physics.

It is likely that I will remain in my major next academic year.

Academic Struggle Items (Limeri et al., 2020a)

Did you encounter struggle in [course name] this semester? (*Yes/No*)

Were you able to overcome the struggle that you encountered? (If ‘Yes’ for item 1)

Appendix B

Article 1 Multilevel Models

Research Question 1a

On average, is there significant linear change in physics ability beliefs over time? Does this change depend on a student's gender, race, ethnicity, academic level, perceived academic struggle in a course, and field-specific ability beliefs?

Levels of Model

Outcome: incremental physics ability beliefs
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (B1)

Level 1: $\text{PhysicsAbilityBeliefs}_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average incremental physics ability beliefs across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of incremental physics ability beliefs across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in physics ability beliefs that exists between students

$1 - \rho$ = proportion of variance in physics ability beliefs that exists within students

Conditional Model: Time (B2)

Level 1 predictor: time

Level 1: $\text{PhysicsAbilityBeliefs}_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$
$\beta_{1i} = \gamma_{10} + u_{1i}$

Conditional Model: All Predictors (B3)

Level 1 predictors: time, semester, academic level (AL), perceived academic struggle (AS)

Level 2 predictors: gender, race/ethnicity, field-specific ability beliefs (FAB)

Level 1: $\text{PhysicsAbilityBeliefs}_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{AL}) + \beta_{3it}(\text{AS}) + \beta_{4it}(\text{Time X AS}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{FAB}) + u_{0i}$
$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Gender}) + \gamma_{12}(\text{Race/Ethnicity}) + \gamma_{13}(\text{FAB}) + u_{1i}$
$\beta_{2i} = \gamma_{20}$
$\beta_{3i} = \gamma_{30}$
$\beta_{4i} = \gamma_{40}$

Research Question 1b

On average, is there significant linear change in ability belonging over time? Does this change depend on a student's physics ability beliefs, gender, race, ethnicity, academic level, and field-specific ability beliefs?

Levels of Model

Outcome: ability belonging
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (B4)

Level 1: $[\text{Ability Belonging}]_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average physics ability belonging across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of physics ability belonging across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in ability belonging that exists between students

$1 - \rho$ = proportion of variance in ability belonging that exists within students

Conditional Model: Time (B5)

Level 1 predictor: time

Level 1: $[\text{Ability Belonging}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

$\beta_{1i} = \gamma_{10} + u_{1i}$

Conditional Model: All Predictors (B6)

Level 1 predictors: time, semester, academic level (AL), physics ability beliefs (PAB)

Level 2 predictors: gender, race/ethnicity, field-specific ability beliefs (FAB)

Level 1: $[\text{Ability Belonging}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{Level}) + \beta_{3it}(\text{PAB}) + \beta_{4it}(\text{Time X PAB}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{FAB}) + \gamma_{04}(\text{FAB X Gender}) + \gamma_{05}(\text{FAB X Race/Ethnicity}) + u_{1i}$
$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Gender}) + \gamma_{12}(\text{Race/Ethnicity}) + \gamma_{13}(\text{FAB})$
$\beta_{2i} = \gamma_{20}$
$\beta_{3i} = \gamma_{30} + \gamma_{31}(\text{Gender}) + \gamma_{32}(\text{Race/Ethnicity})$
$\beta_{4i} = \gamma_{40}$

Research Question 1c

On average, is there significant linear change in social belonging over time? Does this change depend on a student's physics ability beliefs, gender, race, ethnicity, academic level, and field-specific ability beliefs?

Levels of Model

Outcome: physics social belonging
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (B7)

Level 1: $[\text{Social Belonging}]_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average social belonging across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of social belonging across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in physics belonging that exists between students

$1 - \rho$ = proportion of variance in physics belonging that exists within students

Conditional Model: Time (B8)

Level 1 predictor: time

Level 1: $[\text{Social Belonging}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$
$\beta_{1i} = \gamma_{10} + u_{1i}$

Conditional Model: All Predictors (B9)

Level 1 predictors: time, semester, academic level (AL), physics ability beliefs (PAB)

Level 2 predictors: gender, race/ethnicity, field-specific ability beliefs (FAB)

Level 1: $[\text{Social Belonging}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{Level}) + \beta_{3it}(\text{PAB}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{FAB}) + \gamma_{04}(\text{FAB X Gender}) + \gamma_{05}(\text{FAB X Race/Ethnicity}) + u_{1i}$
$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Gender}) + \gamma_{12}(\text{Race/Ethnicity}) + \gamma_{13}(\text{FAB})$
$\beta_{2i} = \gamma_{20}$
$\beta_{3i} = \gamma_{30} + \gamma_{31}(\text{Gender}) + \gamma_{32}(\text{Race/Ethnicity})$

Research Question 1d

On average, is there a significant linear relationship between a student's physics ability beliefs, physics ability belonging, physics social belonging, and intent to persist in a physics major over time? Does this relationship depend on a student's gender, race, ethnicity, academic level, and field-specific ability beliefs?

Levels of Model

Outcome: intended persistence
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (B10)

Level 1: $[\text{Persist}]_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average intended persistence across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of intended persistence across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in intended persistence that exists between students

$1 - \rho$ = proportion of variance in intended persistence that exists within students

Conditional Model: Time (B11)

Level 1 predictor: time

Level 1: $[\text{Persistence}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$
$\beta_{1i} = \gamma_{10} + u_{1i}$

Conditional Model: Physics Ability Beliefs, Social Belonging, Ability Belonging (B12)

Level 1 predictors: time, semester, academic level (AL), physics ability beliefs (PAB)

Level 2 predictors: gender, race/ethnicity, field-specific ability beliefs (FAB)

Level 1: $[\text{Persist}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{Level}) + \beta_{3it}(\text{PAB}) + \beta_{4it}(\text{AbilityBelonging}) + \beta_{5it}(\text{SocialBelonging}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$
$\beta_{1i} = \gamma_{10}$
$\beta_{2i} = \gamma_{20}$
$\beta_{3i} = \gamma_{30}$
$\beta_{4i} = \gamma_{40}$
$\beta_{5i} = \gamma_{50}$

Conditional Model: All Level 1 and Level 2 Predictors (B13)

Level 1 predictors: time, semester, academic level (AL), physics ability beliefs (PAB)

Level 2 predictors: gender, race/ethnicity, field-specific ability beliefs (FAB)

Level 1: $[\text{Persist}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{Level}) + \beta_{3it}(\text{PAB}) + \beta_{4it}(\text{AbilityBelonging}) + \beta_{5it}(\text{SocialBelonging}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{FAB}) + u_{0i}$
$\beta_{1i} = \gamma_{10}$
$\beta_{2i} = \gamma_{20}$
$\beta_{3i} = \gamma_{30} + \gamma_{31}(\text{Gender}) + \gamma_{32}(\text{Race/Ethnicity})$
$\beta_{4i} = \gamma_{40} + \gamma_{41}(\text{Gender}) + \gamma_{42}(\text{Race/Ethnicity})$

$$\beta_{5i} = \gamma_{50} + \gamma_{51}(\text{Gender}) + \gamma_{52}(\text{Race/Ethnicity})$$

Appendix C

Article 2 Survey Scales

Physics Ability Beliefs Scale: Student Version (Modified from van Aalderen-Smeets et al., 2019)

6-point Likert items (1 = *strongly agree* to 6 = *strongly disagree)*

I don't think I personally can do much to increase my physics ability. (r)

My physics ability is something about me that I personally can't change very much. (r)

To be honest, I don't think I can really change my physics aptitude. (r)

With enough time and effort, I think I could significantly improve my physics ability level.

I believe I can always substantially improve on my physics aptitude.

Regardless of my current physics ability level, I think I have the capacity to change it quite a bit.

I believe I have the ability to change my basic physics aptitude level considerably over time.

Physics Ability Beliefs Scale: Instructor Perception Version (Modified from van Aalderen-Smeets et al., 2019)

6-point Likert items (1 = *strongly agree* to 6 = *strongly disagree)*

Identify the extent to which you believe that your course's physics instructor agrees with the following questions:

I *don't think students can do much to increase their physics ability. (r)*

Students' physics ability is something that they can't change very much. (r)

To be honest, I don't think students can really change their physics aptitude. (r)

With enough time and effort, I think students can significantly improve their physics ability level.

I believe students can always substantially improve their physics aptitude.

Regardless of their current physics ability level, I think students have the capacity to change it quite a bit.

I believe students have the ability to change their basic physics aptitude level considerably over time.

Ability Uncertainty Scale (Lewis & Hodges, 2015)

6-point Likert items (1 = *strongly agree* to 6 = *strongly disagree)*

I worry my abilities aren't good enough to do well in my major.

I often wonder if I have what it takes to succeed in my major.

I feel confident about my abilities in my major.

I sometimes feel like other students in my major have skills that I don't.

When I'm doing work in my major, I feel a sense of competence.

My major requires some abilities that I'm not sure I possess.

I worry that no matter how hard I try, I won't be able to perform successfully in my major.

When I'm doing work in my major, I feel I have the skills that I need.

I'm not sure that I'm cut out for my major.

I have no doubts that I possess or can acquire the abilities my major requires.

I feel similar to the kinds of people who have what it takes to succeed in my major.

I'm not certain I "fit in" intellectually in my major.

Social Belonging Scale (Good et al., 2012)

6-point Likert items (1 = *strongly agree* to 6 = *strongly disagree)*

When I am in a physics setting,

I feel that I belong to the physics community.

I consider myself a member of the physics world.

I feel like I am part of the physics community.

I feel a connection with the physics community.

Intent to Persist Scale (Lewis & Hodges, 2015)

6-point Likert items (1 = *strongly agree* to 6 = *strongly disagree)*

I have seriously considered changing my major. (r)

I often wonder if I really want to have a career in my major. (r)

It is important to me to finish my program of study in physics.

It is likely that I will remain in my major next academic year.

Academic Struggle Items (Limeri et al., 2020a)

Did you encounter struggle in [course name] this week? (*Yes/No*)

Were you able to overcome the struggle that you encountered? (If 'Yes' for item 1)

Physics Recognition Scale (Hazari et al., 2020)

5-point Likert-type (1 = *not at all* to 5 = *very much so*)

To what extent do you believe…

Other physics undergraduates see you as an exemplary physics student?

Your physics professors/faculty see you as an exemplary physics student?

Physics Identity Scale (Hazari et al., 2020)

5-point Likert-type (1 = *not at all* to 5 = *very much so*)

To what extent do you…see yourself as an exemplary physics student?

With respect to a physics community, to what extent do you see yourself as a physicist?

Academic Task Type

Please check off the type(s) of tasks that you encountered in this physics course over the past week:
Quiz
Exam
Problem Set
Experimental Lab Write-up
Textbook Reading
Lecture Video
Other: _____

Appendix D

Article 2 Multilevel Models

Research Question 1a

On average, is there significant linear change in physics ability beliefs? Does this change depend on a student's gender, race, ethnicity, course level, perceived academic struggle, type of academic task encountered during the week, and perceived instructor ability beliefs?

Levels of Model

Outcome: incremental physics ability beliefs
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (D1)

Level 1: $\text{PhysicsAbilityBeliefs}_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average incremental physics ability beliefs across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of physics ability beliefs across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in physics ability beliefs that exists between students
$1 - \rho$ = proportion of variance in physics ability beliefs that exists within students

Conditional Model (D2)

Level 1 predictors: time, perceived academic struggle (AS), type of academic task encountered (exam, interactive in-class activity, experimental lab activity)

Level 2 predictors: gender, race/ethnicity, course level (CL), perceived instructor ability beliefs (IAB)

$$\text{Level 1: PhysicsAbilityBeliefs}_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{AS}) + \beta_{3it}(\text{Time X AS}) + \beta_{4it}(\text{Exam}) + \beta_{5it}(\text{Activity}) + \beta_{6it}(\text{Lab}) + r_{it}$$

$$\text{Level 2: } \beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{CL}) + \gamma_{04}(\text{IAB}) + u_{0i}$$
$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Gender}) + \gamma_{12}(\text{Race/Ethnicity}) + \gamma_{13}(\text{CL}) + \gamma_{14}(\text{IAB}) + u_{1i}$$
$$\beta_{2i} = \gamma_{20}$$
$$\beta_{3i} = \gamma_{30}$$
$$\beta_{4i} = \gamma_{40}$$

$\beta_{5i} = \gamma_{50}$
$\beta_{6i} = \gamma_{60}$

Research Question 1b

On average, is there significant linear change in perceived recognition? Does this change depend on a student's gender, race, ethnicity, course level, physics ability beliefs, perceived academic struggle, type of academic task encountered during the week, and perceived instructor ability beliefs?

Levels of Model

Outcome: perceived recognition
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (D3)

Level 1: $\text{Recognition}_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average perceived recognition across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of perceived recognition across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in perceived recognition that exists between students
$1 - \rho$ = proportion of variance in perceived recognition that exists within students

Conditional Model (D4)

Level 1 predictors: time, perceived academic struggle (AS), type of academic task encountered (exam, interactive in-class activity, experimental lab activity), incremental physics ability beliefs (PAB)

Level 2 predictors: gender, race/ethnicity, course level (CL), perceived instructor ability beliefs (IAB)

$$\text{Level 1: Recognition}_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{PAB}) + \beta_{3it}(\text{AS}) + \beta_{4it}(\text{Time X PAB}) + \beta_{5it}(\text{Time X AS}) + \beta_{6it}(\text{PAB X AS}) + \beta_{7it}(\text{Activity}) + \beta_{8it}(\text{Lab}) + \beta_{6it}(\text{Exam}) + r_{it}$$

$$\text{Level 2: } \beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{CL}) + \gamma_{04}(\text{IAB}) + u_{0i}$$
$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Gender}) + \gamma_{12}(\text{Race/Ethnicity}) + \gamma_{13}(\text{CL}) + \gamma_{14}(\text{IAB}) + u_{1i}$$

$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{Gender}) + \gamma_{22}(\text{Race/Ethnicity}) + \gamma_{23}(\text{CL}) + \gamma_{24}(\text{IAB})$
$\beta_{3i} = \gamma_{30}$
$\beta_{4i} = \gamma_{40}$
$\beta_{5i} = \gamma_{50}$
$\beta_{6i} = \gamma_{60}$
$\beta_{7i} = \gamma_{70}$
$\beta_{8i} = \gamma_{80}$
$\beta_{9i} = \gamma_{90}$

Research Question 2a

On average, are there significant linear relationships between a student's physics ability beliefs, perceived recognition, and physics belonging (ability and social) over time? Do these relationships depend on a student's gender, race, ethnicity, course level, and perceived instructor ability beliefs?

Levels of Model

Outcomes: ability belonging and social belonging
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (D5)

Level 1: $[\text{Belonging}]_{it} = \gamma_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average physics belonging across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of physics belonging across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in physics belonging that exists between students
$1 - \rho$ = proportion of variance in physics belonging that exists within students

Conditional Model (D6)

Level 1 predictors: time, incremental physics ability beliefs (PAB), perceived recognition

Level 2 predictors: Gender, race/ethnicity, course level (CL), perceived instructor ability beliefs (IAB)

Level 1: $[\text{Belonging}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{Recognition}) + \beta_{3it}(\text{PAB}) + \beta_{4it}(\text{PAB X Recognition}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{CL}) + u_{0i}$
$\beta_{1i} = \gamma_{10}$
$\beta_{2i} = \gamma_{20}$
$\beta_{3i} = \gamma_{30}$
$\beta_{4i} = \gamma_{40}$

Research Question 2b

On average, are there significant linear relationships between a student's physics belonging (ability and social), perceived recognition, and physics identity over time? Do these relationships depend on a student's gender, race, ethnicity, course level, physics ability beliefs and perceived instructor ability beliefs?

Levels of Model

Outcome: physics identity
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (D7)

Level 1: $[\text{PhysicsIdentity}]_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average physics identity across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of physics identity across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in physics identity that exists between students
$1 - \rho$ = proportion of variance in physics identity that exists within students

Conditional Model

(D8)

Level 1 predictors: time, recognition, physics belonging (ability and social belonging run separately), physics ability beliefs (PAB)

Level 2 predictors: gender, race/ethnicity, course level (CL)

Level 1: $[\text{PhysicsIdentity}]_{it} = \beta_{0it} + \beta_{1it}(\text{Time}) + \beta_{2it}(\text{Recognition}) + \beta_{3it}(\text{Belonging}) + \beta_{4it}(\text{PAB}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{CL}) + \gamma_{04}(\text{IAB}) + u_{0i}$
$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Gender}) + \gamma_{12}(\text{Race/Ethnicity}) + \gamma_{13}(\text{CL}) + \gamma_{14}(\text{IAB})$
$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{Gender}) + \gamma_{22}(\text{Race/Ethnicity}) + \gamma_{23}(\text{CL}) + \gamma_{24}(\text{IAB})$
$\beta_{3i} = \gamma_{30}$
$\beta_{4i} = \gamma_{40}$

Research Question 2c

On average, are there significant linear relationships between a student's physics belonging (ability and social), perceived recognition, physics identity, and intent to persist in the physics major? Do these relationships depend on a student's gender, race, ethnicity, course level, physics ability beliefs and perceived instructor ability beliefs?

Levels of Model

Outcome: intended persistence
Level 1: t = time (individual student trajectories)
Level 2: i = student (variation among students)

Unconditional Model (D9)

Level 1: $[\text{Persistence}]_{it} = \beta_{0it} + r_{it}$
Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

β_{0it}: average intended persistence across all time points for a student
r_{it}: residual for this student around the average across time
γ_{00}: point estimate for the grand mean of intended persistence across time and students
u_{0i}: variability across students from the grand mean

Intraclass Correlation

$\rho = \tau_{00}/(\tau_{00} + \sigma^2)$ = proportion of variance in intended persistence that exists between students
$1 - \rho$ = proportion of variance in intended persistence that exists within students

Conditional Model (D10)

Level 1 predictors: recognition, physics belonging (ability and social run separately), physics identity, physics ability beliefs (PAB)

Level 2 predictors: gender, race/ethnicity, course level (CL), perceived instructor ability beliefs (IAB)

Level 1: $[\text{Persistence}]_{it} = \beta_{0it} + \beta_{1it}(\text{Identity}) + \beta_{2it}(\text{Belonging}) + \beta_{3it}(\text{Recognition}) + \beta_{4it}(\text{PAB}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Gender}) + \gamma_{02}(\text{Race/Ethnicity}) + \gamma_{03}(\text{CL}) + \gamma_{04}(\text{IAB}) + u_{0i}$

$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{Gender}) + \gamma_{12}(\text{Race/Ethnicity}) + \gamma_{13}(\text{CL}) + \gamma_{14}(\text{IAB})$
$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{Gender}) + \gamma_{22}(\text{Race/Ethnicity}) + \gamma_{23}(\text{CL}) + \gamma_{24}(\text{IAB})$
$\beta_{3i} = \gamma_{30} + \gamma_{31}(\text{Gender}) + \gamma_{32}(\text{Race/Ethnicity}) + \gamma_{33}(\text{CL}) + \gamma_{34}(\text{IAB})$
$\beta_{4i} = \gamma_{40} + \gamma_{41}(\text{Gender}) + \gamma_{42}(\text{Race/Ethnicity}) + \gamma_{43}(\text{CL})$

Appendix E

Student Participant Questionnaire

Please respond to the following questions about your background.

Name

Email Address

Pseudonym *(a fictitious name that you generate to ensure your anonymity in this study)*

Gender *(self-describe as you feel comfortable)*

Race/Ethnicity *(self-describe as you feel comfortable)*

Do you identify as a member of the LGBTQIA+ community?

Yes, No, I prefer not to answer

Hometown (i.e., city, state, country of origin)

Parent/Guardian's highest level of education (Parent/Guardian 1)

No high school
Some high school
High school diploma/GED
Some college (no degree)
Business/technical certificate or degree
Associate's degree
Bachelor's degree
Master's degree
Doctoral Degree or professional degree (ex. Ph.D., JD, MD)
Other professional degree(s)
Unknown/Not applicable

Parent/Guardian's highest level of education (Parent/Guardian 2)

No high school
Some high school
High school diploma/GED
Some college (no degree)
Business/technical certificate or degree
Associate's degree
Bachelor's degree

Master's degree
Doctoral Degree or professional degree (ex. Ph.D., JD, MD)
Other professional degree(s)
Unknown/Not applicable

How would you describe your socioeconomic status growing up?

Lower class
Working class
Middle class
Wealthy/Affluent

Major(s)

Minor(s)

Undergraduate Classification

Freshman, sophomore, junior, senior

Are you an external transfer student?

No
Yes, I transferred from another 4-year college/university
Yes, I transferred from a community college

Enrollment status

Fulltime (12+ credit hours per semester)
Parttime

Are you employed either on-campus or off-campus on average more than 10 hours per week?

Yes, on-campus
Yes, off-campus
Yes, both on-campus and off-campus
No

Please identify the physics course(s) that you completed during the 2021-2022 academic year.

What are your current career interests/goals?

List words and/or phrases that you feel best describe yourself as a person

List words and/or phrases that you feel best describe yourself as a college student *(this can of course overlap or not overlap with the words/phrases on your previous list)*

Appendix F

Interview Protocols

Student Interview Protocol

Background Questions

Thank you for taking the time to talk to me today and for filling out the participant questionnaire. My first few questions will ask you to elaborate on some of your responses so that I can get to know you better. Throughout this interview, please only share to the extent that you feel comfortable. I am going to share a copy of these responses for us both to view on Zoom for reference.

Tell me more about yourself as a person

Tell me more about yourself as a college student

Physics Major Questions

My next few questions pertain to your experiences in your major as a whole.

What led you to pursue a bachelor's degree in physics at [Southeastern University]? **Interest**

Imagine that you are talking to high school students who are considering pursuing a bachelor's degree in physics at Southeastern University. How would you describe the undergraduate physics program? **Cultural, Structural**

Imagine that you are talking to an incoming physics major who is similar. How would you describe what your physics instructors believe that it takes to be a good student in the major? **Competence, Cultural**

In your own words can you tell me what it takes to be a good physics student? **Competence, Cultural**

> Describe how you see yourself in relation to a good physics student. **Competence, Identity, Cultural**
>
> Tell me about how you perceive that your physics instructors and peers see you in relation to a good physics student. **Recognition**

Tell me about your experience as a _____ studying physics at Southeastern University (depending on the identities that they isolated in their answers to questionnaire). **Domains of Power**

Describe how your physics program supports and/or not supports you as a _____ studying physics? **Domains of Power**

Potential follow-up: What would make your experience better?

Describe what you feel like it means to belong in the physics major at Southeastern University. **Belonging**

Tell me about a time when you felt like you belonged in your physics major. **Belonging, Domains of Power**

How did your interactions with others in your major impact you feeling that you belonged? **Interpersonal**

What policies and/or practices had an impact on you feeling like you belonged? **Cultural, Structural, Disciplining**

Tell me about a time when you felt like you didn't belong in your physics major. **Belonging, Domains of Power**

How did your interactions with others in your major impact you feeling that you didn't belong? **Interpersonal**

What policies and/or practices had an impact on you feeling like you didn't belong? **Cultural, Structural, Disciplining**

What advice would you give to yourself as a freshman knowing what you now know about being a physics major?

Course and Experimental Lab Activity Experiences

Tell me about your experience in [specific physics course(s)].

Describe a typical week in the course.

How would you describe this courses' structure? **Structural**

What do you feel that your course instructor valued in physics students? **Cultural**

How do you feel about your interactions with your instructor in the course? **Interpersonal**

How do you feel that your instructor perceived you as a student? **Recognition**

How do you feel about your interactions with your peers in the course? **Interpersonal**

How do you feel that your peers perceived you? **Recognition**

Tell me about a time when you felt successful in the course. **Competence**

Tell me about a time when you encountered a challenge in the course. **Competence**

What did you do?

How did it make you feel?

What was the outcome?

How did your identities shape your experiences in the course? **Domains of Power**

What would have made your experience better?

How did your experiences in this course shape your perceptions of yourself in physics? **Identity, Domains of Power**

Tell me about your experience in the experimental lab activity
- How did your identities shape your experience?
- What would have made your experience better?

How did your group divide up tasks? **Interpersonal**
- How did they decide to do so?

How do you feel about your interactions with your group members? **Interpersonal**

What role did the TA play in your experimental lab activity? **Interpersonal, Structural, Disciplining**

How did the experimental lab activity fit into the rest of the course? **Structural**

Career Interests/Goals

What do you feel that it takes to be successful as a physicist? **Identity, Cultural**

Do you consider yourself to be a physicist (or a developing physicist)? Tell me about that. **Identity**

What college experiences have been particularly meaningful to your development as a physicist?

Take a moment to imagine your ideal future employment setting. Describe it to me. **Domains of Power**

- What type of environment it is?
- What type of people are working there with you?
- What types of things are you working on?
- How do people interact with each other?
- What types of things does your workplace value?

Instructor Interview Protocol

Tell me about your experience teaching [specific physics course] in [specific semester]
- How do you structure the course? **Structural**
- How do you support students in learning material? **Interpersonal, Structural, Disciplining**
- How do you feel that students perceived the class?
- How do you feel the students perceived you? **Interpersonal**

Why did you decide to incorporate an experimental lab activity into the class?

How did the experimental lab activity fit in with the rest of the course? **Structural**
What did you like about it?
What could be improved?

How do you define a 'good' student in [specific physics course]? **Cultural, Recognition**

How have your own experiences in physics shaped your approach to teaching undergraduates?

TA Interview Protocol

What led you to TA for the experimental lab activity program?
How long have you been a TA for the program?

Tell me about your experience as a TA for the experimental lab activity program. **Domains of Power**
How has it fit in with your graduate school experience?
What do you like about being a TA for the experimental lab activity program?
What is challenging about being a TA for the experimental lab activity program?
How have your own experiences in physics shaped your approach as a TA?
How do your identities shape your experience as a TA?

Describe your approach to guiding students during their experimental lab activity. **Domains of Power**

Describe your approach to coordinating with course instructors. **Domains of Power**

Describe your approach to grading students' experimental lab activity write-ups. **Domains of Power**

Tell me about how students tend to approach group work during their experimental lab activity. **Interpersonal**

What advice do you have for students on how to be successful during their experimental activity?

What do you think works well?

What could be improved?