Investigating the Relationship Between Departmental Support Structures, Self-Efficacy and Intention to Persist: An Examination of Students' Experience in 19 Physics Graduate Programs Across the United States

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INVESTIGATING THE RELATIONSHIP BETWEEN DEPARTMENTAL SUPPORT STRUCTURES, SELF-EFFICACY AND INTENTION TO PERSIST: AN EXAMINATION OF STUDENTS’ EXPERIENCE IN 19 PHYSICS GRADUATE PROGRAMS ACROSS THE UNITED STATES

by

Diana Sachmpazidi

A dissertation submitted to the Graduate College in partial fulfillment of the requirements for the degree of Doctor of Philosophy
Mallinson Institute for Science Education
Western Michigan University
August 2021

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Science, Technology, Engineering, and Mathematics (STEM) graduate programs experience consistently high attrition rates. Moreover, persistent disparities exist in racial and gender representation. Women and People of Color are significantly underrepresented and have higher attrition rates than men and white and Asian American students. To date, little work is done to understand graduate student attrition or persistence. There is also a lack of information regarding the causes of demographic disparities in attrition. Most past studies in this context have focused on students’ attributes, undergraduate preparation, and mentoring relationships. Moreover, student self-efficacy is a contributing factor for undergraduate student retention. Yet, there is currently minimal research on the role of self-efficacy in STEM graduate student retention. Emerging results from the implementation of the American Physical Society Bridge Program provide support to the idea that departmental factors are significantly correlated to increased retention. However, there are no validated instruments to measure students’ experience of the departmental support structures. This study uses a sociological approach under the notion that the surrounding environment influences student experiences and behavior. We use a social cognitive theory to develop and test a model of graduate student retention. In particular, this study aims to: 1. develop and validate an instrument to measure graduate students’ experiences of departmental support structures; 2. explore demographic differences in students’ self-efficacy beliefs; 3. test a model of physics graduate retention using student and department leadership data. We used a mixed-methods explanatory sequential design approach, gathering 397 student quantita-
tive responses, 20 student follow-up semi-structured interviews, and 9 department leadership semi-structured interviews. This broad study resulted in developing the Aspect of Student Experience Scale (ASES), which exhibited substantial internal consistency and acceptable discriminant and convergent validity. Moreover, this study uncovered patterns of structural inequities reflected in the consistently lower self-efficacy for women than men. These patterns are further exacerbated for women with additional minoritized identities (sexuality, first-generation college status). Finally, this study presents a retention model for graduate education that shows the critical role of student socioacademic integration and self-efficacy on intention persistence. Students’ in-depth interview data corroborate this finding suggesting that a supportive social and academic environment (e.g., working with peers on coursework, socializing, communication with faculty members and mentors) increases students’ self-efficacy and supports them in completing the program degree. However, we found that departments’ leadership are unaware of the struggles students experience due to the departmental environment (lack of socioacademic integration, discrimination, increased workload) and attribute students’ decisions to leave the program to external program reasons. The results of this study urge for cultural change towards supporting student learning and growth, improving work-life balance, and developing and maintaining healthier relationships with faculty members. This study offers a comprehensive view of graduate students’ experiences in their programs. It provides targeted recommendations for policymakers and researchers on practices that could improve students’ experiences and increase retention.
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TABLE OF CONTENTS

ACKNOWLEDGEMENTS........................................................................................................ ii

LIST OF TABLES................................................................................................................ v

LIST OF FIGURES............................................................................................................... vi

CHAPTER

I. INTRODUCTION........................................................................................................... 1
  Theoretical Background................................................................................................. 2
  Purpose of the Study ..................................................................................................... 4
  Study Design.................................................................................................................. 6
  Significance of the Study............................................................................................... 13

II. DEPARTMENTAL SUPPORT STRUCTURES FOR PHYSICS GRADUATE STUDENTS: DEVELOPMENT AND PSYCHOMETRIC EVALUATION OF A SELF-REPORT INSTRUMENT .......................................................... 14
  Abstract ......................................................................................................................... 14
  Introduction ...................................................................................................................... 15
  Theoretical Background ................................................................................................. 17
  Methods .......................................................................................................................... 23
  Results ............................................................................................................................. 32
  Limitations ....................................................................................................................... 44
  Discussion ......................................................................................................................... 45
  Implications for Practice and Research........................................................................... 46
  Conclusions ....................................................................................................................... 47

III. PSYCHOMETRIC EVALUATION OF A SELF-EFFICACY SCALE IN PHYSICS GRADUATE EDUCATION: EXAMINING DEMOGRAPHIC DIFFERENCES .... 49
  Abstract ......................................................................................................................... 49
  Introduction ....................................................................................................................... 50
  Theoretical Background ................................................................................................. 52
  Methods .......................................................................................................................... 60
**IV. THE ROLE OF DEPARTMENTAL SUPPORT STRUCTURES AND SELF-EFFICACY ON PHYSICS STUDENT PERSISTENCE: AN EXAMINATION OF STUDENTS’ EXPERIENCE FROM 19 PHYSICS PROGRAMS**

86

<table>
<thead>
<tr>
<th>Abstract</th>
<th>86</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>87</td>
</tr>
<tr>
<td>Literature Review</td>
<td>88</td>
</tr>
<tr>
<td>Theoretical Framework</td>
<td>95</td>
</tr>
<tr>
<td>Methods</td>
<td>97</td>
</tr>
<tr>
<td>Results</td>
<td>109</td>
</tr>
<tr>
<td>Discussion</td>
<td>141</td>
</tr>
<tr>
<td>Implications for Practice and Research</td>
<td>146</td>
</tr>
<tr>
<td>Conclusions</td>
<td>150</td>
</tr>
</tbody>
</table>

**V. CONCLUSIONS**

151

| Summary of Findings | 151 |
| Limitations | 154 |
| Discussion | 155 |
| Recommendations for Practice and Research | 157 |

**REFERENCES**

162

**APPENDICES**

171

- APPENDIX A: HSIRB Approval Form
- APPENDIX B: Student Interview Protocol
- APPENDIX C: Department Leader Interview Protocol
- APPENDIX D: Full Structural Equation Model
- APPENDIX E: Full Table of SEM
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Characteristics of each of the 19 physics graduate programs.</td>
</tr>
<tr>
<td>2.2</td>
<td>Students’ demographic information</td>
</tr>
<tr>
<td>2.3</td>
<td>Comparison of PCA and PA factors</td>
</tr>
<tr>
<td>2.4</td>
<td>Loading factors from the rotated four factor Varimax solution</td>
</tr>
<tr>
<td>2.5</td>
<td>Summary of ASES components.</td>
</tr>
<tr>
<td>2.6</td>
<td>Results of students’ ASES responses</td>
</tr>
<tr>
<td>2.7</td>
<td>AVE, squared inter-component correlation, CRI and Cronbach’s $\alpha$.</td>
</tr>
<tr>
<td>2.8</td>
<td>$\mu \pm \sigma$ for the two APS-BP affiliated and non affiliated departments on the four ASES components.</td>
</tr>
<tr>
<td>3.1</td>
<td>Characteristics of each of the 19 physics graduate programs.</td>
</tr>
<tr>
<td>3.2</td>
<td>Comparison of PCA and PA factors. If $\lambda_{PCA} &gt; \lambda_{PA}$, accept.</td>
</tr>
<tr>
<td>3.3</td>
<td>Loading factors from the rotated four factor Varimax solution. Note: The stem of the items is ”how confident are you in your ability to...”</td>
</tr>
<tr>
<td>3.4</td>
<td>AVE, squared inter-component correlation, and CRI.</td>
</tr>
<tr>
<td>3.5</td>
<td>Results of students’ beliefs of self-efficacy</td>
</tr>
<tr>
<td>3.6</td>
<td>Effect size of self-efficacy beliefs of Ph.D. students per demographic group.</td>
</tr>
<tr>
<td>3.7</td>
<td>Mean, standard deviation values, and Hedge’s $g$ effect size on differences on key academic related aspects and intention to persist.</td>
</tr>
<tr>
<td>4.1</td>
<td>Characteristics of each of the 19 physics graduate programs.</td>
</tr>
<tr>
<td>4.2</td>
<td>Student Interviewee Demographics</td>
</tr>
<tr>
<td>4.3</td>
<td>Department Leadership Interviewees</td>
</tr>
<tr>
<td>4.4</td>
<td>Model variables</td>
</tr>
<tr>
<td>4.5</td>
<td>Descriptive statistics of departmental support structures and academic self-efficacy</td>
</tr>
<tr>
<td>4.6</td>
<td>Parameter estimates resulted from SEM</td>
</tr>
<tr>
<td>0.1</td>
<td>Full SEM Table - Regressions</td>
</tr>
<tr>
<td>0.2</td>
<td>Full SEM Table - Intercepts</td>
</tr>
<tr>
<td>0.3</td>
<td>Full SEM Table - Variances</td>
</tr>
<tr>
<td>0.4</td>
<td>Full SEM Table - Defined Parameters</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

FIGURE PAGE

2.1 The APS-BP components that loaded into each ASES component. .................. 37

2.2 Hedge’s $g$ effect size between the two APS-BP affiliated and affiliated programs. The error bars illustrate the 95% confidence intervals. $g > 0$ indicate higher mean values for APS-BP affiliated departments. Any value $> .18$ is considered meaningful [1]. ........................................................................................................ 40

4.1 The summary of the hypothetical model tested in this study. Student attributes include student demographic information and semester in the program; experiences of departmental supports include student responses on mentoring & research experience, professional development, social & academic integration, and financial support; self-efficacy refers to the academic self-efficacy. 97

4.2 The resulted retention model in graduate education. This model is the summarized version displaying only the significant relationships. The black lines indicate the effect of each variable to the other. The yellow lines indicate the three covariates of social & academic integration, mentoring & research experience, and financial support that are indicators of supportive departments. The full-version model is shown in Appendix D. .......................... 112
CHAPTER I
INTRODUCTION

Attrition rates in doctoral programs are persistently at high levels. In particular, studies report doctoral attrition ranging from 40% to 50% [2, 3]. Moreover, Science, Technology, Engineering, and Mathematics (STEM) graduate education is characterized by a lack of gender and racial/ethnic diversity [4, 5]. In particular, women comprise about 50% of the U.S. population, but only about 20% earn doctoral degrees in physics [6]. Similarly, although students from racial/ethnic minoritized backgrounds comprise about 33% of the U.S. population [7], these students earn only 9% of the awarded doctoral STEM degrees [4]. In addition to the lack of gender and racial/ethnic diversity in STEM, attrition rates are disproportionally higher for Hispanic/Latinx and Black students than for white and Asian American students [8]. These disparities in representation and persistence of racial and ethnic minoritized students pose a concern for social justice in higher education institutions, particularly in STEM fields. The growing ethnic diversity in the United States, along with the lack of racial/ethnic and gender diversity, pose a more logistical concern for the country’s leading role in technological innovations in the global market [3]. Finally, it is substantially important to identify the factors that lead to attrition. Students invest a significant amount of energy, money, and time, before and after their acceptance in their chosen program. Not completing their degree can be detrimental to their emotional and financial well-being [9, 10].

Understanding the reasons for the high attrition rates has been an important priority for researchers [8, 11, 12, 13, 14]. While several studies have sought to understand the aspects of attrition within one or two doctoral programs, the literature still lacks comprehensive empirical studies across multiple institutions [15]. Moreover, there have been only a few models focused on doctoral attrition, and many of these are now quite dated. Tinto 1993 pointed out the importance of having a developed model as a guide to give shape to doctoral student persistence studies. Our current understanding of the phenomenon of doctoral attrition is quite limited compared to undergraduate attrition. The following
reasons have significantly contributed to this outcome. First, there are no nationwide databases on attrition as there are on doctoral completion rates (e.g., Survey of Earned Doctorates, NSF). Second, there are no systematic ways of recording doctoral attrition data within institutions. If such data exist, these are usually kept within the department and are not publicly available. Third, it is difficult to track students who departed from their programs, and in those instances, the information they provide is based on recollection.

Theoretical Background

While the literature on doctoral persistence is slowly expanding, it is yet significantly limited to the plethora of work in undergraduate retention, which is rich in theoretical models and empirical research [17]. There are clear distinctions between the undergraduate and doctoral student experience; however, considering the limited background in doctoral persistence literature, several studies were built based on the theoretical grounds of the undergraduate literature.

The first studies in undergraduate retention started developing in the 1930s focused on exploring student psychology [17, 18]. In 1970’s the first retention models shifted the direction from student psychology towards a more sociological approach of the student-college interaction [19, 20, 21, 22]. A few decades later, the few models on doctoral attrition emerged, having their foundation on the undergraduate literature on student attrition models [23, 24]).

The doctoral retention models of Girves & Wimmerus 1988 and Vaquera 2007 highlighted the importance of social and academic integration in students’ persistence. Similarly, later studies also corroborated the essential role that social and academic integration has on students’ persistence [25, 26, 27, 28]. However, most studies on doctoral retention focused across multiple disciplines (including STEM and non-STEM programs). There is little work on STEM disciplines [29], and in particular, on the holistic experience of STEM students. The distinctive aspects between science and non-science programs pose the need to study
attrition separately. For example, STEM and non-STEM programs differ in program characteristics (e.g., financial support, work-space), student population, and faculty representation [30]. The approach of focusing and aggregating results across multiple disciplines limits our understanding of the specific aspects of social and academic support that are important for STEM students’ experience.

The focus of the majority of research on doctoral retention spans from student factors (e.g., student academic preparation [2, 13]) to departmental factors [10, 31]. Aspects of departmental factors included social isolation [25, 26, 27], academic integration [10], mentoring relationships [10, 25, 32, 33, 34], and financial support [30, 35]. While these factors are also commonly investigated predictors in the undergraduate literature, student cognitive factors (e.g., self-efficacy) are largely lacking in doctoral retention work as opposed to the undergraduate.

Self-efficacy refers to “one’s beliefs in their ability to manage their functioning and exercise control over events that affect their lives” [36]. In particular, self-efficacy is a significant predictor of student motivation [37], performance [38, 39, 40], and persistence [40, 41, 42, 43, 44] in the K-12 and undergraduate literature. Yet, little work exists on the role of self-efficacy in graduate education. Self-efficacy is a mobile construct that is influenced by the environmental stimuli [45] and reestablishes over time [46]. Multon, Brown, & Lent, 1991 meta-analyses studies found that the effect of self-efficacy on performance and persistence outcomes varies across student types, measures, and study characteristics. Therefore, our understanding of the potential impact of self-efficacy on doctoral persistence is quite limited.

This study used a sociological approach by examining the role of departmental support structures in the student experience and, in particular, in students’ persistence intentions. In particular, using the theoretical guidance of social cognitive theory [36, 45, 47], we tested the notion that the surrounding environment influences students’ persistence ei-
ther directly or indirectly through student cognitive factors that are also subjected to the environmental stimuli.

We tested a model of graduate/doctoral retention informed from the prior literature in undergraduate and graduate research. We focused on one discipline (physics) and follow-up with in-depth student interviews to help us develop an understanding of students’ experiences and the reasons leading students to depart. In this study, we argued that it is the departmental environment in the form of supportive structures as perceived by students that influence persistence intentions either directly or through the mediating role of students’ academic self-efficacy. We view the role of academic self-efficacy as a mobile construct that is influenced by the environmental context [45] and reestablishes over time [46]. Using students’ personal stories in their graduate program, we also examined emerging aspects of their experience. We also elicited students’ experiences of the impact of graduate experience on work-life balance and mental health. We should note that this study mainly focused on doctoral programs but includes two graduate (M.S.) granting institutions. Therefore, we use the term doctoral/graduate interchangeably throughout this dissertation.

Purpose of the Study

While the first systematic research on doctoral attrition started more than 30 years ago, our understanding of the causes of attrition remains limited. Attrition is a complex phenomenon that involves the interplay of departmental and student factors [15, 16]. Several reasons contributed to the limited state of our knowledge on doctoral attrition. First, empirical studies on doctoral attrition use inconsistent definitions and measures of persistence, preventing us from integrating the results of those studies. Second, attrition rates vary significantly across disciplines, implying that there are discipline-specific features of students and department/program characteristics. Third, there is a lack of updated comprehensive models of doctoral attrition informed from current empirical studies to give proper shape to the problem area. Fourth, although several studies indicate the association be-
tween departmental-based factors on student persistence, there are no validated instruments
to measure students’ experiences of these factors.

The development of this dissertation is motivated from the positive outcomes on the
American Physical Society - Bridge Program (APS-BP) students’ persistence. The APS-BP
was built to help increase the racial/ethnic diversity in physics graduate education. Through
this program, minoritized students are invited to apply to the APS-BP and receive funding to
start their graduate education at selected departments across the U.S. The APS-BP initiated
a key of departmental support recommendations that departments are invited to implement
to increase the chances of student success. These recommendations included admission
practices, building a physics graduate student association to promote social relationships,
mentoring and advising, induction (integration practices), research engagement, monitoring
student progress, resources for professional development, and practices to achieve APS-BP
sustainability [48]. 79% of the 299 placed Bridge students continue to make good progress
toward their degrees [49].

This study aims to fill in the literature gap by developing and testing a preliminary
model of graduate student persistence in the field of physics. This study has several innova-
tive features. The study begins by developing and validating a survey instrument to assess
students’ experience of departmental support structures influenced from the APS-BP key
recommendations for supportive departments. Second, this study focuses on a single dis-
cipline (physics) to control for discipline-specific variables while targeting multiple physics
programs across the U.S. Finally, instead of measuring attrition/retention and dealing with
the complicated use of the term across institutions, the outcome variable is students’ inten-
tion to complete their intended degree (master’s or doctoral) as reported by the students,
which is a direct determinant of persistence [16].

The present dissertation is comprised by three distinct research articles (chapters
2, 3, and 4), each serving a purpose towards our understanding of the graduate student
experience and the reasons that lead to students’ departure. In the following paragraphs,
we present the research questions and the used methodology.

Study Design

The review of the literature suggests that despite the significant efforts to understand graduate attrition, this research area is much less robust than the body of undergraduate attrition literature [50]. Graduate attrition is a complicated issue by nature and should be approached separately from the factors associated with undergraduate attrition. Moreover, past studies found that scientific discipline is one of the strongest predictors of degree completion [51]. Thus, context-specific discipline-based elements pose the need to tackle graduate attrition from a discipline-based point of view.

In this study, we explored the role of departmental support structures on physics graduate students’ intention to persist and examine the mediating role of self-efficacy. Moreover, the substantial role self-efficacy has been proven to have on student outcomes in high-school and undergraduate levels suggests an emerging need to gain insight into the development of graduate students’ self-efficacy and how departments can support this development. To test our hypothesized model, we identified a lack of validated and up-to-date instruments to measure departmental supports. Therefore, in the two first studies, we filled in this gap by developing the Aspects of Student Experience Scale (ASES) and assessing the psychometric properties of the developed instrument and two previously developed self-efficacy instruments. Finally, the third study used these instruments to quantitatively test the hypothesized retention model and used students’ and department leaders’ interview data to further dig into the student experience of the departmental environment. The three articles are part of the broader study on graduate student persistence under the present dissertation. The participant selection and data collection was a single source for the three articles, where different parts of the dataset were used in each article. Below, we describe the process of participant and data collection.
Study Participants and Recruitment

We recruited students enrolled in physics graduate programs from nineteen institutions across the U.S. Three of these institutions were programs that are sites of the APS-BP. Another six of these nineteen institutions were programs that are partnership institutions to the APS-BP. This means that these programs accept marginalized students through the APS-BP but do not receive funding from the APS-BP and are not required to implement all institutional policies suggested by the Bridge Program. Finally, the remaining ten institutions were not affiliated with the APS-BP but share similar characteristics to the bridge sites and partnership institutions in terms of geographical region and an approximate number of graduate students enrolled.

At the time of the study design, there were only six Bridge-site institutions in total, and we invited them to participate in the study. These APS-BP institutions were located in three geographical regions in the U.S., including West (1), Midwest (2), and South (3). Partnership and not-affiliated institutions were chosen to match the geographic representation of the APS-BP institutions. In addition, the size of the institutions (number of students enrolled) was also matched as closely as possible in selecting the institutions. All nineteen institutions were public.

Based on the above criteria, we made a list of potential institutions to be invited to the study. Next, we asked for feedback from the APS-BP management team to suggest the priority of which sites should be contacted first, based on the likeliness of site leaders responding to our request. The first step in our research plan was to identify an appropriate contact for each of the nineteen institutions. The appropriate contact might be the chair or the head of graduate studies in the physics department. Once a contact was identified, this person was asked to provide contact information for the physics graduate students in the department. Moreover, we asked for an endorsement from the chair (or other appropriate department leader) to encourage students to participate. We promised and provided a summary report of the results for each individual institution that compared their spe-
cific results to the study averages. To avoid the risk of individual student identification, we shared the reports with survey results if more than five students from the department have participated in the survey. The summary report had the potential to be useful to graduate program designers at these institutions in learning about students’ perspectives of effective and non-effective practices at their programs. Furthermore, we asked the site leaders (chairs, or directors of graduate studies) to participate in an interview, later in the semester, where they were asked to share information about the departmental structures in place and their perceptions of how students utilize and experience them.

Once we received students’ contact information, we sent them an email describing the study and invited them to participate. The consent form and all survey items was online on the Western Michigan University’s Qualtrics system. The email inviting students to participate included a link to the Qualtrics online surveys and the electronic consent form. In addition to agreeing to fill out the surveys, the consent form asked for students’ permission to access their institutional records about entering scores (undergraduate GPA and GRE scores) as well as their records of progress and completion of their PhD program. Moreover, in the consent form we informed students that they might be invited to participate on an hour-long interview at a later date.

Once we received the first set of data from students (survey data and students’ grade records) and analyzed them, we updated the interview protocol to highlight the parts from these results that are difficult to interpret and that we wished to ask about in the interviews. Then, we sent the second round of emails asking a significantly smaller subset of students to participate a virtual interview.

Finally, we contacted site leaders to ask for their participation and arranged the virtual interviews. The reason we decided to interview site leaders after conducting interviews with students is because we wanted to include emergent aspects that were evident as important into the interview protocol when talking with the site leaders. Our goal from both interviews was to compare students’ experiences of the departmental structures
with site leaders’ perceptions of how these are important to students. Below, we list the research questions/goals explored in each of the three studies and the followed methodologies.

ARTICLE 1

Departmental support structures for physics graduate students: Development and psychometric evaluation of a self-report instrument

Research Goals/Questions

1. Develop an instrument to measure students’ experiences of departmental support structures.

2. Assess the psychometric properties of the developed instrument.

3. How do department leadership interview data support the validity of the developed instrument?

Instrumentation and Analytical Approach

We developed the instrument of departmental support structures inspired from the prior literature and the APS-BP recommendations for departmental practices that are intended to better support students. We assessed the instrument for content validity through expert feedback and think-aloud interviews with physics graduate students. Once we received the results on students’ responses to the items, we performed principal components analysis to uncover the underlying structure of the items that were designed to capture the extent to which students experience a supportive departmental environment. We used Composite Reliability Index (CRI) and Cronbach’s $\alpha$ [52] to assess the internal consistency for each of the components. Internal consistency is a measure of the extent that all the items in a test measure the same underlying concept or construct [53].

Also, convergent and discriminant validity were used to assess the construct validity of the instrument. Convergent validity was assessed using the Average Variance Extracted
The squared inter-component correlation values will be used to assess divergent validity by meeting the criterion of the AVE values to be higher than the squared inter-component correlation values.

The instrument was intended to measure many of recommendations of the APS-BP. Therefore, as a further validity check, we used students’ responses enrolled at APS-BP institutions and compared those with students’ responses from similar institutions (in terms of size and ranking) that are not related to the APS-BP. In particular, we used data from programs that apply the APS-BP recommendations across all students, such that we can test if students’ responses captured the intended constructs. The magnitude of difference in the mean ratings of the instrument between respondents in the APS-BP and non-APS-BP affiliated sites was assessed using Hedges’ $g$ effect size analysis and confidence intervals (CIs) [54]. We also used department leaders’ interview data of these programs to get their perspectives on the department’s implemented practices. We used thematic analysis [55] which is a qualitative method for identifying, analyzing, and reporting patterns in the data [56]. The analysis followed the six phases described by Braun and Clark 2006. These six phases are: familiarizing with data, generalizing initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report.

ARTICLE 2

Psychometric evaluation of a self-efficacy instrument: Examining demographic differences in students’ development of self-efficacy
Research Goals/Questions

1. Assess the psychometric properties of two self-efficacy instruments.

2. Are there differences in students’ self-efficacy across demographic groups?

Instrumentation and Analytical Approach

The Research Self-efficacy scale was adopted from Greeley, et al., 1989. It is a 53-item scale designed to measure an individual’s perceived ability to accomplish various research-related tasks and previously assessed for utility by Bieschke, Bishop, & Garcia, 1996. The Academic Self-efficacy scale was adopted from Santiago & Einarson 1998. It is a 10-item instrument designed to measure an individual’s perceived ability to perform a series of degree-related tasks.

We followed the same analytical procedure as in Article 1 to assess the psychometric properties of the instrument. To understand where demographic differences exist in students’ self-efficacy, we used the effect size which is a standardized measure of the magnitude or strength of the difference in outcome between two groups [54, 60]. In particular, we used the adjusted Hedge’s $g$ for small sample sizes. Effect sizes were reported along with the confidence interval (CI) to evaluate the precision of the findings [61]. We used the 95% CI which is an indicative measure of uncertainty.

ARTICLE 3

The role of departmental support structures and self-efficacy on physics student persistence: An examination of students’ experience from 19 physics graduate programs
Research Questions

1. What aspects of the graduate program are correlated with students’ intentions to persist?

2. What are the reasons that graduate students and graduate program leaders give for students’ decision to leave the program?

3. What other factors emerge as important in students’ positive and negative experiences in their graduate program?

Instrumentation and Analytical Approach

In this study, we used all instruments developed in Articles 1 & 2 (responses to the ASES instrument of departmental support structures and academic self-efficacy), as well as students’ demographic information (e.g., gender, race, socioeconomic status), and their intention to persist. We also used interview data from students and department leaders.

This study used a mixed-methods convergent design approach to analyze the data [62]. As such, we separately used and analyzed students’ close-ended quantitative data (survey responses) and then collected and analyzed students’ in depth personal students’ perspectives and experiences. We selected participants and developed aspects of the interview protocols (departmental support structures) based on the students’ quantitative responses. We also explored emerging aspects of students’ experiences and additional aspects (mental health, work-life balance) that were not included in the quantitative design. We used the qualitative data to explain and interpret the quantitative results and combined both data to draw interpretation based on the combined strengths of both data sets. The analysis to testing the hypothesized model follows structural equation modeling, and the qualitative data were analyzed using thematic analysis.
Significance of the Study

This study approached the phenomenon of attrition by filling important gaps in the literature. First, there is the support that departmental structures could be related to attrition [10, 26, 27, 31, 32, 33, 34]. Second, self-efficacy has been shown to be an important predictor for student outcomes at the undergraduate level [37, 38, 39, 40, 40, 41, 42, 43, 44]. Finally, while there is evidence that attrition differs across disciplines, there are no studies to approach this area, focusing on a single discipline across multiple programs.

Moreover, we used a mixed-methods approach which is particularly important to help holistically approach a complicated phenomenon. Using students’ stories and personal experiences provided a better understanding of the research problem. The study results and recommendations are useful to policymakers and department leaders in designing interventions and implementing informed decisions that could potentially reduce doctoral attrition by improving the experiences of graduate students in physics doctoral programs.
CHAPTER II

DEPARTMENTAL SUPPORT STRUCTURES FOR PHYSICS GRADUATE STUDENTS: DEVELOPMENT AND PSYCHOMETRIC EVALUATION OF A SELF-REPORT INSTRUMENT

Abstract

High attrition rates in STEM disciplines are an ongoing problem. Graduate student attrition, in particular, is understudied. Most past studies have focused on students’ attributes, undergraduate preparation, and mentoring relationships. Emerging results from the implementation of the American Physical Society-Bridge Program (APS-BP) suggest that departmental support structures could lead to increased retention. However, there are no validated instruments to measure students’ experience of the departmental support structures. This paper describes the development and psychometric evaluation of the Aspects of Student Experience Scale (ASES). Items were developed based on prior literature and the APS-BP recommendations, revised based on APS-BP feedback, and subjected to psychometric evaluation. Principal components analysis of data from 397 students at 19 physics graduate programs (2 M.S. and 17 Ph.D.) across the U.S. resulted in 4 distinct factors (a) Mentoring and Research Experience, (b) Professional Development, (c) Social and Academic Integration, and (d) Financial Support. ASES meets the standard criteria for divergent validity, discriminant validity, and internal consistency. Results of students’ ASES response ratings are discussed, along with comparisons between students enrolled at APS-BP and non-APS-BP affiliated graduate programs. On average, we find that physics graduate students experience adequate mentoring and financial support; however, they report experiencing limited social and academic integration and a lack of professional development. We also find that students in APS-BP-affiliated programs report better experiences on all four factors than students in non-APS-BP affiliated programs, with higher differences in social and academic integration and financial support. This study is a starting point for
the refinement process of this instrument.

Introduction

Retention rates for graduate students in science and engineering doctoral-granting departments are only 59% [3]. Understanding the reasons for this high attrition is an important priority for researchers [8, 11, 12, 13, 14]. A larger concern is that attrition disproportionately affects underrepresented students (e.g., women, students of color) [8]. It is substantially important to identify the factors that lead to attrition. Students invest a significant amount of energy, money, and time, before and after their acceptance in their chosen program. Not completing their degree can be detrimental to their emotional and financial well-being [9, 10]. However, neither departments nor institutions are left unaffected by this outcome. The impact of graduate attrition on departmental resources is also high [10].

Despite increased attention, the underlying factors leading to attrition are still not fully clear. A substantial limitation to approach this phenomenon is the lack of a systematic way of recording the reasons that lead students to depart. Those students tend to leave silently instead of staying and voicing dissatisfaction about what eventually contributed to the decision to depart from the program [9]. Additionally, there is a clear disconnect between the factors that faculty believe lead to attrition and research outcomes related to attrition. Faculty attribute attrition to students’ academic incompetence [e.g., 25, 26, 63, 64]. However, if GRE scores can be considered a measure of academic competence, most studies examining academic achievement scores as predictors of graduate attrition across many disciplines found no significant relationship, except for advanced GRE scores [2]. A recent study focused on STEM disciplines found no effect of GRE scores on female students’ program completion and a negative effect for male students, meaning that those with higher GRE scores were more likely to depart [13]. A qualitative study surveying graduate students and faculty from many disciplines showed that students attributed attrition at about 30% to departmental reasons placing it as the second-highest reason. These include inadequate advising, financial
support, faculty attrition, departmental politics. At the same time, none of the faculty members attributed attrition to any departmental factors; they believed that student factors caused attrition [63].

Similarly, most past studies examining attrition placed disproportionally more emphasis on the student, neglecting external aspects of students’ academic experience. The work of Lovitts [25] shifted that direction. Since then, more studies have started to examine the effect of students’ experience of departmental and institutional factors as predictors of attrition.

For many years, students’ demographic characteristics, mentoring relationships, and academic competency monopolized a substantial literature. Since then, the research focus has expanded, including factors such as departmental climate and socialization processes, which are found to be correlated to attrition [25]. This leads us to the conclusion that graduate attrition is a multifactorial phenomenon. The recent outcomes from the application of key departmental recommendations from the American Physical Society-Bridge Program (APS-BP) add value to this notion.

Women and students of color are significantly underrepresented in physics graduate education [65, 66, 67]. At the same time, students of ethnic and racial minority backgrounds are more likely not to complete their program than white students [14]. The APS-BP was founded to help increase racial/ethnic diversity in physics graduate education. Through this program, minority students are placed in selected graduate programs. The APS-BP has also developed several key recommendations (e.g., mentoring, research engagement, monitoring student progress) that those programs were to implement to help better support student experience. Data show that those students affiliated with the APS-BP have a 92% retention rate [68]. This surprising, but yet early record indicates that experiencing supportive departmental practices increase graduate retention. Based on the recommendations of the APS-BP for creating supportive and inclusive departmental practices, we developed an instrument to quantify students’ experience of such departmental practices. That could,
in turn, be used to test whether students' experiences of such supports predict retention.

Theoretical Background

The purpose of the APS-BP is to increase the diversity in physics graduate education by increasing the number of underrepresented racial minority (URM) students. Students of URM background apply to the APS-BP and receive funding to start their graduate education at selected departments across the United States. In parallel, to increase the chances of student success at these competitive programs, the APS-BP has a list of key recommendations that departments are asked to apply to the bridge students. Those recommendations include admission practices, building a physics graduate student association to promote social relationships, mentoring and advising, induction (social integration practices), research engagement, monitoring student progress, resources for professional development, and practices to achieve APS-BP sustainability [48]. In the following paragraphs, we review the literature on the impact of some of these APS-BP practices on graduate retention and students’ overall experience.

Social Integration

Tinto's influential research on undergraduate attrition [16] asserts that attrition results from the interaction between the individual student and their institution. Some recent studies focused on graduate-level education adopted this perspective. Barbara Lovitts pointed out that “the reasons for attrition are deeply embedded in the organizational culture of graduate school and the structure and process of graduate education.” [p.2, 25] Results from the study indicated that a lack of academic and social integration are predictors of attrition. Lovitts claimed that departments’ physical space can help build a cooperative and social environment where integration can naturally occur. However, she pointed out that there should be a balance between task and social integration. A student who is too heavily
task-oriented may fail to integrate into the community’s social culture, which might lead to a sense of isolation and, in turn, lead to frustration and attrition. On the other side, a similar outcome may result if a student is much more heavily integrated socially than academically. More recent studies confirmed that experiencing social isolation at graduate school predicts attrition [26]. Also, it’s important to note that women are more likely to experience social isolation in STEM departments than men [69]. Unfortunately, graduate programs often exhibit two characteristics that contribute to a sense of social isolation: an unfamiliar environment to most incoming students and its stressful nature [27]. Another aspect that seems to contribute to attrition is the mismatch in how students and departments view student roles and responsibilities [26, 28, 32]. Therefore, as part of the socialization process into the department, faculty and administrative support are essential to help set clear expectations and discuss guidelines [28, 70]. Along these lines, the APS-BP acknowledged the importance of the social integration aspect and recommended that departments create opportunities that could foster a friendly and supportive environment for incoming students. This set of recommendations is listed as the APS-BP induction component.

Academic Integration

Another aspect that was shown to be correlated with attrition is the lack of support within the graduate program to help less prepared students cope with the degree requirements [10]. Golde pointed out that across the four studied departments (two science and two humanities), there was the notion that underprepared students would catch up on their own. Therefore departments lacked strategies to help support those students. Elaborating on this lacking structure, Golde concluded that (p. 686) “the pressures to demonstrate quite quickly that one is capable of course and research work meant that those who needed “remedial” work were likely to be counseled to leave if they were unable to help themselves.” The author urged us to consider how this Darwinian perspective could affect students from non-elite backgrounds. Building on this idea, we can imagine how the existence of
those structures (e.g., tutoring, individualized coursework plan) could increase diversity, particularly in STEM fields. The APS-BP specifically encourages departments to create an individualized coursework plan for each incoming student that will be determined based on a placement test. Under this component, other suggestions are the guided group-work sessions to help address any academic or personal issue a student might face and tutoring opportunities. The APS-BP refers to this component as monitoring student progress.

Mentoring and Research Experience

The most highly cited external factor related to the student experience and retention is the relationship with advisors [32]. This is because the advisor is usually the department representative with whom graduate students interact the most during their graduate program [25, 33, 34]. The impact of advisors’ practices influence students’ experiences in the program related to their research activities, opportunities for professional development, the integration to the professional field of study, and the development of students’ confidence through encouragement and praise [25, 33, 70]. Golde [10] found that inharmonious advising relationships, characterized by a lack of interaction, trust, and intellectual support, accounted for the attrition in two science departments. A longitudinal study of Santiago and Einarson [71] examined the influence of specific departmental structures (funding, being a member of the research group, mentorship) on science and engineering graduate students’ self-efficacy and expected career outcomes upon the completion of the degree. They found that students who reported positive faculty-student interactions in their program had higher academic self-efficacy ratings. However, participation in a research group was found to negatively impact one’s expectations of finding a field-related job by 65%. In this context, a field-related job may involve continuation in academia or research-focused employment by governmental or industrial laboratories. These paths are related to students’ research experience, which is heavily related to their perceived mentoring experience. Four reasons may explain this latter outcome.
First, through participation in a research group, students compare themselves with other competent peers and realize the competitive nature of academia. Second, the exposure to research life reveals to a large extent, the nature of faculty-life, which is characterized by intense amounts of work and limited work-life balance [10, 72]. Third, students might hold incorrect views on the nature of science and, in particular, of experimentation. Research often results in a high failure rate of experiments, which might lead to frustration and disappointment. Golde [10] showed that students exhibited feelings of disappointment and discouragement when realized that scientific research and scholarship work is “incremental and slow,” which was reported as one of the reasons that students in that study decided not to complete their program. And lastly, particularly in STEM disciplines, students’ research projects are “assigned” by their faculty advisor. However, students in STEM fields depend on the faculty’s research grant for funding their education [10, 29] and, therefore, might not leave the research group right away, even if they don’t find themselves to be interested in the assigned project.

These points suggest that attention should be given to how students view the nature of faculty-life. Also, faculty and graduate students should openly communicate the nature and process of conducting research early on, instead of finding them out at later stages of the program. Finally, the research rotation method helps students learn about research opportunities and identify their interests. Findings from Sverdlik’s review study on student-faculty supervision relationships [32] suggested that students who chose their supervisors instead of being allocated one by the department were more likely to be satisfied with their degree programs. Furthermore, it was emphasized that during the dissertation stage, students are still uncomfortable working in ill-defined environments that are different from the well-structured coursework they were experiencing as undergrads. In this case, it is the supervisors’ role to guide, redirect, and monitor students’ progress in the dissertation process.
The APS-BP recognizes the value of effective mentoring and its effect on student experience; thus, it created a list of key points that could promote an effective student-mentor interaction. More specifically, the APS-BP recommends that the department should designate multiple mentors to each student (such as peer, academic, and research mentors). The APS-BP suggests that the mentor should meet regularly with the student, integrate them into the program and the physics community, guide them in selecting courses, and help them develop and complete their academic plans. These recommendations for an effective mentoring model are included under the mentoring and advising APS-BP component.

The APS-BP has created a list of practices to guide departments into providing a fruitful student research engagement. This component includes the suggestion to create the opportunity for research rotations, helping students identify their research interests. Also, departments are encouraged to provide resources and help the student integrate into the research group culture and encouraging them to attend and give presentations at group meetings.

Professional Development

Departmental factors include providing opportunities for student professional development. A study by O’Meara et al. [73] explored the ways that STEM departments facilitated student career advancement by reinforcing a sense of student agency. The authors pointed out that a sense of agency over career advancement could contribute to degree completion, and concluded that departments should develop structured opportunities to support student agency.

The professional development component of the APS-BP recommends that departments develop practices to help students develop time-management skills and learn about best practices for effective teaching. Also, departments are encouraged to create training to prepare students for the role of postdoc, develop mentoring skills, learn how to organize the
laboratory, and develop effective networking skills.

Financial Support

Students’ financial situation has been found to contribute to doctoral persistence [74, 75]. Students who receive financial support in any form (fellowship, graduate assistantship, scholarship) have higher chances of completing their degree than those who are self-supported. However, depending on the student’s life condition, financial aid, if present, may not always be adequate. In some cases, financial aid is uncertain, or absent [76]. In other cases, students are financially dependent on their research advisors’ external grants. This dependence could negatively affect student experience if they do not find interest in the advisor’s research project. In this situation, the student may decide to continue working on the subject only because of the financial support or else discontinue their degree.

The APS-BP provides direct funding to the bridge students for two academic years. After that, the department is responsible for providing or finding external support to students until they complete their degree.

Graduate students’ life is intense in terms of time spent on coursework, teaching, and research responsibilities. This experience can be overwhelming even for the most motivated and competent student. As discussed above, there are a plethora of research studies suggesting that departments can design interventions to better support students in this process. While most of these studies focus across many disciplines [e.g., 9, 10, 25, 72], there is very little work focusing solely on STEM disciplines [29], and in particular, on the holistic experience of STEM students. Distinctive aspects of the nature of science departments suggests the need to study attrition of science disciplines in particular. Also, there is a lack of research-validated instruments to measure students’ experiences regarding the existing structures in their programs. Most quantitative studies examining graduate experience focus solely on mentoring relationships (e.g., [71]). Following the recommendations of the APS-BP to physics graduate programs on creating supportive departmental structures, we started the
process of developing an instrument to quantify students’ experiences. Researchers can use this instrument to examine whether and to what individual degree factors contribute to retention. Administrators can help identify lacking or weak structures at their programs from students’ perspectives. This study serves as a first step towards the development process of this survey instrument.

In the following paragraphs, we describe the methodology of instrument development and the results from its administration to a sample of physics graduate students from 19 programs across the U.S. We also report the results of the survey’s administration to students enrolled at APS-BP and non-APS-BP affiliated programs, as well as interview data from the chairs or graduate advisors of those programs, which is used a further validity check of the instrument.

Methods

Developing the Aspects of Student Experience Scale (ASES)

In the Fall of 2017, we reviewed prior literature on the factors that affect graduate student retention. Looking more closely at physics, we found that students enrolled in the APS-BP have a much higher retention rate than the national average [48].

The APS-BP had developed several recommendations to departments to foster a supportive environment. These recommendations span the space from individual advisor’s actions (e.g., mentoring) to more broad administrative measures. They also include a wide chronological window, from admission practices to opportunities for professional development and research experience. We decided to develop a study to identify and quantify the outcomes for student success from the implementation of such recommendations. To do so, we needed a way to measure the departmental environment.

Inspired by the APS-BP key recommendations, we developed several items about departmental factors that students could report on. For instance, the APS-BP recommends
that once a student issue is identified (personal or academic), departments should designate at least one individual who will be responsible for monitoring progress on addressing the issue [48]. To capture whether students experience this practice, we included the following item: “Whenever I face(d) a challenge succeeding on coursework, someone from my department helped me overcome it.” None of the recommendations for departments that students could not report upon were included (e.g., Do not use GRE scores to eliminate any students from consideration).

We then shared the developed items with the APS-BP group and received their written feedback. We also met with the APS-BP and discussed each of the items to ensure that those captured the intended recommendations. We revised the items based on their feedback and retained 35-items aimed to measure aspects of the student experience at their graduate program. We then recruited two physics graduate students and asked them to read each item and think-aloud of how they approach each question. The purpose of this step was to examine whether the students understood the questions as intended and to identify biased responses through the students’ answers. This helped improve survey comprehension. Three more graduate students were asked to respond to the survey to help us identify the estimated time required to respond to the items. Finally, we asked those three students to reflect on the clarity of the items and the response scale. Those retained 35-items were measured on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). All items were framed and coded in the same direction; thus, no reverse coding was required. Finally, we named this instrument the aspects of the student experience scale (ASES).

Procedure

In the Spring of 2019, we administered an online survey (15-minutes via Qualtrics) that elicited participants’ demographic information, perceived experiences of departmental structures through ASES, self-efficacy, and intention to persist. In this paper, we solely focus on students’ responses to the ASES and use their demographic information.
Table 2.1: Characteristics of each of the 19 physics graduate programs.

<table>
<thead>
<tr>
<th>ID</th>
<th>Region</th>
<th>Highest degree</th>
<th>Size</th>
<th>Rank</th>
<th>Response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPT. 1</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>10.9%</td>
</tr>
<tr>
<td>DEPT. 2</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>33.6%</td>
</tr>
<tr>
<td>DEPT. 3</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>23.0%</td>
</tr>
<tr>
<td>DEPT. 4</td>
<td>West</td>
<td>M.S.</td>
<td>Medium</td>
<td>NA</td>
<td>43.4%</td>
</tr>
<tr>
<td>DEPT. 5</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>18.2%</td>
</tr>
<tr>
<td>DEPT. 6</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Small</td>
<td>NA</td>
<td>65.5%</td>
</tr>
<tr>
<td>DEPT. 7</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>High</td>
<td>30.0%</td>
</tr>
<tr>
<td>DEPT. 8</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>17.2%</td>
</tr>
<tr>
<td>DEPT. 9</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Medium</td>
<td>23.8%</td>
</tr>
<tr>
<td>DEPT. 10</td>
<td>West</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>30.0%</td>
</tr>
<tr>
<td>DEPT. 11</td>
<td>Northeast</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>11.4%</td>
</tr>
<tr>
<td>DEPT. 12</td>
<td>South</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Low</td>
<td>16.7%</td>
</tr>
<tr>
<td>DEPT. 13</td>
<td>West</td>
<td>M.S.</td>
<td>Medium</td>
<td>NA</td>
<td>28.3%</td>
</tr>
<tr>
<td>DEPT. 14</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>Medium</td>
<td>17.6%</td>
</tr>
<tr>
<td>DEPT. 15</td>
<td>West</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>31.5%</td>
</tr>
<tr>
<td>DEPT. 16</td>
<td>West</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>High</td>
<td>26.4%</td>
</tr>
<tr>
<td>DEPT. 17</td>
<td>West</td>
<td>Ph.D.</td>
<td>Small</td>
<td>Medium</td>
<td>35.9%</td>
</tr>
<tr>
<td>DEPT. 18</td>
<td>South</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Low</td>
<td>18.0%</td>
</tr>
<tr>
<td>DEPT. 19</td>
<td>Southwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Medium</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

Note: The average response rate is 23.4%. The response rate is the ratio of the number of students that completed more than 90% of the survey items to the total number of students enrolled in the program. We purposefully do not disclose the exact number of students enrolled at each program to avoid program identification. The size refers to the total number of students enrolled at the program, where: a) ≤ 50: small; b) 51-100: medium; c) ≥ 101: large. Similarly, the program’s ranking is presented in the following categories: a) 1-50: high; b) 51-100: medium; c) ≥ 101: low. Information on the size of each program was obtained from the American Institute of Physics [65], and the ranking from the U.S. News & World Report [77].
The APS-BP helped us identify a list of APS-BP sites. Using the data from the American Institute of Physics [65], we created a list of non-APS-BP sites that shared similar characteristics with the APS-BP sites (region, the number of students enrolled, rank). All the sites in the list were research-intensive physics graduate programs. We also identified the email addresses of the department chairs and the graduate advisors of those programs. The first step was to invite the chairs of those departments to participate in our study by providing us with a list of all their graduate students’ contact information and sending their students an email encouraging them to take the survey. However, some programs that agreed to participate would not provide the list of students. In these cases, the chair/graduate advisor sent the invitation to the survey (on our behalf) and an anonymized link to the survey. The students were expected to click on the survey link to read the consent form and then decide whether they choose to participate. To help increase program participation, we promised to share a summary report (sent to the chair) of student responses to the survey and comparison data from the other programs in the study. The graduate committees could use this information to improve their practices. We contacted 60 physics graduate programs across the U.S. (sending two follow-up emails), and 20 programs agreed to participate. Among these 20 institutions, one had a low response rate (less than 5%) and was excluded from the results. At 14 departments, we contacted the students via direct personalized emails, which resulted in an average response rate of 28%. In comparison, at the remaining five departments where we contacted the students through the chair who sent the anonymized link to the survey, the corresponding response rate was 15.3%. We sent two weekly follow-up emails (direct or via the chair/graduate advisor) to increase participation.

The email invitation to students ensured the confidentiality of data responses. The average response rate from all the 19 departments is 23.4%. The obtained response rate is slightly lower than the reported rate for email/online surveys [78, 79]. Table 4.1 displays the characteristics of each department, along with the response rate. The average number of enrolled students per Ph.D. program is 93.3 students, while the reported national average
of students enrolled at Ph.D. departments is 72.4 students [65].

Sample of Participants

A total of 397 physics graduate students responded to more than 90% of the ASES items. Forty-six students either attempted the survey (completing less than 5%) or completed only the demographic items and maybe some ASES items. Those 46 students were excluded from the analysis. Of these 397 students who completed almost all the survey items, 86% are seeking a Ph.D. degree and 14% a Master’s degree. 61% of the respondents have passed the fourth semester (2nd-year) of their studies, and 86.5% belong to a research group. 25.4% self-identified as cis-women or nonbinary and 74.6% as cis-men. 72% were U.S. citizens, while 28% were international students. Of the U.S. citizens, 54%, 8%, 2%, 6%, and 2% self-identified as racially White, Asian, Black/African American, ethnically Latino/Hispanic, and with more than one race, respectively. Finally, 9% are first-generation college students, 7% are parents, and 6% identified as LGBTQIA. According to the national data on physics graduate education of the American Institute of Physics (AIP) [65, 66, 67], students that self-identified as cis-women/non-binary are slightly over-represented in our sample (25% vs. 20%), non-US citizens are significantly underrepresented (28% vs. 43%), and among the U.S. citizens, URM students are also slightly over-represented in our sample (8% vs. 5.7%).
Table 2.2: Students’ demographic information

<table>
<thead>
<tr>
<th></th>
<th>Gender</th>
<th>Race &amp; Ethnicity</th>
<th>Other demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cis-women/ Cis-men</td>
<td>White (%)</td>
<td>Black (%)</td>
</tr>
<tr>
<td>APS-BP (n=38)</td>
<td>26.3</td>
<td>73.3</td>
<td>52.6</td>
</tr>
<tr>
<td>non-APS-BP (n=60)</td>
<td>20.0</td>
<td>80.0</td>
<td>66.7</td>
</tr>
</tbody>
</table>

*Note:* The students that self-identified with more than one races were 5.2% from the two APS-BP sites, and 5.1% from the two non-APS-BP sites.
Data Analysis

Principal Components Analysis

All statistical analyses were conducted using the SPSS version 26.0 software. We performed a principal component analysis (PCA) using the 397 student responses to uncover the underlying structure of the 35-items that were designed to capture the extent to which students experience a supportive departmental environment. First, we ran PCA on the 35-items, which resulted in 8 retained components with eigenvalues greater than one [80]. Then, using Horn’s parallel analysis (PA) [81] on all the 35-items, we retained those components whose eigenvalues were smaller than the eigenvalues of the previously obtained from PCA. PA approach is widely recommended for factor retention in PCA [82]. This approach supported a 4-factor solution. Table 2.3 shows the eigenvalues from PCA and PA and the decision for factor retention. We then reran PCA requesting four extracting factors. To identify the appropriate matrix of rotation, we requested an oblique rotation to obtain the factor correlation matrix. The factor correlation matrix for correlations was lower than .32, suggesting that the data are orthogonal (uncorrelated). Therefore, we rerun PCA requesting now a Varimax rotation, which is appropriate for orthogonal data [83, 84]. We found that four items did not load on any factor. These four items were omitted from further analysis. We then reran PCA using Varimax rotation to obtain the final model.

Reliability and Construct Validity

We used the Composite Reliability Index (CRI) and Cronbach’s $\alpha$ [52] to assess the internal consistency for each of the components. Internal consistency is a measure of the extent that all the items in a test measure the same underlying concept or construct [53]. This measure ranges from 0 to 1. CRI should be above the acceptable level of .60 [85], while Cronbach’s $\alpha$ values should surpass the acceptable level of .70. Also, convergent and discriminant validity were both used to assess the construct validity of the instrument.
Table 2.3: Comparison of PCA and PA factors

<table>
<thead>
<tr>
<th>Component</th>
<th>$\lambda$ from Criterion</th>
<th>$\lambda$ from PA</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.55</td>
<td>1.68</td>
<td>Accepted</td>
</tr>
<tr>
<td>2</td>
<td>3.46</td>
<td>1.58</td>
<td>Accepted</td>
</tr>
<tr>
<td>3</td>
<td>2.40</td>
<td>1.52</td>
<td>Accepted</td>
</tr>
<tr>
<td>4</td>
<td>1.87</td>
<td>1.46</td>
<td>Accepted</td>
</tr>
<tr>
<td>5</td>
<td>1.39</td>
<td>1.42</td>
<td>Rejected</td>
</tr>
<tr>
<td>6</td>
<td>1.25</td>
<td>1.37</td>
<td>Rejected</td>
</tr>
<tr>
<td>7</td>
<td>1.16</td>
<td>1.33</td>
<td>Rejected</td>
</tr>
<tr>
<td>8</td>
<td>1.12</td>
<td>1.30</td>
<td>Rejected</td>
</tr>
</tbody>
</table>

Convergent validity was assessed using the Average Variance Extracted (AVE). The squared inter-component correlation values were used to assess divergent validity by meeting the criterion of the AVE values to be higher than the squared inter-component correlation values.

Hedge’s g effect size

The instrument was designed to measure many of recommendations of the APS-BP. Therefore, as a further validity check, we used students’ responses enrolled at APS-BP institutions and compared those with students’ responses from similar institutions (in terms of size and ranking) that are not related to the APS-BP. In particular, we attempted to use data from programs that apply the APS-BP recommendations across all students, such that we can test if students’ responses capture the intended constructs. We also aimed to interview the graduate advisors of those programs to get their perspectives on the department’s implemented practices. In our sample, 9 out of 19 departments are affiliated with the APS-BP. Of these nine APS-BP programs, two are known to apply the APS-BP recommendations widely, across all students enrolled at the program. Here, we use students’ responses and interview data from the graduate advisors of these two APS-BP sites that apply to APS-BP recommendations across all students. We compare those data with student survey responses and graduate advisor’s interviews from two non-APS-BP sites of similar size and rank.
The two APS-BP affiliated programs are DEPT. 1 & 7, and the two non-APS-BP affiliated are DEPT. 3 & 10. Table 4.2 summarizes students’ demographic characteristics from the two types of programs. We also found that the same percentage of the respondents have completed the second year of their studies (31.6% and 31.7% at APS-BP and non-APS-BP sites, respectively). While the respondents at both types of programs are at the same stage at their programs, we found that 94.7% of students at APS-BP mentioned having a mentor, while this number is only 78.3% for students at non-APS-BP.

The magnitude of difference in the mean ratings of the ASES between respondents in the two APS-BP and the two non-APS-BP affiliated sites were assessed using Hedges’ $g$ effect size analysis and confidence intervals (CIs) [54].

Researchers and editors suggest using effect size (ES) statistics with confidence intervals (CIs) to report and interpret results [e.g., 86, 87], as the commonly used test statistics using $p$ value can easily be misleading [60, 88]. $P$ value statistics are sensitive to sample size and do not indicate meaningful or practical significance. ES is a standardized measure of the magnitude or strength of the difference in outcome between two groups [54, 60]. We use the adjusted Hedges’ $g$ for small sample sizes. CIs are used to evaluate the precision of the findings [61], which is an indicative measure of uncertainty.

Bosco et al., [1] showed that ES fluctuate across research domains, constructs, and measures. Cohen [89] proposed benchmarks for interpreting power for ES. An ES of .20 is “small” in magnitude, .50 is “medium,” and values of .80 and above are “large.” However, he noted that these values should be used carefully as a general rule of thumb, especially when there is no previous empirical evidence in the particular research area to compare to [61]. Based on previous empirical evidence for attitude factors in applied psychology, Bosco et al., [1] suggested medium ES ranging from .18 to .39. Hence, in this paper, any ES values equal to or higher than .18 are considered meaningful.
Interviews

We conducted in-depth, semi-structured interviews with the chairs or graduate advisors of those four programs. The interviews were online, lasting for about one hour. The interview protocol included topics such as the vision for student outcomes, program admission processes, program practices to support students, departments’ culture, attrition and reasons leading to it, and alumni’s trajectory. The interviews were audio and video recorded and were transcribed verbatim. Pseudonyms were assigned to protect participants’ identity.

We used thematic analysis using a deductive approach [55]. Thematic analysis is a qualitative method for identifying, analyzing, and reporting patterns in the data [56]. The analysis captured the main themes in participants’ interviews related to selected graduate programs’ supports/practices. In particular, we wanted to explore how these existing support structures look from the department chairs/graduate advisors’ perspectives. We identified themes at a semantic level, where we solely focused on the content of data at a surface level without examining underlying ideas or nuances. In this paper, we present the qualitative results to complement the quantitative data on the two components, where we found meaningful differences across the two types of programs.

The analysis followed the six phases described by Braun and Clark. These six phases are: familiarizing with data, generalizing initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report [55]. Here, we report the results focused on the practices to support students’ social and academic integration.

Results

Principal Components Analysis

The Bartlett’s test of sphericity, $\chi^2=5038.15$, $df=496$, $p<0.001$, and a Kaiser-Meyer-Olkin measure of sampling adequacy, $KMO=.883$ indicated that the resulting matrix of correlations was appropriate for factor analysis. PCA was used to determine the items that
fall into each of the four identified factors by meeting the criterion of loading at least 0.4 on their respective factor. Table 2.4 displays the loading factors from the rotated four-factor Varimax solution. The resulted in 4 factors are (a) Mentoring and Research Experience (MRE), (b) Professional Development (PD), (c) Social and Academic Integration (SAI), and Financial Support (FS). The four-factor solution accounted for 48.66% of the total variance in the 31-items. More specifically, MRE (n=11) accounted for 24.95% of the variance in the data, PD (n=9) accounted for an additional 10.74%, SAI (n=8) accounted for an additional 7.17%, and finally, FS (n=3) accounted for 5.80% of the variance in the data.

Items from the two APS-BP components of mentoring and advising and research engagement loaded on the first ASES component of MRE. Similarly, items from the two APS-BP components of induction and progress monitoring loaded on the third ASES component of SAI. The APS-BP items on professional development are loaded on the second ASES component. Finally, the three unrelated of the APS-BP items loaded on the last component of FS. Figure 2.1 shows how each APS-BP corresponds to each ASES component. Table 2.5 displays the descriptions of each of the four ASES components.

Table 2.4: Loading factors from the rotated four factor Varimax solution

<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Factor 1: Mentoring and Research Experience</strong></td>
<td></td>
</tr>
<tr>
<td>I have frequent meetings with my mentor to discuss on my research progress and any challenges I face.</td>
<td>.81</td>
</tr>
<tr>
<td>My mentor(s) helped me selecting courses and develop my academic plans.</td>
<td>.61</td>
</tr>
<tr>
<td>I have informal meetings with my mentor(s) where I get assistance/support with any issues I face.</td>
<td>.62</td>
</tr>
</tbody>
</table>

Continued on next page
<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>My mentor(s) helped me integrate into the program and the physics community.</td>
<td>.66</td>
</tr>
<tr>
<td>My mentor(s) taught me what it means to be a research physicist and a scholar.</td>
<td>.71</td>
</tr>
<tr>
<td>A senior peer mentor provided invaluable resources and inducted me into departmental and/or laboratory cultures.</td>
<td>.54</td>
</tr>
<tr>
<td>In my research group meetings, we devote time to reading and discussing the current state of knowledge in the field.</td>
<td>.48</td>
</tr>
<tr>
<td>I have regular meetings with my research mentor and receive feedback on a regular basis.</td>
<td>.78</td>
</tr>
<tr>
<td>My research mentor was very flexible with my research assignments when I was struggling with one or more courses.</td>
<td>.53</td>
</tr>
<tr>
<td>The research project I am working on matches my research interests.</td>
<td>.65</td>
</tr>
<tr>
<td>I have presented/am planning to present my research at a group meeting or in a journal club.</td>
<td>.58</td>
</tr>
</tbody>
</table>

**Factor 2: Professional Development**

I attend mini-conferences where students from nearby universities can share research progress and learn networking skills.  .32 .50 .00 -.16

At the beginning of each semester, my faculty advisor(s) and I developed a time-management plan that helps me identify areas where my time could be used more effectively.  .34 .45 .25 -.30

Continued on next page
Table 2.4 – continued from previous page

<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>My department hosts a seminar that focuses on time management skills.</td>
<td>1</td>
</tr>
<tr>
<td>I attend activities for graduate students that include training or professional development on best practices for effective teaching.</td>
<td>0.05</td>
</tr>
<tr>
<td>I attend activities for graduate students that include training or professional development on the role of a postdoc.</td>
<td>0.10</td>
</tr>
<tr>
<td>I attend training that focuses on how to maximize my chances of finding a career that is a good fit for my interests and skills.</td>
<td>0.04</td>
</tr>
<tr>
<td>I attend training on learning about mentoring skills as future faculty or postdoc.</td>
<td>0.06</td>
</tr>
<tr>
<td>I attend training in organizing a research laboratory.</td>
<td>0.05</td>
</tr>
<tr>
<td>I attend activities where I can learn about effective networking.</td>
<td>0.09</td>
</tr>
</tbody>
</table>

**Factor 3: Social and Academic Integration**

The department hosts social activities that are valuable in allowing me opportunities to share my thoughts and struggles with my peers, and discuss research areas.

The department offered a space where students can build an academic and social community.

People in my department were supportive and caring about my accommodation needs when I first moved into town.

At the beginning of my program, I took a pre-course assessment that was designed to measure my incoming preparation.
Table 2.5: Summary of ASES components.

<table>
<thead>
<tr>
<th>ASES component</th>
<th>ASES Items</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mentoring and Research Experience</td>
<td>11</td>
<td>Students experience supportive mentorship and are actively engaged in research.</td>
</tr>
<tr>
<td>Professional Development</td>
<td>9</td>
<td>Students participate in training and activities to help them develop professionally as researchers and scholar.</td>
</tr>
<tr>
<td>Social and Academic Integration</td>
<td>8</td>
<td>Students are integrated socially into the department’s culture and provided support to help them overcome academic challenges.</td>
</tr>
<tr>
<td>Financial Support</td>
<td>3</td>
<td>Students basic financial needs are met.</td>
</tr>
</tbody>
</table>

Table 2.4 – continued from previous page

<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was offered a personalized coursework plan in my graduate program.</td>
<td>.06</td>
</tr>
<tr>
<td>Faculty, postdocs, or experienced TAs lead guided group-work sessions to encourage students work collaboratively on concepts covered in core courses.</td>
<td>.17</td>
</tr>
<tr>
<td>Whenever I face(d) a challenge succeeding on coursework, someone from my department helped me overcome it.</td>
<td>.19</td>
</tr>
<tr>
<td>My department makes tutoring available to graduate students.</td>
<td>.05</td>
</tr>
</tbody>
</table>

Factor 4: Financial Support

<table>
<thead>
<tr>
<th></th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>My tuition is covered for my entire program.</td>
<td>.07</td>
</tr>
<tr>
<td>My college/department/program offers me health benefits.</td>
<td>.10</td>
</tr>
<tr>
<td>I have no financial concerns about completing my degree.</td>
<td>.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Eigenvalues</th>
<th>% variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.99</td>
<td>3.44</td>
</tr>
<tr>
<td>2.29</td>
<td>1.86</td>
</tr>
<tr>
<td>1.86</td>
<td>1.86</td>
</tr>
<tr>
<td>1.86</td>
<td>1.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% variance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>24.95</td>
<td>10.74</td>
</tr>
<tr>
<td>7.17</td>
<td>5.80</td>
</tr>
</tbody>
</table>
Figure 2.1: The APS-BP components that loaded into each ASES component.

Table 2.6: Results of students’ ASES responses

<table>
<thead>
<tr>
<th></th>
<th>MRE</th>
<th>PD</th>
<th>SAI</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (%)</td>
<td>75.8</td>
<td>44.4</td>
<td>55.6</td>
<td>80.0</td>
</tr>
<tr>
<td>Mean (%)</td>
<td>74.3</td>
<td>46.5</td>
<td>55.5</td>
<td>77.4</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>14.1</td>
<td>15.0</td>
<td>13.3</td>
<td>21.1</td>
</tr>
<tr>
<td>Skewness</td>
<td>-0.7</td>
<td>0.5</td>
<td>-0.1</td>
<td>-0.9</td>
</tr>
<tr>
<td>Std. Error of Skewness</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>0.7</td>
<td>-0.5</td>
<td>-0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Std. Error of Kurtosis</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Table 2.7: AVE, squared inter-component correlation, CRI and Cronbach’s α.

<table>
<thead>
<tr>
<th>Component</th>
<th>MRE</th>
<th>PD</th>
<th>SAI</th>
<th>FS</th>
<th>CRI</th>
<th>α</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRE</td>
<td>(0.41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.87</td>
</tr>
<tr>
<td>PD</td>
<td>0.14</td>
<td>(0.42)</td>
<td></td>
<td></td>
<td></td>
<td>0.85</td>
</tr>
<tr>
<td>SAI</td>
<td>0.16</td>
<td>0.31</td>
<td>(0.33)</td>
<td></td>
<td></td>
<td>0.78</td>
</tr>
<tr>
<td>FS</td>
<td>0.06</td>
<td>0.01</td>
<td>0.04</td>
<td>(0.57)</td>
<td></td>
<td>0.78</td>
</tr>
</tbody>
</table>

Psychometric Evaluation

Evidence for substantial internal consistency was found for all four retained factors. Using CRI, we found that all the components are above the acceptable value of 0.6 [85]. To assess construct validity, we computed both convergent and discriminant validity. Convergent validity was assessed using the AVE. We found that the values for MRE, PD, and SAI are below the acceptable value of .5. According to Fornell and Larcker [85] values of AVE below .5 are adequate, if CRI value is above .6 [90]. All four components satisfy this criterion; thus, we can claim that we found support for relative convergent validity. Moreover, we computed the squared inter-component correlation values. Meeting the criterion of the AVE values to be greater than the squared inter-correlation values, we also found evidence of substantial divergent validity. Table 2.7 shows the AVE, squared inter-component correlation values, and CRI values. Thus, we conclude that ASES exhibited substantial internal reliability and acceptable construct validity within this context.

Descriptive Statistics

Descriptive statistics were established for each of the four retained components. The results are presented in Table 2.6. These results suggest that while students report experiencing components of MRE and FS at a somewhat adequate degree (74.3% and 77.4%, respectively), there is a lack of experiencing practices related to PD and SAI (only 46.5% and 55.5%, respectively).
Table 2.8: $\mu \pm \sigma$ for the two APS-BP affiliated and non affiliated departments on the four ASES components.

<table>
<thead>
<tr>
<th></th>
<th>APS-BP sites (n=38)</th>
<th>non-APS-BP sites (n=60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRE (%)</td>
<td>78.8 ± 9.0</td>
<td>74.0 ± 15.6</td>
</tr>
<tr>
<td>PD (%)</td>
<td>50.5 ± 15.4</td>
<td>47.9 ± 14.4</td>
</tr>
<tr>
<td>SAI (%)</td>
<td>67.9 ± 8.2</td>
<td>50.2 ± 11.6</td>
</tr>
<tr>
<td>FS (%)</td>
<td>91.8 ± 11.4</td>
<td>82.4 ± 15.9</td>
</tr>
</tbody>
</table>

Results from the Use of the ASES on APS-BP and non-APS-BP sites

The mean values of students’ responses from the APS-BP and non-APS-BP affiliated programs to the four ASES components are presented in Table 2.8. Figure 2.2 shows the effect sizes and 95% CIs on the four ASES components. We found that Hedge’s $g$ shows a meaningful ES of .17 and 95% CI of [-.24, .58] between the two APS-BP affiliated and non-affiliated departments on PD, and an ES of .36 with 95% CI of [-.05, .77] on the MRE. At the same time, we found a very large effect size of 1.71 and 95% CI of [1.24, 2.19] on the SAI component. Moreover, we found a large effect size of .65 and 95% CI of [.24, 1.07] on the FS component. These measures indicate that students at the two APS-BP affiliated departments reported being better supported than students at the two non-APS-BP affiliated departments on all components and with the stronger signals for SAI and FS components.

Next, we used chairs’ or graduate advisors’ interview data on aspects related to items included on the component of SAI, on which we found a highly large effect size between the two types of departments. We explored further for differences in the the two types of departments’ (APS-BP affiliated and not) approaches on practices related to helping students integrate socially and academically in the program.
Figure 2.2: Hedge’s $g$ effect size between the two APS-BP affiliated and affiliated programs. The error bars illustrate the 95% confidence intervals. $g>0$ indicate higher mean values for APS-BP affiliated departments. Any value $> .18$ is considered meaningful [1].

Social Integration

The two graduate advisors of the non-APS-BP departments reported that there are no formal structures designed by the departments in encouraging students’ socialization processes. The graduate advisor of Dept. 10, Noah, mentioned:

*There are these introductory meetings of the TA training and things like that. Otherwise, not much. I will be on honest, but yeah.* - Noah

Similarly, the graduate advisor of Dept. 3, Anderson, mentioned that there are no formal structures initiated by the department to help student social integration. He described that while there are practices to support socialization among graduate students, especially incoming students, those are mostly organized by the local graduate student organization. More specifically, he mentioned:

*So, we have an orientation, a week before classes start. There’s not a ton that’s officially organized; the graduate student society that runs in the department is the graduate association of physics (GAP) [students]. As part of that orientation week, they do some social events for the incoming class, so that the*
incoming students can feel a little bit more part of the department. Then, throughout the school year, we have weekly colloquial on seminars that students can go to be part of the department. One of the nice things that GAP does is monthly mentoring with the incoming class throughout their first year. So, once a month, they meet with the incoming class or the new class, I should say, and talk about issues they might be having with classes. [...] And then, I usually meet with GAP not long after they have these mentoring things, so I can be aware of anything going on. That requires my attention. So yeah, that’s about it. - Anderson

While at the non-APS-BP affiliated departments, we found that there are not rigidly formal structures to support students’ socialization, the contrary exists for the APS-BP affiliated departments. In particular, Michael, the chair of Dept. 1, mentioned that the department has an official peer mentoring program to support incoming students’ socialization and blending into the department. The department also offers a room where the different graduate students’ societies can host their meetings to support incoming students. More specifically, Michael, mentioned:

When they come, there is an orientation. [...] we have a mentoring program that the senior students mentor the newcomers. We have, for the graduate teaching assistants, we have this room where they sit, we have a graduate student association. We have a women in physics society at the department. There are a couple of physics societies that help new students for everything. - Michael

Similarly, Keith, the graduate advisor of Dept. 7, described how the department makes sure that each incoming student is assigned a senior student as a mentor to help them better integrate into the department’s culture. He also mentioned that there are social activities among graduate students. Keith, below, described these opportunities for student socialization:

We have a small program, and it’s a very tight group, even though we have a big university, and we start with matching them [incoming students] with the
existing students. Everyone gets a peer mentor before they arrive on our campus.
So, we encouraged [incoming students] to get in touch and talk about the program,
provide help with local engagements, things like that. We pay much attention
to make sure that the [incoming] students are immediately integrated with the
existing students. There are lots of social activities, and we do a lot of one-on-
one meetings on the academic side, but we also encourage incoming first-year
students to ask advice from the second- and third-year students. - Keith

As shown above, the APS-BP affiliated departments have developed structures
to boost the social integration of incoming students. In particular, we saw that those
structures involve peer mentoring programs, student societies, and one-on-one faculty and
student meetings. These qualitative data from the department leadership complement the
quantitative observed difference from student responses to the departments’ approach to
help student social integration.

Academic Integration

Similarly to the social integration aspect, we found meaningful differences in the
approach of the two types of programs related to student academic integration. More specif-
ically, we found that the non-APS-BP departments do not have a formal plan to help students
with the core courses. For example, Anderson, the graduate advisor of Dept. 3, described
how it is up to the teaching assistants (TAs) in these graduate core courses to offer office
hours. He also mentioned that the department only makes a personalized coursework plan
available only to some women students. More specifically, Anderson, mentioned:

The core physics courses, each core physics course has a TA. So it’d be a
more senior graduate student. Those senior grad students will most likely have
office hours that students can come and ask them. However, those TAs are not
necessarily chosen based on their pedagogical prowess. [...] So, not all, I would
say, it hasn’t necessarily worked out that those TAs are particularly good mentors. Some are, but some are not. - Anderson

and continued,

So we’re actually in the midst of changing things. Basically, up to now, all incoming grad students normally would take the same course load in their first year. The only exception would usually be when women are coming in. You might have an unusual background who would go through the senior [undergraduate] courses, but then the following year takes that same suite of grad courses. - Anderson

As shown in the above quotes, this non-APS-BP department does not offer targeted practices to assess students’ academic preparation and design a plan to increase the chances of academic success for its students. Contrary to this program, the leadership of both APS-BP departments mentioned that at their departments, there are formal structures to offer an individualized coursework plan based on incoming students’ preparation. Also, both noted that there are built up practices, such as problem-solving recitations, to help students cope with the coursework material. For example, Michael described these two aspects below:

I meet individually with each of the new graduate students, and we look at their background, academic background, and we do a placement test, which is to see where they are, and I discuss with them. And then if I see that there is some weakness, I say, ‘okay, don’t take three-credit core courses this semester, take just two and spread things over two years instead of doing one year and then you are going to be burnt out and not perform well.’ So, I tried to spot people who will struggle too much and might fail. - Michael

and continued,

We have those recitations, and for each course, there’s some recitation for problem-solving. Some senior students help with the problem-solving. - Michael
Similarly, the graduate advisor of Dept. 7 informed us that the department offers tutoring sessions and encourages incoming to consult with senior students. Moreover, students at this department receive an individualized coursework plan based on their incoming academic standing. Keith, below, described these departmental supports:

*We do a lot of one-on-one meetings on the problem-solving side, but we also encourage first-year students to ask second and third-year students for advice. [...] Every student has an individualized course plan. [...] It is not unusual for me to suggest multiple courses for a student.* - Keith

These interview data suggest that there are substantial differences in the approach that these two types of graduate programs take concerning student social and academic integration. These results are in agreement with the quantitative effect size differences between these programs in the ASES’s component of SAI.

**Limitations**

We identify the following limitations in the current study and discuss how future research directions could help eliminate them. First, although the psychometric evaluation of the developed instrument suggests that ASES exhibits acceptable construct validity and substantial internal consistency within this context, the process of instrument development is complex and more tests are required to refine further and improve this emerging instrument. More specifically, future work is needed to administer ASES to a different population of physics graduate students and use confirmatory factor analysis to test whether measures of the four identified constructs in this study are consistent with the new data. A test-retest is also needed to establish the internal consistency of the constructs further.

Moreover, the differences in the response rates among graduate programs (ranging from 11% to 66%) suggest that self-selection might exist that, in turn, could introduce response bias. In particular, we must note that students’ response rate in medium to small departments was higher than in large-size departments. We can expect that non-response
bias might be present in some departments. Furthermore, although we ensured respondents’ anonymity in the email text and the consent form, we expect that some students could have avoided taking the survey in fear of identity exposure. This might have contributed to non-response bias, especially from students that are unhappy at their programs.

Finally, we administered the instrument to a population mostly enrolled in large and highly ranked programs. This population does not necessarily capture a representative sample of the physics departments in the country. Future work should elicit students’ responses from a diverse range of departments in terms of rank and size and compare them to the results of this work.

Discussion

This study was designed to develop and test the Aspect of Student Experience Scale (ASES) that measures students’ self-reported experiences of supportive structures in their physics graduate program. ASES has thirty-one items and four components.

The application of Principal Components Analysis (PCA) identified four ASES components. The loadings of the clustered items under their extracted factors and the total variance explained by each factor are within the acceptable thresholds, indicating statistical significance and practical importance of the retained items, and therefore can be used in future studies. ASES’s components initially demonstrated acceptable construct validity after the application of PCA through the examination of the total variance and the measures of convergent and divergent validity. We also found that ASES exhibits substantial internal consistency. However, an instrument’s psychometric properties are established through a pattern of results across multiple studies and not through a single study. This work is only the beginning of the refinement of this instrument.

The application of ASES in 19 graduate programs suggested that, on average, students experience adequate Mentoring and Research Experience (MRE) and Financial Support (FS), but report a lack of support in aspects related to Professional Development (PD)
and Social and Academic Integration (SAI). Interviews with chairs and graduate advisors of the two American Physical Society-Bridge Program (APS-BP) departments and the comparison with interview data of similar non-APS-BP departments supported the validity of ASES. It confirmed the observed quantitative difference in SAI ($g = 1.71$). Those interview data also suggested that the APS-BP departments have practices to support students’ social and academic integration more rigidly than similar departments.

Finally, it is worth mentioning that the four interviewees reported very different average departmental retention rates. More specifically, the two APS-BP departments reported an average of 90% or more retention rates. In contrast, one of the two non-APS-BP reported 60%, and the other mentioned that it always used to be 50% and only recently has increased to 80%. We see that the observed difference in students’ reports of experiencing SAI and/or FS aspects could be correlated with increased retention. This is consistent with prior work that found a link between social isolation and attrition [26]. A lack of social and academic isolation is more likely to predict early attrition in the program’s first two academic years. At that stage, a typical graduate student has not yet started their research. Their primary interaction during the first two years is with their peers and instructors. Similarly, the mentoring and research experience component is expected to have a high value after the second year when students focus heavily on their research. Testing this hypothesis will be the focus of a future publication.

Implications for Practice and Research

The ASES was designed to help graduate programs assess students’ experiences. We note that the purpose of ASES is not to evaluate the effectiveness of the graduate program. However, a pattern in student responses might indicate areas of strengths and weaknesses of the program per se. Through ASES, we intended to provide a tool for program administrators to conduct end-of-semester/year evaluations of the student experience. For example, the program might have practices to support student socialization and academic
integration. However, the students might not take advantage of those valuable resources. Thus, the program would need to reflect on the resources offered and talk with students to understand why they were not being used as intended. As this is an early stage in the survey development process, we encourage graduate program administrators to view the individual item responses as the essential data provided by the instrument.

Use of the ASES might be particularly valuable for large graduate programs where student-faculty interaction is less frequent at early stages in the student program, and isolation is more likely to occur. Similarly, ASES’s purpose is not to evaluate the provided mentoring from the research advisor; instead, ASES assesses whether the student received adequate mentoring regardless of the source (mentor could be from inside or outside the department).

ASES is also intended for use in scholarly work. ASES has been validated in the set of 19 institutions reported here. However, as noted earlier, further assessment of the psychometric properties in additional contexts is needed to fully evaluate this instrument’s usefulness. A paper and online version of the ASES is available upon request from the authors.

Conclusions

Results from the implementation of the American Physical Society-Bridge Program (APS-BP) suggest that physics departments can create structures that help improve the student experience and result in increased retention. In this study, we developed an instrument based on the APS-BP recommended practices. The psychometric evaluation of the developed instrument suggests that the Aspects of Student Experience Scale (ASES) exhibited acceptable construct validity and substantial internal reliability within this context.

In our effort to further examine the validity of aspects of ASES, we used quantitative data from student responses and qualitative data from two APS-BP and two non-APS-BP departments. We found trends in both types of data that support the validity of the ASES.
For example, the large effect size on students’ experience of SAI was also indicated in the administrators’ responses to those structures offered in their programs. We also found an indication that departmental factors could be correlated with increased average departmental retention.

ASES can be used by researchers in graduate education to identify areas associated with student success. Also, practitioners can use ASES to identify the lack of practices at their departments and develop structures to support the student experience. Changes in department practices have the potential to increase retention and contribute towards a constructive and valuable experience for all students.
Abstract

STEM graduate programs experience persistent high attrition rates. Student self-efficacy has been shown to be an important factor in understanding attrition in undergraduate programs, yet there is limited research on the role of self-efficacy in STEM graduate education. There is also a lack of research on demographic differences in self-efficacy for graduate students. In this study, we adapted two previously developed self-efficacy instruments: a research self-efficacy and an academic self-efficacy instrument. Both had been validated across multiple disciplines. We administered both instruments to 396 physics graduate students from 19 programs in the United States. We evaluated the psychometric properties of the combined instrument and used effect sizes to describe demographic differences in physics graduate students’ self-efficacy beliefs. Four factors were identified for the combined self-efficacy instrument: self-efficacy for initiating a research project, self-efficacy for experimental procedures, self-efficacy for computer/technology usage, and academic self-efficacy. We found evidence for internal consistency and construct validity for the four retained factors. Students who do not intend to persist in their program reported lower self-efficacy across all four measures than students who intend to persist. We also found that mentoring and belonging to a research group are correlated with higher self-efficacy. We also detected significant gender differences favoring men over women/nonbinary students. The gender difference is further exacerbated for LGBTQIA and first-generation college students. Having a validated self-efficacy instrument for graduate programs can support program improvement as well as future research. This work furthers our understanding of the important role self-efficacy plays on student outcomes and works as a starting point for identifying structural inequalities in graduate education.
Introduction

The United States (U.S.) doctoral education system is globally considered to offer high-quality programs and thus attracts top students from around the world [91]. However, despite the high reputation, persistent underlying issues undermine the quality of student experiences and success in graduate education. These are issues that researchers, policymakers, and funding agencies have long been trying to tackle. One of these issues is the high attrition rates that occur across all disciplines in graduate education. Roughly 4 out of 10 students will not complete their intended degree [31, 92]. Moreover, substantial disparities in gender, racial, and ethnic representation in Science, Technology, Engineering, and Mathematics (STEM) disciplines continue to exist in graduate education [4, 5]. Although the number of earned doctoral degrees in science and engineering by women and racially minoritized students (blacks or African Americans, Latinx or Hispanics, and American Indians or Alaska Natives [93]) is higher than ten years ago, these groups are still underrepresented in these fields. While women comprise about 50% of the U.S. population, fewer than 20% earn doctoral degrees in physics [6]. Individuals from Latin, black, and Indigenous (Lat/bl/Ind) backgrounds constitute about 33% of the U.S. population [7], but account for only 9% of the awarded doctoral STEM degrees [4]. Lat/bl/Ind students’ underrepresentation is exacerbated further by the disproportionately higher attrition rates compared to white and American Asian students [5]. For example, a 2008 study found that the ten-year completion rate for Black/African American students in STEM graduate programs was 43% as opposed to 56% for white students [94].

There is an increasing number of voices who call attention to identifying and tackling the systemic inequalities posed by institutional actors. Bensimon [95, p.2] states that inequality in student educational outcomes results from “a learning problem (through attitudes, beliefs, values, and actions) of institutional actors—faculty members, administrators, counselors, and others—rather than a learning problem of students.” In other words, it is individual assumptions, and institutional barriers, not student deficiencies, that create unequal
student outcomes, especially among traditionally marginalized students [96]. Bensimon argues that to tackle the persistent unequal educational outcomes, light should be shed on the nature of racial patterns in educational outcomes [95].

When focusing on the issue of graduate attrition, several past studies approached the phenomenon focusing on student aspects, such as student entering grade points [e.g., 2, 13] and demographic characteristics. Other studies focused on the environmental factors. The most commonly identified environmental factors are social isolation [e.g., 25, 26, 27], lack of academic integration [10], mentoring relationships [10, 25, 32, 33, 34], and financial support [35].

In this study, we argue that the cognitive factor of self-efficacy can help uncover the patterns of inequity in educational outcomes that stem from the systemic inequities embedded in higher education institutions. Self-efficacy is one’s beliefs about their capabilities to produce specific attainments [97]. Self-efficacy is a central component of Bandura’s social cognitive theory (SCT) of human learning. According to SCT, learning is affected by three factors, personal (which includes self-efficacy), environmental, and behavioral, that interact with one another. This model implies that human behavior is not affected solely by environmental stimuli, but it is also subjected to personal cognitive processes, such as the construct of self-efficacy. Self-efficacy is a self-directness mechanism (the ability to regulate and adapt behavior) that strongly impacts thought, affect, motivation, and action [98]. We particularly focus on the construct of self-efficacy for the following reasons: 1) self-efficacy is a dynamic construct that changes over time and is subjected to environmental influences [36]; thus, it can be viewed as a reflection of student experiences of their environments; 2) self-efficacy has been established in the undergraduate literature as an essential factor that influences student motivation [37], performance [38, 39], and persistence [41, 42, 43, 44]; and 3) several studies in K-12 and undergraduate education detected gender and racial disparities in student self-efficacy [99, 100, 101]. Thus, we hypothesize that students from groups who are underrepresented in physics (women, Lat/bl/Ind, LGBTQIA) will have lower self-efficacy.
than straight white men. We also hypothesize that mentored students and students with experience working in research groups will have higher self-efficacy than students who do not have mentors and do not belong in research groups.

In this study, we aim to explore the following research questions:

- Are there differences in self-efficacy reported by students with different demographic identities?
- What is the role of self-efficacy in having a mentor and belonging to a research group?
- What is the role of self-efficacy in student persistence?

In the first research question, we also explore the aspect of intersectionality on students’ self-efficacy. Collins [102, p.2] expressed the commonly accepted definition of intersectionality as the term that “references the critical insight that race, class, gender, sexuality, ethnicity, nation, ability, and age operate not as unitary, mutually exclusive entities, but as reciprocally constructing phenomena that in turn shape complex social inequalities.” Through this approach, we aim to understand structural inequality reflected in students’ self-efficacy involving the overlap of multiple social dynamics. In particular, we examine the intersectionality of gender with race/ethnicity, sexuality, and college generation status.

Theoretical Background

The construct of self-efficacy was first introduced by Bandura as “beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” [36, p.3] and was later situated within the SCT [47]. According to this model, people influence and are influenced by their environment. Moreover, behavioral change can be enacted by a personal sense of control; people’s views of their abilities to perform a task will act as a motivation to pursue that task. Bandura [103] emphasized the substantial difference between having the necessary skills and knowledge to perform a task from being able to
use them properly under certain circumstances. The degree to which one can successfully perform a task depends not only on the person’s capabilities but also on the self-belief to use them successfully. For example, a study by Collins [104] found that self-efficacy was a predictive factor of students’ performance on mathematical problem solving within the same mathematical ability group.

A few years after the development of SCT, researchers applied the construct of self-efficacy to an educational context [105]. Focusing mainly on adolescents and undergraduate students, several studies found that self-efficacy has an effect on student interest, task achievement, and persistence [38, 41, 42, 43, 44, 105, 106, 107]. Bandura [103] argues that self-efficacy contributes to academic development through three main ways: students’ perceptions of their self-efficacy to learn and master various subject matters, individual teachers’ beliefs in their efficacy to motivate and promote learning in their students, and finally through the collective sense of efficacy in the department that their school can accomplish significant academic progress.

Bandura suggests four principal sources of information that contribute to the development of a student’s self-efficacy: personal mastery experiences, vicarious (observational) experiences, social persuasions, and physiological states [36]. Personal mastery experiences are the most influential source for the development of self-efficacy [36, 108], and it refers to students’ actual performance records. Repeated failures tend to lower one’s mastery expectations, while repeated successes enhance one’s expectations of their ability to accomplish similar tasks. Bandura noted that once high mastery expectations have been developed, occasional failures no longer negatively impact self-efficacy.

The second source of information for the development of self-efficacy is vicarious experiences. Those experiences refer to observing others perform tasks by which students can develop a self-judgment expectation of their performance under a similar situation [36]. Vicarious experiences affect the development of self-efficacy of those with little personal
mastery experience. Moreover, the self-efficacy of those with mainly vicarious experiences is more easily subjected to change over time.

Being led in believing that one can cope with a challenging situation through external encouragement, suggestions, and feedback is the third source for the development of self-efficacy [36], which is referred to as social persuasion. Bandura suggests that social persuasion has a small impact on self-efficacy as it is not relied upon authentic experience as opposed to one’s personal mastery experiences. Zeldin et al., [109] examined how men and women STEM students’ self-efficacy is developed and influences their career choices. The authors found that women and men draw on different sources for the development of their self-efficacy. Women shape their self-efficacy from social persuasions and vicarious experiences, while mastery experiences are the primary sources for men’s self-efficacy. This is a possible explanation for the unclear findings across studies on the intersectionality of race with gender on self-efficacy.

Physiological conditions in the form of, for example, anxiety, stress, or tension, negatively influence self-efficacy [36]. In part, people use the information of their emotional states to self-assess their capabilities [110]. This is the fourth source affecting self-efficacy, known as physiological states.

While the above processes influence the development of self-efficacy, in turn, self-efficacy exerts its influence on behavior through four processes: cognitive, affective, motivational, and selection [103]. For example, within the cognitive processes that affect self-efficacy is the perception of ability [103]. Some view ability as an acquirable skill that can potentially grow over time with increasing knowledge and competencies. On the other hand, some view ability as an inherent capacity. Those who view ability as an acquirable skill regard errors as a natural part of developing ability and seek challenging tasks to increase their skills. While for those that view ability as an inherent capacity, performance is diagnostic of their existing ability, and they usually avoid situations of demanding tasks in fear that it might reveal that they are not smart. For example, Chemers et al. [106] found that undergraduate students
with higher self-efficacy were more likely to perceive academic demands as challenging rather than threatening and that these students exhibited better performance.

Another cognitive process that affects one’s self-efficacy is social comparison [103]. An experiment of Bandura and Jourden [? ] with 60 graduate students in business studies tested their managerial skills on performing a specific complex task. Students were randomly assigned to one of the four treatment conditions based on the comparison score with the other group. The four conditions were: similar capabilities, superior capabilities, progressive mastery (consistently surpassing comparison group), and progressive decline (consistently attaining poorer performance than comparison group). After each trial, the participants would receive quantitative feedback on their performance and the attainments of the comparison group. The results indicated that the similar and superior comparative conditions reported the same self-efficacy levels across the three assessment periods. However, self-efficacy levels of participants in the progressive mastery group were highly increased, while those on the declining condition had decreasing self-efficacy throughout the treatment. This study’s results show that repeated negative feedback showing declined performance relative to peers lowers one’s self-efficacy. Huyn et al., [111] found that self-reported physiological needs (mental health) were significantly and positively correlated with competitiveness between students in a graduate program. Physiological states are also related to the affective process described by Bandura [103].

Affective processes describe how people’s view of their capabilities influences their stress levels, depression, and motivation [103]. Wilks [112] defined academic stress as “the product of a combination of academic-related demands that exceed the adaptive resources available to an individual” (p.107). As stated in Hyun et al.’s work [111] “graduate students are particularly vulnerable to pressures related to conducting research and teaching, publishing, and finding employment, in addition to stress from the often ambiguous expectations of advisors” (p. 248). Self-efficacy influences stress and anxiety through thought control mechanisms, the notion of perceived efficacy to control disturbing thoughts. For
example, students’ past failures increase anxiety through their negative effects on perceived self-efficacy [103, 113]. However, as noted by Bandura [103], a strong sense of self-efficacy helps control and regulate academic anxiety. Chwalisz et al. [114] found that those with high levels of self-efficacy managed the anticipated stressors by resolving problems. In contrast, those with lower self-efficacy avoided dealing with academic problems. Overall, few studies have focused on graduate students’ physiological states, such as mental health; instead, most such studies are focused on undergraduates [115].

The above studies pose the need to study self-efficacy more rigorously in graduate education. It is necessary to understand how self-efficacy affects graduate student outcomes and identify interventions and structures to support the development of self-efficacy. However, to do so, researchers need tools to measure graduate student self-efficacy. In this paper, we use responses from physics graduate students to assess the psychometric properties of a self-efficacy instrument and identify some factors related to self-efficacy. We view this work as a starting point to approaching graduate attrition from a holistic perspective, considering constructs of increased importance for student outcomes in other educational contexts.

In the following paragraphs, we discuss findings from the literature in other educational contexts on self-efficacy among gender, sexual orientation, racial/ethnic groups, generation status, the role of key academic variables (having a mentor, in a research group) on self-efficacy, and the role of self-efficacy on persistence.

Student Demographics and Self-Efficacy

Several studies detected gender gaps in student self-efficacy, with women reporting lower self-efficacy of their science-related abilities than men despite having similar levels of prior achievement and outcomes [e.g., 99, 100]. Gender role socialization is highly correlated with self-efficacy, resulting in higher and lower self-efficacy judgments for men and women, respectively [97, 101].
Although many studies are focusing on self-efficacy and how it differs between men and women, currently, there is not much research on the development of self-efficacy for lesbian, gay, bisexual, transgender, queer, intersex, and asexual (LGBTQIA) students, especially in STEM fields. However, there is a slowly expanding literature on the experiences of LGBTQIA students in science fields. These studies suggest that LGBTQ students’ identities are central to their educational experiences [116] and that several LGBT physicists report experiencing exclusionary behavior based on their gender expression or being a woman [117]. The combination of these aspects (LGBTQ identity central to the pursuit of STEM education and experiencing microaggression and harassment because of identity) can be detrimental for students’ success in STEM fields and an example supporting Bensimon’s and other scholars’ [e.g., 95, 96] arguments on the impact of systemic inequalities posed by institutional actors on student educational outcomes.

The experiences and adjustment to college of first-generation college students concerns a vast portion of the undergraduate literature [e.g., 118, 119]. First-generation college students are defined as those whose parents did not attend college, while continued-generation college students are those whose at least one parent graduated from a 4-year university [120]. Studies have consistently shown that first-generation college students encounter more challenges before and when attending college than continued-generation students [e.g., 118]. One of these challenges stems from the lack of parental guidance in making the transition to the academic environment. Several studies in the undergraduate literature explored the role of cognitive processes, such as self-efficacy, on first-generation college student educational outcomes. It is found that higher self-efficacy is directly related to 1st-year students’ academic performance [106], and that self-efficacy is associated with academic demands perceived as challenging rather than threatening, with greater academic expectations and better performance [106]. Studies also reported that continued-generation college students have significantly higher self-efficacy than first-generation college students [e.g., 119].
The role of race and ethnicity on student self-efficacy was examined in several studies [109, 121, 122] resulting in mixed findings. While some studies support that white students have higher self-efficacy than marginalized students [123, 124], a review by Graham [125] found that in 7 out of 18 studies, African American students had higher self-efficacy levels than white students [121]. A qualitative study [46] explored the influences of self-efficacy and expectancy outcomes on decisions of African-American graduate students to pursue careers in STEM-related fields. The authors found that self-efficacy influences persistence in the field and that teachers, parents, mentors, counselors, and peers significantly influence student self-efficacy. Moreover, Chen & Graham [126] suggest that Asian American students have the highest grade point average but the lowest self-esteem among the four major racial/ethnic groups (white, Black, Latino, Asian Americans). A study found that the quality of the parent-child relationship was positively associated with self-efficacy for Asian Americans but not for white students [127]. The literature also found gender gaps among racial/ethnic groups. In particular, research showed that white and Latino men report higher self-efficacy than white and Latina women, respectively [128, 129]. However, African American women consistently report higher self-efficacy than African American men [128].

Mentoring, Persistence, and Self-Efficacy

The most highly explored environmental factor related to the student experience and retention is the relationship with advisors [32]. The advisor is usually the department representative with whom graduate students will interact the most during their graduate program [25, 33, 34]. The effects of advisor’s roles span across students’ experiences in the program related to their research activities, opportunities for professional development, the integration to the professional field of study, and the development of students’ confidence through encouragement and praise [25, 33, 70]. Golde [10] found that inharmonious advising relationships, characterized by a lack of interaction, trust, and intellectual support, accounted for the attrition in two science departments. Moreover, it is found that women who are less
confident of their science and math skills are less likely to persist in STEM fields than
women who are more confident of holding these abilities [130]. Several studies highlight the
important role of mentoring on student self-efficacy. Positive faculty-student interactions
are found to contribute to higher academic self-efficacy ratings [71]. In particular, a study
found that the psychosocial aspect of mentoring (role modeling, counseling in crises, informal
friendship) positively predicted graduate students’ research self-efficacy [131].

Studies in the undergraduate literature have long explored the role of self-efficacy
on student persistence finding positive correlations [e.g., 42, 43, 132]. Moreover, studies
found that women with higher self-efficacy are more likely to persist in predominately male
disciplines than women with lower self-efficacy [133].

Despite the significant efforts to understand graduate attrition, this research area is
much less robust than the body of undergraduate attrition literature [50]. Graduate attrition
is a complicated issue and should be approached separately from the factors associated with
undergraduate attrition. Moreover, past studies on doctoral programs found that scientific
discipline is one of the strongest predictors of degree completion [51], with social science
departments reporting the highest attrition rates. Thus, context-specific discipline-based
elements pose the need to tackle graduate attrition from a discipline-based point of view.

The substantial role self-efficacy has been shown to have on student outcomes in
high-school and undergraduate levels suggests that it is important to gain insight into the
development of graduate students’ self-efficacy and the ways in which education can support
this development. To date, there is limited understanding of aspects related to STEM
graduate attrition and the role of self-efficacy. Moreover, there is a lack of information
regarding the role of student identities on self-efficacy for graduate students. There is also
a lack of reliable and validated instruments to measure graduate students’ self-efficacy. We
found two that have been developed and validated more than 20 years ago.

In this study, we adapted one instrument (research self-efficacy) [57] that has been
previously developed and validated across multiple disciplines in graduate education, and
one (academic self-efficacy) that had been previously used for STEM graduate students [59]. We adapted the instruments to reflect the context of STEM graduate students and also modified the scales so that both instruments had the same response options. We then administered both instruments to physics graduate students to assess the psychometric properties of the combined instrument. We use student responses to explore gender, race, sexual orientation, generation status, and intersectionality of gender with race/ethnicity, sexuality, and college generation status effects for physics graduate students’ self-efficacy, as well as important academic variables (having a mentor, belonging in a research group) and persistence intentions.

Methods

In the Spring of 2019, we administered an online survey (15-minute-long via Qualtrics) to physics graduate students that elicited their demographic information, students’ perceived experiences of departmental structures, their self-efficacy, and intention to persist. In this paper, we focus on students’ responses to assess the validity of the self-efficacy portion of the survey.

Procedures

First, we identified a list of sixty research-intensive physics graduate programs in the U.S. We also identified the email addresses of the department chairs and the graduate advisors of those programs. We invited those department chairs to participate in our study, asking them to provide us with a list of all their graduate students’ contact information. We also asked them to send their students an email encouraging students to take the survey. Some programs that agreed to participate would not provide the list of students. In these cases, the chair/graduate advisor sent the survey invitation (on our behalf) along with an anonymized link to the survey. The students were expected to click on the survey link to
read the consent form and decide whether they wanted to participate. We sent up to two reminder emails, and twenty programs agreed to participate. Only one had a low response rate (< 10%) and was excluded from the study results. At 14 departments, we contacted the students via direct personalized emails, which resulted in an average response rate of 28%. For the remaining 9 departments, the chair sent an anonymized link to the survey, resulting in a response rate of 15.3%. The average response rate from all the 19 departments is 23.4%. Table 3.1 displays the characteristics of each department, along with the response rate. The average number of enrolled students per Ph.D. program is 93.3 students, while the reported national average of students enrolled at Ph.D. departments is 72.4 students [65]. Of the students that attempted the survey, a total of 396 participants responded to more than 90% of all the survey items, and a total of 46 students completed less than 90%. The latter group was not used in the analysis.

Participants

Of the 396 students who completed more than 90% of the items, 86% seek a Ph.D. degree and 14% a Master’s degree. 61% of the respondents have passed the fourth semester (2nd-year) of their studies, 82.8% have a mentor, and 86.5% belong to a research group. 25.4% self-identified as women or nonbinary and 74.6% as men. One student self-identified as gender nonbinary, and we placed the student into the women/nonbinary group because of the traditionally marginalized aspect of their identity in STEM fields.

72% were U.S. citizens, while 28% were international students. Among only U.S. citizens, 54%, 8%, 2%, 6%, and 2% self-identified as racially white, Asian, black/African American, ethnically Latino/Hispanic, and with more than one race, respectively. Finally, 9% are first-generation college students, 7% are parents, and 6% identified as lesbian, gay, bisexual, transgender, queer, intersex, and asexual (LGBTQIA). According to the national data on physics graduate education of the American Institute of Physics (AIP) [65, 66, 67],
Table 3.1: Characteristics of each of the 19 physics graduate programs.

<table>
<thead>
<tr>
<th>ID</th>
<th>Region</th>
<th>Highest degree</th>
<th>Size</th>
<th>Rank</th>
<th>Response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPT. 1</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>10.9%</td>
</tr>
<tr>
<td>DEPT. 2</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>33.6%</td>
</tr>
<tr>
<td>DEPT. 3</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>23.0%</td>
</tr>
<tr>
<td>DEPT. 4</td>
<td>West</td>
<td>M.S.</td>
<td>Medium</td>
<td>-</td>
<td>43.4%</td>
</tr>
<tr>
<td>DEPT. 5</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>18.2%</td>
</tr>
<tr>
<td>DEPT. 6</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Small</td>
<td>-</td>
<td>65.5%</td>
</tr>
<tr>
<td>DEPT. 7</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>High</td>
<td>30.0%</td>
</tr>
<tr>
<td>DEPT. 8</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>17.2%</td>
</tr>
<tr>
<td>DEPT. 9</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Medium</td>
<td>23.8%</td>
</tr>
<tr>
<td>DEPT. 10</td>
<td>West</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>30.0%</td>
</tr>
<tr>
<td>DEPT. 11</td>
<td>Northeast</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>11.4%</td>
</tr>
<tr>
<td>DEPT. 12</td>
<td>South</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Low</td>
<td>16.7%</td>
</tr>
<tr>
<td>DEPT. 13</td>
<td>West</td>
<td>M.S.</td>
<td>Medium</td>
<td>-</td>
<td>28.3%</td>
</tr>
<tr>
<td>DEPT. 14</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>Medium</td>
<td>17.6%</td>
</tr>
<tr>
<td>DEPT. 15</td>
<td>West</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>31.5%</td>
</tr>
<tr>
<td>DEPT. 16</td>
<td>West</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>High</td>
<td>26.4%</td>
</tr>
<tr>
<td>DEPT. 17</td>
<td>West</td>
<td>Ph.D.</td>
<td>Small</td>
<td>Medium</td>
<td>35.9%</td>
</tr>
<tr>
<td>DEPT. 18</td>
<td>South</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Low</td>
<td>18.0%</td>
</tr>
<tr>
<td>DEPT. 19</td>
<td>Southwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Medium</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

Note: The average response rate from all the 19 departments is 23.4%. The response rate is the ratio of the number of students that completed more than 90% of the survey items to the total number of students enrolled at the program. We purposefully do not disclose the exact number of students enrolled at each program to avoid program identification. The size refers to the total number of students enrolled at the program, where: a) ≤ 50: small; b) 51-100: medium; c) ≥ 101: large. Similarly, the program’s ranking is presented in the following categories: a) 1-50: high; b) 51-100: medium; c) ≥ 101: low. Information on the size of each program was obtained from the American Institute of Physics [65], and the ranking from the U.S. News & World Report [77].
students that self-identified as women are slightly over-represented in our sample (25% vs. 20%), non-US citizens are significantly underrepresented (28% vs. 43%). Among the U.S. citizens, Lat/bl/Ind students are also slightly over-represented in our sample (8% vs. 5.7%). 18 students identified as Latinx/Hispanic, 8 as black/African American, and 22 identified with more than race which included one the NSF identified “minoritized” race/ethnicity in STEM. We combined these 48 students under the Lat/bl/Ind group.

Measures

Research Self-Efficacy

The Research Self-efficacy scale was adopted from Greeley et al., [57]. It is a 53-item scale designed to measure an individual’s perceived ability to accomplish various research-related tasks and was previously assessed for utility by Bieschke, Bishop, & Garcia, [58]. This scale was developed with six factors: find and research idea, present and write the idea, finalize the research idea, conduct the research, analyze data, write and present results. Bieschke et al.’s [58] utility assessment revealed four underlying factors with 51 retained items: conceptualization (16 items), implementation (20 items), early tasks (5 items), and presenting the results (8 items). Using coefficient α, internal consistency measures ranged from .75 to .96 for the four retained factors. Bieschke et al.’s study used the responses of 177 doctoral students from various disciplines at a large U.S. university with a 100-point response scale, ranging from 0 (no confidence) to 100 (complete confidence). Only 17% of the respondents were in STEM-related disciplines. We used 37-items from the Research Self-efficacy scale, omitting the items related to Presenting the Results in order to make the survey shorter and more concise and a few items that we deemed not relevant for STEM fields, as these seemed more appropriate for the social sciences (e.g., Obtain approval to pursue research).
Academic Self-Efficacy

The Academic Self-efficacy scale was adopted from Santiago & Einarson [59]. It is a 10-item instrument designed to measure an individual’s perceived ability to perform a series of degree-related tasks. Using the responses of the Fall 1995-96 Graduate Experience Project data of about 234 science and engineering students, the internal consistency measure was reported to be $r=.80$. While the authors used a 3-point response scale ranging from 2 for very confident, 1 for somewhat confident, and 0 for not confident at all, we modified the scale to match the Research Self-efficacy 100-point response scale.

Additional Items

In this survey, we asked the respondents to indicate whether they have an academic mentor at their current institution and belong to a research group. Students responded on a nominal scale of yes or no. This paper uses students’ responses to these two questions to examine whether students who identify with a mentor or belong to a research group have different self-efficacy beliefs than those who do not. Finally, we asked the respondents whether they intended to obtain their degree. In particular, students read the statement I intend to complete my degree program, and were asked to select their response on an ordinal five-point Likert scale. We coded students’ responses on the intention to complete their degree program on a nominal scale because the combined sample of students who responded strongly disagree/disagree/neutral was very small (n=25). In particular, strongly disagree, disagree, and neither agree nor disagree were coded as no, while strongly agree and agree were coded as yes.
Data Analysis

Principal Components Analysis

All statistical analyses were conducted using the SPSS version 26.0 software. We performed a principal component analysis (PCA) using the 396 student responses to uncover the underlying structure of the 47-items that were designed to measure physics graduate students’ self-efficacy. Our goal by using PCA is to reduce the number of items and explain the same amount of variance with as few items as possible. First, we ran PCA on the 47-items, which resulted in 8 retained components with eigenvalues greater than 1 [80]. Then, using Horn’s parallel analysis (PA) [81] on all the 47-items, we retained those components whose eigenvalues were smaller than the eigenvalues of the previously obtained from PCA. PA approach is widely recommended for factor retention in PCA [82]. This approach supported a 4-factor solution. Table 3.2 shows the eigenvalues from PCA and PA and the decision for factor retention. We then reran PCA requesting four extracting factors. To identify the appropriate rotation matrix, we requested an oblique rotation to obtain the factor correlation matrix. The factor correlation matrix for correlations was higher than .32, suggesting that the data are orthogonal (uncorrelated). Therefore, we reran PCA requesting now an Oblimin rotation, which is appropriate for non-orthogonal data [83, 84]. We found that one item did not load on any factor and was omitted from further analysis. We then reran PCA to obtain the final model.

Reliability and Construct Validity

We used the Composite Reliability Index (CRI) and Cronbach’s $\alpha$ [52] to assess the internal consistency for each of the components. Internal consistency is a measure of the extent that all the items in a test measure the same underlying concept or construct [53]. This measure ranges from 0 to 1. CRI should be above the acceptable level of .60 [85], while Cronbach’s $\alpha$ values should surpass the acceptable level of .70. Also, convergent
Table 3.2: Comparison of PCA and PA factors. If $\lambda_{PCA} > \lambda_{PA}$, accept.

<table>
<thead>
<tr>
<th>Component</th>
<th>$\lambda$ from PCA</th>
<th>Criterion $\lambda$ from PA</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.081</td>
<td>1.802</td>
<td>Accepted</td>
</tr>
<tr>
<td>2</td>
<td>3.552</td>
<td>1.725</td>
<td>Accepted</td>
</tr>
<tr>
<td>3</td>
<td>3.014</td>
<td>1.658</td>
<td>Accepted</td>
</tr>
<tr>
<td>4</td>
<td>2.217</td>
<td>1.592</td>
<td>Accepted</td>
</tr>
<tr>
<td>5</td>
<td>1.522</td>
<td>1.542</td>
<td>Rejected</td>
</tr>
<tr>
<td>6</td>
<td>1.371</td>
<td>1.499</td>
<td>Rejected</td>
</tr>
<tr>
<td>7</td>
<td>1.230</td>
<td>1.454</td>
<td>Rejected</td>
</tr>
<tr>
<td>8</td>
<td>1.121</td>
<td>1.425</td>
<td>Rejected</td>
</tr>
</tbody>
</table>

and discriminant validity were both used to assess the construct validity of the instrument. Convergent validity was assessed using the average variance extracted (AVE). The squared inter-component correlation values were used to assess divergent validity by meeting the criterion of the AVE values to be higher than the squared inter-component correlation values.

Hedge’s $g$ Effect Size

Test statistics using $p$ value are sensitive to sample size and do not indicate meaningful or practical significance, thus can easily be misleading [60, 88]. To overcome this shortcoming, researchers and editors have suggested the use of effect size for reporting and interpreting results [e.g., 86, 87]. Effect size is a standardized measure of the magnitude or strength of the difference in outcome between two groups [54, 60]. Here, we use the adjusted Hedge’s $g$ for small sample sizes, as shown in eq. 1. Effect sizes must be reported along with the confidence interval (CI) to evaluate the precision of the findings [61]. We use the 95% CI calculated, as shown in eq. 3 [54, 61] which is an indicative measure of uncertainty.

$$g = \left( \frac{M_A - M_B}{SD_{pooled}} \right) \times \left( \frac{N - 3}{N - 2.5} \right) \times \sqrt{\frac{N - 2}{N}}, \quad (1)$$
where $SD_{pooled}$ is shown below on eq. 2 and $N = n_A + n_B$:

$$SD_{pooled} = \sqrt{\frac{[(SD_A)^2(n_A - 1)] + [(SD_B)^2(n_B - 1)]}{n_A + n_B - 2}},$$

(2)

$$CI = 1.96 \times \sqrt{\frac{N}{n_A * n_B} + \frac{g^2}{2N}}$$

(3)

Cohen [89] proposed benchmarks for interpreting power for ES, namely, ES of .20 is “small” in magnitude, .50 is “medium,” and values of .80 and above are “large.” However, he noted that these values should be used carefully as a general rule of thumb, especially when there is no previous empirical evidence in the particular research area to compare to [61]. Along these lines, Bosco et al., [1] showed that ES fluctuates across research domains, constructs, and measures. For example, Kraft [134] proposed new ES benchmarks for interpreting education interventions based on previous empirical intervention results on student achievement data. He suggested ES values less than .05 to be considered “small,” values of .05 to .20 to be “medium,” and values above .20 to be considered “large.” Based on previous empirical evidence for psychological factors in applied psychology, Bosco et al., [1] suggested medium ES ranging from .10 to .23. Therefore, in this study, we consider any values as important and meaningful when the ES is higher than .10.

Results

Principal Components Analysis

The Bartlett’s test of sphericity, $\chi^2=13121.179$, $df=1081$, $p<0.001$, and a Kaiser-Meyer-Olkin measure of sampling adequacy, $KMO=0.935$ indicated that the resulting matrix of correlations was appropriate for factor analysis. PCA was used to determine the items that fall into each of the four identified factors by meeting the criterion of loading at least 0.4 on their respective factor. Table 3.3 displays the factors from the rotated four-factor
Oblimin solution. The resulting four factors are (a) *self-efficacy for initiating a research project* (SE-RP), (b) *self-efficacy for experimental procedures* (SE-EP), (c) *academic self-efficacy* (A-SE), and *self-efficacy for computer/technology usage* (SE-CU). The four factor solution accounted for 59.28% of the total variance in the 46-items. More specifically, SE-RP (n=21) accounted for 40.60% of variance in the data, SE-EP (n=10) accounted for an additional 7.56%, A-SE (n=10) accounted for an additional 6.41%, and finally, SE-CU (n=5) accounted for 4.72% of variance in the data.

Table 3.3: Loading factors from the rotated four factor Varimax solution. Note: The stem of the items is “how confident are you in your ability to...”

<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Factor 1: Self-efficacy for initiating a research project</strong></td>
<td></td>
</tr>
<tr>
<td>...complete a significant project</td>
<td>.46</td>
</tr>
<tr>
<td>...brainstorm areas in the literature to read about</td>
<td>.68</td>
</tr>
<tr>
<td>...locate references by manual search</td>
<td>.46</td>
</tr>
<tr>
<td>...find needed articles which are not available in your library</td>
<td>.43</td>
</tr>
<tr>
<td>...evaluate journal articles in terms of the theoretical approach, experimental design and data analysis techniques</td>
<td></td>
</tr>
<tr>
<td>...participate in generating collaborative research ideas</td>
<td>.77</td>
</tr>
<tr>
<td>...work interdependently in a research group</td>
<td>.54</td>
</tr>
<tr>
<td>...discuss research ideas with peers</td>
<td>.53</td>
</tr>
<tr>
<td>...consult senior researchers for ideas</td>
<td>.63</td>
</tr>
</tbody>
</table>

Continued on next page
Table 3.3 – continued from previous page

<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>...decide when to quit searching for related research/writing</td>
<td>.72</td>
</tr>
<tr>
<td>...decide when to quit generating ideas based on your literature review</td>
<td>.73</td>
</tr>
<tr>
<td>...synthesize current literature</td>
<td>.81</td>
</tr>
<tr>
<td>...identify areas of needed research, based on reading the literature</td>
<td>.89</td>
</tr>
<tr>
<td>...develop a logical rationale for your particular research idea</td>
<td>.80</td>
</tr>
<tr>
<td>...generate researchable questions</td>
<td>.86</td>
</tr>
<tr>
<td>...organize your proposed research ideas in writing</td>
<td>.68</td>
</tr>
<tr>
<td>...effectively edit your writing to make it logical and succinct</td>
<td>.41</td>
</tr>
<tr>
<td>...present your research ideas orally or in written form</td>
<td>.52</td>
</tr>
<tr>
<td>...utilize criticism from reviews of your idea</td>
<td>.41</td>
</tr>
<tr>
<td>...choose an appropriate research design</td>
<td>.59</td>
</tr>
<tr>
<td>...be flexible in developing alternative research strategies</td>
<td>.56</td>
</tr>
<tr>
<td><strong>Factor 2: Self-efficacy for experimental procedures</strong></td>
<td></td>
</tr>
<tr>
<td>choose methods of data collection</td>
<td>.40</td>
</tr>
</tbody>
</table>

Continued on next page
Table 3.3 – continued from previous page

<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>...choose measures of dependent and independent variables</td>
<td>.34</td>
</tr>
<tr>
<td>...choose appropriate data analysis techniques</td>
<td>.28</td>
</tr>
<tr>
<td>...obtain appropriate participants/general supplies/equipment</td>
<td>.16</td>
</tr>
<tr>
<td>...train assistants to collect data</td>
<td>.08</td>
</tr>
<tr>
<td>...perform experimental procedures</td>
<td>-.09</td>
</tr>
<tr>
<td>...ensure data collection is reliable across trial, raters, and equipment</td>
<td>.04</td>
</tr>
<tr>
<td>...supervise assistants</td>
<td>-.00</td>
</tr>
<tr>
<td>...attend to all relevant details of data collection</td>
<td>.04</td>
</tr>
<tr>
<td>...organize collected data for analysis</td>
<td>-.03</td>
</tr>
</tbody>
</table>

**Factor 3: Academic self-efficacy**

|                        | 1       | 2       | 3       | 4       |
|...complete your degree | .02     | .05     | .86     | .01     |
|...complete your degree in a timely manner | .13     | -.01    | .76     | -.07    |
|...complete your degree at this university | -.05    | 0.02    | .84     | .08     |
|...secure funding for your graduate training | -.15    | -.09    | .59     | .04     |
|...know about degree requirements | -.09    | -.1     | .54     | .22     |
|...maintain a balance between school and your personal life | .03     | .01     | .68     | -.14    |
|...handle the coursework | .12     | .07     | .54     | .20     |
|...your ability to conduct research | .36     | -.14    | .39     | .08     |

Continued on next page
Table 3.3 – continued from previous page

<table>
<thead>
<tr>
<th>Item content by factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>...handle stress related to graduate work</td>
<td>.21</td>
<td>-0.01</td>
<td>.65</td>
<td>-0.10</td>
</tr>
<tr>
<td>...do well in your program</td>
<td>.21</td>
<td>-0.04</td>
<td>.76</td>
<td>-0.07</td>
</tr>
<tr>
<td><strong>Factor 4: Self-efficacy for computer/technology usage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...conduct a computer search of the literature in a partic-</td>
<td>.40</td>
<td>.17</td>
<td>.13</td>
<td>.49</td>
</tr>
<tr>
<td>ular area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...use computer software to prepare texts (word processing)</td>
<td>-.21</td>
<td>-.27</td>
<td>.17</td>
<td>.58</td>
</tr>
<tr>
<td>...use computer software to generate graphics</td>
<td>.06</td>
<td>-.03</td>
<td>.01</td>
<td>.80</td>
</tr>
<tr>
<td>...use computer for data analysis</td>
<td>-.04</td>
<td>-.12</td>
<td>-.00</td>
<td>.86</td>
</tr>
<tr>
<td>...develop computer programs to analyze data</td>
<td>.09</td>
<td>.02</td>
<td>-.04</td>
<td>.81</td>
</tr>
</tbody>
</table>

| Eigenvalues        | 19.08 | 3.55  | 3.01  | 2.22  |
| Percent Variance   | 40.60 | 7.56  | 6.41  | 4.72  |

Psychometric Evaluation

Evidence for substantial internal consistency was found for all four retained factors. Using CRI, we found that all the components are above the acceptable value of 0.6 [85]. Moreover, using Cronbach’s alpha to assess internal consistency, we found a value of .953 for SE-RP, .939 for SE-EP, .890 for A-SE, and .846 for SE-CU. To assess construct validity, we computed both convergent and discriminant validity. Convergent validity was assessed using the AVE. We found that the values for SE-RP and A-SE were below the acceptable value of .5. According to Fornell and Larcker [85] values of AVE below .5 are adequate,
Table 3.4: AVE, squared inter-component correlation, and CRI.

<table>
<thead>
<tr>
<th>Component</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>CRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(.413)</td>
<td></td>
<td></td>
<td></td>
<td>.933</td>
</tr>
<tr>
<td>2</td>
<td>.142</td>
<td>(.502)</td>
<td></td>
<td></td>
<td>.905</td>
</tr>
<tr>
<td>3</td>
<td>.162</td>
<td>.305</td>
<td>(.456)</td>
<td></td>
<td>.889</td>
</tr>
<tr>
<td>4</td>
<td>.057</td>
<td>.006</td>
<td>.038</td>
<td>(.523)</td>
<td>.841</td>
</tr>
</tbody>
</table>

if CRI value is above .6 [90]. Both components satisfied this criterion; thus, we can claim that we find support for relative convergent validity. Moreover, we computed the squared inter-component correlation values. Meeting the criterion of the AVE values to be greater than the squared inter-correlation values, we also found evidence of substantial divergent validity. Table 3.4 shows the AVE, squared inter-component correlation values, and CRI values. Thus, we found that the self-efficacy scale exhibited construct validity within this particular context.

Descriptive Statistics

Results from Master’s and doctoral student responses on the self-efficacy scale suggest that students have on average slightly higher self-efficacy beliefs than on studies previously reported using these instruments. Self-efficacy on research procedures (SE-RP) has a mean value of 74.02 ± 15.47, self-efficacy for experimental procedures (SE-EP) of 74.66 ± 18.07, academic self-efficacy (A-SE) of 78.61 ± 15.24, and the highest mean value is of self-efficacy for computer usage (SE-CU) of 86.05 ± 14.74. The results are presented in Table 3.5. Both A-SE and SE-CU are negatively skewed and leptokurtic.
Table 3.5: Results of students’ beliefs of self-efficacy

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (%)</td>
<td>75.29</td>
<td>78.60</td>
<td>81.60</td>
<td>90.90</td>
</tr>
<tr>
<td>Mean (%)</td>
<td>74.02</td>
<td>74.66</td>
<td>78.61</td>
<td>86.05</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>15.47</td>
<td>18.07</td>
<td>15.24</td>
<td>14.74</td>
</tr>
<tr>
<td>Skewness</td>
<td>-.63</td>
<td>-.97</td>
<td>-1.28</td>
<td>-1.5</td>
</tr>
<tr>
<td>Std. Error of Skewness</td>
<td>.13</td>
<td>.13</td>
<td>.13</td>
<td>.13</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>.03</td>
<td>.94</td>
<td>1.92</td>
<td>2.05</td>
</tr>
<tr>
<td>Std. Error of Kurtosis</td>
<td>.26</td>
<td>.26</td>
<td>.25</td>
<td>.25</td>
</tr>
</tbody>
</table>


Effect Size across Aspects of Identity

We present 396 doctoral students’ responses to report effect size differences for gender, race, sexuality, and first-generation college status and intersectionality of gender and these other identities as shown in Table 3.6. We found gender gaps across all self-efficacy categories, with men having consistently higher self-efficacy than women/non-binary students, with the largest effect size being for academic self-efficacy ($g=.47$).

When examining race, we found mixed findings on the self-efficacy differences between American white and American Asian students. American Asian students have higher self-efficacy than white students on experimental procedures and academic self-efficacy ($g=.14$ and $.29$ respectively). On the other hand, white students have higher self-efficacy on initiating a research project and computer usage ($g=.12$ and $.17$, respectively). Lat/bl/Ind students reported higher self-efficacy than white students on starting a research project and academic self-efficacy ($g=.19$), but lower self-efficacy than all the other racial/ethnic categories (white, Asian, visa-holders) on computer usage. Finally, we found mixed results on the self-efficacy of international students. These students tend to have higher self-efficacy than white students on initiating a research project and academic self-efficacy but lower on experimental procedures and computer usage.
Interestingly, we found that the gender gap in students’ self-efficacy increased when looking for the intersectionality of gender and race on all racial/ethnic groups besides Lat/bl/Ind students. The gender gap favoring men is significantly more evident for Asian American students. On the other hand, we found that Lat/bl/Ind women/nonbinary students have higher self-efficacy than Lat/bl/Ind men.

Sexual orientation is another aspect of identity that is correlated with self-efficacy. We find that LGBTQIA students have lower self-efficacy than straight students on all but one self-efficacy measure (self-efficacy for computer usage; $g=.02$). We also detected the gender gap in LGBTQIA students, with LGBTQIA men having higher self-efficacy than LGBTQIA women/nonbinary students.

Finally, as expected, we found that continued-generation college students have higher self-efficacy than first-generation college students but only on two measures (academic self-efficacy and self-efficacy for computer usage). Similar to all the other identities (race, sexual orientation), we found first-generation college men to have higher self-efficacy on all four measures than first-generation women/nonbinary students.
## Table 3.6: Effect size of self-efficacy beliefs of Ph.D. students per demographic group.

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Hedge’s g Effect Size [95% Confidence Interval]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td>SE-RP</td>
</tr>
<tr>
<td>men (n=266)</td>
<td>women (n=91)</td>
<td>-0.32 [-1.03, .39]</td>
</tr>
<tr>
<td><strong>Race/Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US:white (n=193)</td>
<td>US:Lat/Bl/Ind (n=45)</td>
<td>-0.12 [-.59, .36]</td>
</tr>
<tr>
<td>US:Lat/Bl/Ind (n=45)</td>
<td>visa-holders (n=99)</td>
<td>0.19 [-.15, .52]</td>
</tr>
<tr>
<td>visa-holders (n=99)</td>
<td></td>
<td>0.18 [-.33, .69]</td>
</tr>
<tr>
<td>US:Asian (n=30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US:Lat/Bl/Ind (n=45)</td>
<td>visa-holders (n=99)</td>
<td>0.28 [-.36, .91]</td>
</tr>
<tr>
<td>visa-holders (n=99)</td>
<td></td>
<td>0.28 [-.34, .89]</td>
</tr>
<tr>
<td>US:Lat/Bl/Ind (n=45)</td>
<td>visa-holders (n=99)</td>
<td>0.00 [-.36, .36]</td>
</tr>
<tr>
<td><strong>Gender*Race/Ethn.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US:white men (n=141)</td>
<td>US:white women (n=50)</td>
<td>-0.33 [-.87, .20]</td>
</tr>
<tr>
<td>US:Asian men (n=25)</td>
<td>US:Asian women (n=5)</td>
<td>-1.75 [-2.88, -.62]</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Hedge's g Effect Size [95% Confidence Interval]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lat/Bl/Ind men (n=34)</td>
<td>Lat/Bl/Ind wom. (n=12)</td>
<td>.30 [-.41, 1.00]</td>
</tr>
<tr>
<td>visa-holders men (n=66)</td>
<td>visa-holders wom. (n=29)</td>
<td>-.34 [-.93, .32]</td>
</tr>
<tr>
<td>Sexual orientation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight (n=350)</td>
<td>LGBTQIA (n=25)</td>
<td>-.32 [-.75, .11]</td>
</tr>
<tr>
<td>LGBTQIA men (n=9)</td>
<td>LGBTQIA women (n=16)</td>
<td>-.50 [-1.36, .37]</td>
</tr>
<tr>
<td>First-gen. students</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continued-gen. (n=338)</td>
<td>First-gen. (n=37)</td>
<td>-.05 [-.75, .65]</td>
</tr>
<tr>
<td>First-gen. men (n=26)</td>
<td>First-gen women (n=11)</td>
<td>-.44 [-1.14, .26]</td>
</tr>
</tbody>
</table>

Note: Negative and positive effect size values mean higher mean values for groups 1 and 2, respectively. **Bolded ES above .10 demonstrate meaningful differences between group 1 and group 2** [1]. Self-Efficacy on Research Procedures (SE-RP), Self-Efficacy on Experimental Procedures (SE-EP), Academic Self-Efficacy (A-SE), and Self-Efficacy on Computer Usage (SE-CU).
Table 3.7: Mean, standard deviation values, and Hedge’s $g$ effect size on differences on key academic related aspects and intention to persist.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Have a mentor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No (n=61)</td>
<td>68.5 $\pm$ 19.4</td>
<td>70.2 $\pm$ 20.4</td>
<td>71.2 $\pm$ 20.6</td>
<td>81.7 $\pm$ 17.4</td>
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<tr>
<td>Yes (n=311)</td>
<td>75.1 $\pm$ 14.4</td>
<td>75.5 $\pm$ 17.5</td>
<td>79.9 $\pm$ 13.5</td>
<td>86.9 $\pm$ 14.0</td>
</tr>
<tr>
<td>$g$ [95% CI]</td>
<td>.43 [-.26, 1.12]</td>
<td>.29 [-.35, .93]</td>
<td>.58 [-.12, 1.28]</td>
<td>.35 [-.35, 1.06]</td>
</tr>
<tr>
<td><strong>In a research group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No (n=45)</td>
<td>70.2 $\pm$ 16.5</td>
<td>65.0 $\pm$ 22.4</td>
<td>74.0 $\pm$ 18.8</td>
<td>77.1 $\pm$ 19.6</td>
</tr>
<tr>
<td>Yes (n=327)</td>
<td>74.6 $\pm$ 15.3</td>
<td>75.9 $\pm$ 17.1</td>
<td>79.2 $\pm$ 14.6</td>
<td>87.3 $\pm$ 13.5</td>
</tr>
<tr>
<td>$g$ [95% CI]</td>
<td>.28 [-.03, .60]</td>
<td>.61 [.28, .94]</td>
<td>.34 [.02, .65]</td>
<td>.71 [.39, 1.02]</td>
</tr>
<tr>
<td><strong>Intend to persist</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No (n=25)</td>
<td>60.9 $\pm$ 19.3</td>
<td>61.2 $\pm$ 21.0</td>
<td>55.1 $\pm$ 21.7</td>
<td>78.6 $\pm$ 18.9</td>
</tr>
<tr>
<td>Yes (n=350)</td>
<td>74.9 $\pm$ 14.8</td>
<td>75.6 $\pm$ 17.5</td>
<td>80.1 $\pm$ 13.4</td>
<td>86.6 $\pm$ 14.3</td>
</tr>
<tr>
<td>$g$ [95% CI]</td>
<td>.92 [.21, 1.64]</td>
<td>.81 [.15, 1.47]</td>
<td>1.77 [.98, 2.57]</td>
<td>.54 [-.15, 1.24]</td>
</tr>
</tbody>
</table>

*Note: Self-Efficacy on Research Procedures (SE-RP), Self-Efficacy on Experimental Procedures (SE-EP), Academic Self-Efficacy (A-SE), and Self-Efficacy on Computer Usage (SE-CU).*

Effect Size across Academic Related Aspects and Intention to Persist

Besides identity aspects, we also elicited information regarding student status related to key academic aspects such as having a mentor and belong to a research group. Table 3.7 presents the mean values and effect size differences in student responses on these aspects. As expected, we found large effect size differences on all four self-efficacy measures for students who have a mentor and students who belong to a research group. The highest difference between students who do and do not have a mentor is observed for academic self-efficacy ($g=.58$). The self-efficacy effect size differences are found on more technical aspects such as experimental procedures and computer usage ($g=.61$ and $.71$, respectively) for students who do belong and do not belong to a research group. Finally, when examining student self-efficacy among those who intend and do not intend to persist in their programs, we observed meaningful and large effect size differences for all four self-efficacy measures.
Discussion

Self-efficacy is established as a substantial construct within the educational context of K-12 and undergraduate education [37, 38, 39, 41, 42, 43]. However, the construct has not yet received equivalent attention in the graduate education literature. The few studies that explored the self-efficacy effect for graduate students either explored it qualitatively [46, 135] with small sample sizes or quantitatively [57, 59] across several disciplines. To better understand the persistent issues within graduate education, such as attrition and gender and racial/ethnic underrepresentation, it is important to have studies of self-efficacy focused on single disciplines with large sample sizes.

Limitations

In this work, we assessed the psychometric properties of two self-efficacy instruments in physics graduate education. Although both instruments exhibit acceptable construct validity and substantial internal consistency within this context, some limitations must be noted.

Although the overall sample size for the psychometric evaluation is considered adequate, the response rate is low (23.4%). A significant limitation is the low sample size of individual subgroups (Lat/Bl/Ind, LGBTQIA, first-generation college students), especially when we examine the intersectionality of these identities with gender. Most importantly, the response rate per program varied significantly (ranging from 11% to 66%). This shortcoming suggests that non-response bias could be present within specific departments. Moreover, we found high internal consistency for all four subscales. We should note here that the first and second components (self-efficacy on initiating a research project (SE-RP) and experimental procedures (SE-EP)) exhibited high internal consistency values above .90. Both components include a large number of items (SE-RP with 21 and SE-EP with 10). It is argued that a high internal consistency measure of above .90 might indicate that
some items are redundant [53?]. Another limitation is the lack of previous studies on STEM graduate student self-efficacy. Even by using Cohen’s [89] ambiguous benchmarks for interpreting effect sizes, we detect meaningful and large effect size differences among several demographic groups. However, we need more work to tell whether those differences are actual or overestimated due to the small sample size for specific demographic populations (e.g., Lat/bl/Ind or Asian American, women/men Lat/bl/Ind or Asian American students). Moreover, the wide CI ranges indicate that large uncertainty exists, especially for groups with smaller sample sizes, such as LGBTQIA students, which prevents us from making strong claims. Finally, we must note that most of our respondents are enrolled in large and highly ranked programs, which are not a representative sample of physics graduate students in the U.S.

Psychometric Evaluation

In this work, we adopted two self-efficacy instruments that have been designed for graduate education and have been validated across several disciplines. After adapting the research self-efficacy instrument [57] to make it more relevant for physics graduate students, and changing the 3-point scale of the academic self-efficacy [59] into the 100-point scale, we used 396 responses from physics graduate students to evaluate its psychometric properties. The ten academic self-efficacy items loaded on the same factor; thus, we retained the same name of Academic Self-Efficacy (A-SE). We identified three factors related to research self-efficacy: Self-Efficacy for Initiating a Research Project (SE-RP), Self-Efficacy for Experimental Procedures (SE-EP), and Self-Efficacy for Computer Usage (SE-CU). The four-factor solution accounted for 59.3% of the total variance in the 46-items. We found high internal consistency for all four subscales. Cronbach’s alpha values ranged from .85 to .95.
Demographics and Self-Efficacy

Using MS and Ph.D. student responses on the four retained factors, we found high mean self-efficacy beliefs ranging from 74.02 on self-efficacy on initiating research projects to 86.05 on self-efficacy for computer usage. Those high values are consistent with Bieschke et al.’s [58] findings with 177 doctoral students from a range of disciplines.

We found that a gender gap for self-efficacy exists, with men having higher self-efficacy than women/nonbinary students, with the highest effect size being for academic self-efficacy. This gap is larger for American white and Asian American students, with American white and Asian American men having higher self-efficacy on all measures than American white and Asian women/non-binary students, respectively. However, we found the opposite for Lat/bl/Ind students. Lat/bl/Ind women/nonbinary students have higher self-efficacy than Lat/bl/Ind men. The literature suggests that African American women tend to have higher self-efficacy than African American men [128, 136]. However, our Lat/bl/Ind sample consisted of 38% by Latinx/Hispanic, 17% black/African American, and 46% from students who identified with more than one race which included one of the NSF identified marginalized racial/ethnic categories. To help interpret this result, we split the Lat/bl/Ind category into gender. None of the black students included women/non-binary students; only two women/non-binary students identified as Latinas. The rest of the women/non-binary Lat/bl/Ind students were students of more than one race (which included Lat/bl/Ind). The observed difference of women/nonbinary Lat/bl/Ind with higher self-efficacy than Lat/bl/Ind men came from the latter racial group (multiracial minoritized students). In a 2008 study [109], the authors found that women and men draw on different sources for the development of their self-efficacy. Women shape their self-efficacy from social persuasions and vicarious experiences, while mastery experiences are the primary sources for men’s self-efficacy. Therefore, a qualitative approach is needed to help explain the reverse outcome across gender among majority (white, Asian American) and minoritized (Lat/bl/Ind) students’ self-efficacy.
In regards to self-efficacy differences among racial/ethnic categories, the results vary for different self-efficacy measures. American white students have higher self-efficacy than American Asian students on initiating a research project and computer usage, while Asian students have higher academic self-efficacy and self-efficacy on experimental procedures. Contrary to our hypothesis, Lat/bl/Ind reported higher self-efficacy than white students on academic self-efficacy and starting a research project. Finally, international students have higher self-efficacy than white American students on self-efficacy for initiating research projects and academic self-efficacy and lower for experimental procedures and computer usage.

Next, as expected, we found that sexual orientation status is negatively correlated with students’ self-efficacy. For example, we found a large, meaningful difference between LGBTQIA and straight students on academic self-efficacy, which refers to students’ perceived ability to cope with academic-related tasks and situations, such as completing their degree and handling stress related to graduate work. Moreover, we found meaningful differences for gender for LGBTQIA students, with LGBTQIA women having significantly lower self-efficacy than LGBTQIA men. This finding is in agreement with prior results on the experiences of LGBT physicists, which found that LGBT women face exclusionary behavior at three times the rate of LGBT men [137]. However, we must note the wide CI range, which indicates the large underlying uncertainty for this correlation. Finally, similarly to the undergraduate education literature [119, 138], we found meaningful differences for the first-generation college status. First-generation college students have lower self-efficacy than continued-generation college students on academic self-efficacy and self-efficacy on computer usage. The gender gap persists for first-generation college students and favors men on all four measures of self-efficacy.

The results of this study indicate the concerning large gender gap on student self-efficacy. The gender gap favoring men increases for students with more than one “minoritized” identity (sexual orientation, college generation status). This suggests that
intersectionality is an important aspect of one’s identity and should be considered in social research studies. We recognize that students in our sample hold additional identities (e.g., disability status) that could influence their perceived experiences due to their interaction with their environment. However, we argue that a better approach to understanding students’ experiences with multiple “minoritized” identities is through qualitative design studies.

Mentoring, Persistence, and Self-Efficacy

As expected, we found that academic-related aspects are important for shaping students’ self-efficacy. This finding aligns with a number of studies exploring the effect of mentoring on self-efficacy [121, 131]. Here, we measured whether students identify with a mentor and not the quality of mentoring. We found that students who have a mentor report higher self-efficacy across all subscales than students without a mentor. Similarly, we found that students who belong to a research group tend to have higher self-efficacy than students who do not work within a research group. This latter finding has implications for socialization aspects that may contribute to a stronger sense of efficacy through the mechanisms of vicarious experiences and social persuasion [103].

Finally, and most importantly, we found a strong indication that low self-efficacy may contribute to graduate attrition. Many studies in other education contexts found a correlation between self-efficacy and persistence [41, 42, 43, 44]; however, there is little work examining the effect of self-efficacy on STEM graduate persistence. The effect size differences between students who intend and do not intend to persist are large and meaningful across all four measures, with the greatest being for academic self-efficacy.
Implications

The self-efficacy instrument presented in this paper can be useful for department leaders and researchers. For example, department leaders could use the instrument as a diagnostic tool to understand how department support structures affect student self-efficacy. We will assess the correlation between student experiences of departmental support structures and their self-efficacy using additional data from this broad survey study in a future publication. We also call for more research to further refine this instrument and help make it more concise and efficient at the same time.

Due to the limitations noted for the two measures of self-efficacy on initiating a research project (SE-RP) and on experimental procedures (SE-EP), we recommend department leaders to show preference to the academic self-efficacy measure. The academic self-efficacy detected the large gender difference that persisted increasingly among intersectionality effects (LGBTQIA women, first-generation college women, and women of racial/ethnic groups) and persistence intentions.

Finally, the large differences between LGBTQIA and straight students’ self-efficacy urge for more research. In this study, we found that LGBTQIA women have significantly lower self-efficacy than other student demographics. There is a need to understand the experiences of LGBTQIA students at their programs and how these experiences influenced the development of students’ self-efficacy. More specifically, we suggest a qualitative study that would be useful in providing a social explanation to these results. The same research design is needed to understand the development of Lat/bl/Ind students’ self-efficacy in depth. We found that Lat/bl/Ind students’ self-efficacy is higher than white students’. The results of this study add to the unclear findings across other studies in K-12 and undergraduate literature. Our sample of Lat/bl/Ind students consisted of mainly multiracial minoritized students, Latinx/Hispanic students, and black/African American men. There is a need for an in-depth follow-up study to explore the social influences of Lat/bl/Ind students’ self-efficacy, especially of multiracial minoritized students who comprise most of our Lat/bl/Ind
sample. More importantly, further work is needed to help understand the intersectionality effects between gender and other student identities in STEM fields. As expected, self-efficacy is an important construct that can help detect cultural and departmental factors that could be the sources of these observed differences.

Conclusions

Persistent attrition and the underrepresentation of historically racially marginalized students in STEM graduate education pose the need to explore factors related to the student experience. Looking at this problem through the lenses of social cognitive theory, one should consider examining environmental factors (e.g., graduate program policies, culture), student cognitive factors (e.g., self-efficacy), and student outcome behavior (e.g., performance, persistence). In our effort to approach graduate attrition from a social cognitive theory perspective, we encountered the issue of limited and up-to-date resources for measuring STEM graduate student self-efficacy. Moreover, the literature on graduate student self-efficacy is underexplored. Therefore, in this work, we focused on validating a self-efficacy instrument based on two previously-developed instruments. Using graduate students’ responses within a single discipline (physics), we showed that the instrument resulted in four self-efficacy factors, which we used to examine demographic-related differences in students’ self-efficacy.

We found meaningful differences in self-efficacy across demographic groups. In particular, we found that women/non-binary students reported lower self-efficacy than their men counterparts. This gender gap is further exacerbated for white and Asian American students. In particular, white and Asian American women/non-binary have lower self-efficacy on all four measures. However, we found that Lat/bl/Ind women/non-binary students reported higher self-efficacy than Lat/bl/Ind men. This study found important gender differences across demographic groups. These gender differences suggest that future research should emphasize studying intersectionality effects through qualitative or mixed-methods study designs.
We also found that LGBTQIA students have lower academic self-efficacy than straight students. Similarly, first-generation college students have lower self-efficacy than continuing-generation college students on two self-efficacy measures. Moreover, we found an indication that self-efficacy is correlated with mentoring, research experience (belonging to a research group), and persistence (intention to persist). These findings add to the existing literature in other educational contexts, suggesting self-efficacy’s critical role for educational outcomes.

More studies are needed to fully understand demographic differences for graduate students and identify the underlying cultural and institutional factors that might result in those differences. We hope that our study will work as a starting point for more research focused on understanding departmental and cultural contexts that affect student self-efficacy and help identify interventions and policies that could better support student self-efficacy development.
CHAPTER IV

THE ROLE OF DEPARTMENTAL SUPPORT STRUCTURES AND SELF-EFFICACY ON PHYSICS STUDENT PERSISTENCE: AN EXAMINATION OF STUDENTS’ EXPERIENCE FROM 19 PHYSICS PROGRAMS

Abstract

Science, Technology, Engineering, and Mathematics graduate and doctoral programs experience consistently high attrition rates. Moreover, persistent disparities exist in gender and racial representation. Minoritized students have lower retention rates than white and Asian American students. To date, little work is done to understand the student experience and how it contributes to attrition or persistence. There is also a lack of information regarding the causes of demographic disparities in graduate student attrition. Past studies in this context primarily focused on student academic preparation and mentoring relationships. Although, student self-efficacy is found to be a contributing factor for undergraduate student retention, there is currently minimal research on the role of self-efficacy in STEM graduate student retention. This study uses a sociological approach under the notion that the surrounding environment influences student experiences and behavior, to understand student retention in physics graduate education. In particular, we examine the relationship between four departmental support structures (mentoring & research experience, professional development, social & academic integration, and financial support) and students’ intentions to persist. We also examine the mediating role of academic self-efficacy in this relationship. We use a mixed-method convergent design approach. We collected 396 student responses from 19 physics graduate programs across the United States, 20 follow-up semi-structured student interviews, and 9 department leadership interviews. This study presents a retention model for graduate education that shows the critical role of student socioacademic integration and self-efficacy on intention to persist. Students’ in-depth interview data corroborate this finding, supporting that a supportive social and academic environment (e.g., working with peers on coursework, socializing, communication with faculty members and mentors)
supports them in completing the program degree. However, we found that departmental leaders are unaware of the struggles students experience due to the departmental environment (increased workload, lack of socioacademic integration, discrimination) and attribute students’ decisions to leave the program to factors external to the program, such as desire for career change. The results of this study urge for cultural change towards supporting student learning and growth, improving work-life balance, and developing and maintaining healthier student-faculty relationships.

Introduction

Doctoral education literature started slowly expanding after the development of the first retention models in the undergraduate education [16, 20, 21]. Those studies started in the late 1980s and were driven by high attrition rates at the doctoral level. The general estimation of doctoral attrition across studies is reported to be around 50% [15, 30, 31, 35]. While there are annual national reports on doctoral degree completion (e.g., Survey of Earned Doctorates, [93]), there is little we know about the students who end up not completing their degrees.

Another persistent negative aspect of Science, Technology, Engineering, and Mathematics (STEM) education is the lack of gender and racial/ethnic diversity [4, 5]. In particular, women comprise about 50% of the U.S. population, however only about 20% earn doctoral degrees in physics [6]. Similarly, although students from racial/ethnic minoritized backgrounds comprise about 33% of the U.S. population [7], these students earn only 9% of the awarded doctoral STEM degrees [4].

While it was found that attrition rates differ across disciplines [30], there are no systematic data that keep track of retention and attrition rates per discipline, and most studies on graduate/doctoral retention focus across many disciplines [9, 10, 25, 72]. There is very little work focusing solely on STEM disciplines [29], and in particular, on the holistic experience of STEM students. Distinctive aspects of the nature of science departments pose
for the need to study attrition of science disciplines in particular. For example, there are distinct differences in program characteristics (e.g., financial support, work-space), student population, and faculty representation across STEM and non-STEM programs [30]. Those differences signal the need to approach doctoral attrition within single disciplines across several programs.

Several studies in this context focused on examining student factors, such as student academic preparation [2, 13]. Other studies focused on the departmental factors [10, 31], such as social isolation [25, 26, 27], lack of academic integration [10], mentoring relationships [10, 25, 32, 33, 34], and financial support [30, 35]. This study uses a sociological approach by examining the role of departmental support structures in the student experience and, in particular, in students’ persistence intentions. We test a quantitative model of graduate/doctoral retention focused in physics and follow-up with in-depth student interviews to help us better understand and interpret the model outcomes. In this study, we argue that it is the departmental environment in the form of supportive structures as perceived by students that influence persistence intentions either directly or through the mediating role of students’ academic self-efficacy. We view the role of academic self-efficacy as a mobile construct that is influenced by the environmental context [45] and reestablishes over time [46]. We should note that this study mainly focuses on doctoral programs but includes two M.S. granting institutions. Therefore, we use the term doctoral/graduate interchangeably throughout this paper.

**Literature Review**

While many studies address the phenomenon of undergraduate attrition, there is little work on the doctoral level. Although there are clear distinctions between the undergraduate and doctoral student experience, the lack of sufficient resources to consider when building the theoretical grounds of doctoral attrition leads us to consider the literature on the undergraduate level as a useful starting point. The literature on undergraduate student
retention is rich in theoretical models and empirical research, which started developing in the 1970s [17]. Later on, the few models on doctoral attrition had their foundation on the undergraduate literature on student attrition models [23, 24]). Updated comprehensive models of doctoral retention informed from current empirical studies are necessary to give proper shape to the problem area [16]. In the following paragraphs, we review previous retention models and discuss findings from the literature on the role of the key variables used in this study (departmental support structures and self-efficacy).

Retention Models

Before 1970, the primary focus of studies on retention was grounded in student psychology attempting to explain attrition through students’ characteristics and personal attributes [17, 18]. Spady [19] developed the first sociological model of student retention that shifted the focus from the student alone to the student-college interaction. Since then, several studies developed theoretical models grounded in the sociological aspects of the student experience, such as Tinto’s Institutional Departure Model [16, 20], Bean’s Student Attrition Model [21, 139, 140], and Pascarella’s Student-Faculty Informal Contact Model [22].

To date, little work exists on doctoral retention compared to the overwhelming literature on undergraduate persistence. Moreover, the few theoretical models on doctoral attrition have their roots in undergraduate models, such as Tinto’s [20]. The first model on doctoral student retention was developed by Girves & Wemmerus [23]. By adapting Spady’s [19, 141] and Tinto’s [20] models to the context of doctoral education, the authors added variables to the model that they considered essential for the graduate student experience, such as student-adviser relationship and financial support. This study used responses from 486 incoming graduate students (M.S. and Ph.D.) from 42 departments at a major Midwest university. The authors found that graduate grades have no impact on student degree progress, with performance on qualifying examinations and the ability to conduct
independent research being important predictors of degree progress. It was also found that integration (involvement in one’s program) is related to degree progress.

Another model of doctoral retention was developed by Vaquera [24]. Vaquera tested Tinto’s model after adjusting it for the context of doctoral education, aiming to examine doctoral student persistence during the earlier stages of the program. The study was conducted at a Research I-Hispanic Serving Institution. Vaquera’s study focused primarily on minority students as the target group population. The tested theory suggested that doctoral student persistence is primarily the outcome of the combination of departmental characteristics and student social and academic integration opportunities.

Departmental Support Structures

The motivation for this study was initiated from the positive outcomes of the American Physical Society-Bridge Program (APS-BP). The purpose of the APS-BP is to increase the diversity in physics graduate education by increasing the number of minoritized students. Minoritized students are invited to apply to the APS-BP and receive funding to start their graduate education at selected departments across the U.S. In parallel, to increase the chances of student success at these competitive programs, the APS-BP has a list of key recommendations that departments are asked to apply to the Bridge students, although some programs may choose to apply these practices across all enrolled students. Those recommendations include admission practices, building a physics graduate student association to promote social relationships, mentoring and advising, induction (integration practices), research engagement, monitoring student progress, resources for professional development, and practices to achieve APS-BP sustainability [48]. 79% of the 299 placed Bridge students continue to make good progress toward their degrees [49].

We developed a survey instrument to capture the APS-BP recommendations for facilitating supportive departmental structures. This instrument resulted in the Aspects of Student Experience Scale (ASES) comprising four factors, mentoring & research experience,
professional development, social & academic integration, and financial support [142]. In the following paragraphs, we review the literature on the role of the four ASES factors on graduate retention and students’ overall experience.

Mentoring & Research Experience

The definition of mentoring has long been a subject of discussion in a plethora of studies in higher education and other contexts. Review studies recognized the absence of a consistent and commonly accepted term for mentoring [e.g., 143]. For example, some studies use the term to describe a set of activities, while others a set of concepts or processes [143]. Moreover, Noonan, Ballinger, and Black [144] found that doctoral student protégés, peer mentors, and faculty mentors emphasize different aspects when defining mentoring. Protégés define mentoring as guiding, assisting, and keeping on track; peer mentors emphasize the personal relationship that acknowledges, encourages, and supports the protégé; and for faculty members mentoring is a means for facilitating, socializing, and preparing the protégé for the professional role. This finding suggests that students define mentoring in different ways as they progress toward the doctorate, as their experience and needs change [144, 145]. In a review study, Jacobi identified the common elements in which studies agree upon the definition and context of mentoring [143, 146]. That is that mentoring entails growth and accomplishment of an individual under a broad means of support (professional and career development, role modeling, and psychological support).

The student-advisor relationship is an important aspect of the student experience [32]. The mentor–mentee relationship influence a number of students’ experiences in the program (research activities, professional development, the integration to the professional field of study, and the development of students’ confidence through encouragement and praise) [25, 33, 70]. Research suggests the existence of a correlation between ineffective mentoring and attrition [e.g., 10, 147]. Moreover, it was found that mentored students
achieve higher GPA scores and have a lower dropout rate than non-mentored students [147].

Social & Academic Integration

The construct of socioacademic integration into higher education context was first introduced by Spady [19, 141] and Tinto [16, 20] and was later adopted in doctoral retention studies. Tinto [16, 20] defined academic integration in terms of students’ academic performance, level of intellectual development, and perception of having a positive experience in academic settings. Similarly, he defined social integration as students’ involvement in social activities and holding positive relationships with peers.

The early models in undergraduate retention asserted the idea that a lack of social and academic integration is correlated with attrition [19, 20]. Studies in doctoral education confirm this relationship [25, 26, 27, 28]. For example, in terms of academic integration, Golde [10] suggests that a lack of support to help less prepared students advance in the program is correlated with increased attrition. In particular, departments that supported the notion that students must catch up on their own and lacked structures to support student development were more likely to consult students who could not catch up on their own to leave the program.

Zhou & Okahana [30] found that within STEM graduate programs, providing work-space, training in writing and teaching, and having a graduate student association (indicators of socioacademic integration) are positively related to completion rates. Similarly, Ali & Kohun [26] argue that the sense of isolation, which takes place in various forms at different stages in the doctoral program, could contribute to attrition. In particular, the authors identify two issues that contribute to the development of a sense of isolation. In the first case, students may develop this feeling because of confusion about program requirements, a situation that can later transform into feeling left behind or overwhelmed. In the second case, students may lack effective communication among peers and faculty. The three contributors leading to the development of a sense of isolation are lack of communication,
miscommunication, and confusion. Moreover, the authors argue that isolation differs at different stages of the program.

**Professional Development**

Professional development refers to one’s advancement in skills, knowledge, and experience towards increasing chances of obtaining a desired job and being successful in it. Professional development in the doctoral academic setting mainly lies in the hands of the students’ advisor. However, such opportunities should be spanned across students’ experience in the program. The APS-BP identifies as professional development opportunities for the student to advance networking, time-management, presentation, mentoring skills and participation in various formal and informal training.

O’Meara et al. [73] suggest that a sense of agency over career advancement is likely to be correlated to retention. The authors found that physics students believed that they were less strategic towards achieving their career goals than students in biological sciences, engineering, and chemistry, and reported lower levels of holding agentic perspectives in their ability to conduct research than biological science students. Finally, the authors suggest five ways in which departments enabled student agency in career advancement: encouraging and legitimizing multiple career paths, providing structured opportunities for students to practice skills and experience different work environments, facilitating networking, and offering mentoring and guidance.

**Financial Support**

Financial support is another indicator of increased persistence at doctoral programs [74, 75]. Zhou & Okahana [30] identified that STEM and non-STEM programs differ in faculty characteristics in terms of research productivity (STEM faculty produce fewer and more cited publications than non-STEM faculty) and received grants (80% of STEM faculty
received grants vs. 30% of non-STEM faculty). Therefore, students within STEM programs are more likely to be financially supported and hold research assistantships than students in non-STEM fields. However, students’ life conditions influence the adequacy of any financial aid, if present. In other cases, financial assistance is uncertain, or absent [76]. Finally, the type of financial support is correlated with completion rates. Within STEM fields, a positive relationship exists between research assistantships and fellowships to completion rates and a negative relationship between teaching assistantships and completion rates [30].

Self-Efficacy

Self-efficacy is a central and pervasive mechanism of human agency that affects action [36, 45]. Self-efficacy refers to “one’s beliefs in their ability to manage their functioning and exercise control over events that affect their lives” [36]. Bandura [45] states that peoples’ daily decisions are affected by their self-judgments of personal efficacy, their exerted efforts, and their resilience in the face of obstacles and failures. Self-efficacy also influences the nature of peoples’ thought patterns (self-hindering or self-enhancing) and the stress levels they experience during their interaction with the environment.

As mentioned earlier, self-efficacy is a mobile construct that is influenced by the environmental stimuli [45] and reestablishes over time [46]. As such, self-efficacy is used in this context to understand students’ experiences in their programs. Finally, while self-efficacy is found as a significant predictor of student motivation [37], performance [38, 39, 40], and persistence [40, 41, 42, 43, 44] in the K-12 and undergraduate literature, little work exists on the role of self-efficacy in graduate education. Multon, Brown, & Lent [40] meta-analyses studies found that the effect of self-efficacy on performance and persistence outcomes varies across student types, measures, and study characteristics. Therefore, the role of self-efficacy in graduate education remains largely unknown.
Theoretical Framework

This study uses the social cognitive theory (SCT) of human behavior to guide the study design and analysis. SCT supports a model of causation for human behavior based on reciprocal causation between three constructs [36, 45, 47]. This model asserts that behavior, personal factors (e.g., cognition, self-efficacy), and environmental stimuli all influence each other bidirectionally [45]. Reciprocal causation between the constructs does not necessarily imply equal strength nor that they coincide; instead, some connections may be more robust than others, and it takes time for one construct to influence the other and activate other reciprocal influences [45].

Bandura [45] explains the reciprocal causation links between the constructs in this model. For example, the interaction link between personal factors and behavior reflects the interaction between thought, affect, and behavior. In this way, peoples’ thoughts and emotions influence their actions; in turn, the results of their actions influence how they think and feel.

The interaction link between environmental and personal factors refers to the social influences that activate ones’ internal mechanisms of thoughts and emotions through modeling, instruction, and social persuasion [45, 47]. The reverse direction of this interaction also occurs when one’s personal and physical characteristics (e.g., age, race, gender, sexuality) evoke different reactions from their social environments.

Another aspect of the SCT is the interaction between behavior and the environment. This bidirectional interaction asserts that behavior influences the environmental conditions, as the environment is not a fixed entity, but can be changed upon human actions. Bandura [45] states this interaction implies that “people are both products and producers of their environment.” The influence of the surrounding environment is activated by appropriate behavior. For example, a student would not be awarded a scholarship (reinforcing and supportive environment) unless the student applied for that scholarship (student behavior). Similarly, people shape their experienced environment through their choices and actions. In
turn, aspects of the environment determine which behavior aspects will be activated and developed. For example, one will speak and act in a friendly manner when surrounded by people who create a friendly environment, and the same person may act aggressively when being in a hostile environment.

In this study, we developed the hypothesized model in Figure 4.1 based on the triadic reciprocal deterministic model of SCT. We argue that students’ personal determinants (e.g., gender, race/ethnicity) influence their experience of departmental structures. For example, one’s identity (e.g., gender) will trigger different behavior from the departmental environment because of pre-conceived stereotypical notions around that particular identity. As such, we expect students with minoritized identities in STEM to report experiencing less supportive departments than students with majority-type identities. We also argue that these experiences of the extent of departmental support structures influence other personal and cognitive determinants (self-efficacy). We finally argue that the perceived environment of departmental structures affects students’ behavior regarding their intention to persist either directly or indirectly through the mediating role of academic self-efficacy. Using students’ interviews, our goal is to gain a deeper understanding of the influence of departmental support structures on the student experience.

More specifically, this research study aims to answer the following research questions in the context of graduate programs in physics:

1. What aspects of the graduate program are correlated with students’ intentions to persist?
2. What are the reasons that graduate students and graduate program leaders give for students’ decision to leave the program?
3. What other factors emerge as important in students’ positive and negative experiences in their graduate program?

We integrate quantitative and qualitative data to draw conclusions on understanding the graduate student experience and the aspects that contribute to persistence. Finally, in
Figure 4.1: The summary of the hypothetical model tested in this study. Student attributes include student demographic information and semester in the program; experiences of departmental supports include student responses on mentoring & research experience, professional development, social & academic integration, and financial support; self-efficacy refers to the academic self-efficacy.

Using department leaders’ interviews, we aim to gain insight into their perspectives of the students’ experiences and assess to what extent those are in accordance with emerging results from the students’ interviews.

Methods

Recruitment

In the Spring of 2019, we administered an online survey (~15-minutes via Qualtrics) that elicited participants’ demographic information, perceived experiences of departmental structures through ASES, self-efficacy, and intention to persist.

The APS-BP helped us identify a list of APS-BP sites. Using the data from the American Institute of Physics [65], we created a list of non-APS-BP sites that shared similar characteristics with the APS-BP sites (region, the number of students enrolled, rank). All the sites in the list were research-intensive physics graduate programs. We also identified the email addresses of the department chairs and the graduate advisors of those programs. The first step was to invite the chairs of those departments to participate in our study by providing
us with a list of all their graduate students’ contact information and sending their students an email encouraging them to take the survey. However, some programs that agreed to participate would not provide the list of students. In these cases, the chair/graduate advisor sent the invitation to the survey (on our behalf) and an anonymized link to the survey. The students were expected to click on the survey link to read the consent form and then decide whether they choose to participate. To help increase program participation, we promised to share a summary report (sent to the chair) of student responses to the survey and comparison data from the other programs in the study. The graduate committees could use this information to improve their practices. We contacted 60 physics graduate programs across the U.S. (sending two follow-up emails), and 20 programs agreed to participate. Among these 20 institutions, one had a low response rate (less than 5%) and was excluded from the results. At 14 departments, we contacted the students via direct personalized emails, which resulted in an average response rate of 28%. In comparison, at the remaining five departments where we contacted the students through the chair who sent the anonymized link to the survey, the corresponding response rate was 15.3%. We sent two weekly follow-up emails (direct or via the chair/graduate advisor) to increase participation.

The email invitation to students ensured the confidentiality of data responses. The average response rate from all the 19 departments is 23.4%. The obtained response rate is slightly lower than the reported rate for email/online surveys [78, 79]. Table 4.1 displays the characteristics of each department, along with the response rate. The average number of enrolled students per Ph.D. physics program is 93.3 students, while the reported national average of students enrolled at Ph.D. physics departments is 72.4 students [65].
Table 4.1: Characteristics of each of the 19 physics graduate programs.

<table>
<thead>
<tr>
<th>ID</th>
<th>Region</th>
<th>Highest degree</th>
<th>Size</th>
<th>Rank</th>
<th>Response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPT. 1</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>10.9%</td>
</tr>
<tr>
<td>DEPT. 2</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>33.6%</td>
</tr>
<tr>
<td>DEPT. 3</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>23.0%</td>
</tr>
<tr>
<td>DEPT. 4</td>
<td>West</td>
<td>M.S.</td>
<td>Medium</td>
<td>NA</td>
<td>43.4%</td>
</tr>
<tr>
<td>DEPT. 5</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>18.2%</td>
</tr>
<tr>
<td>DEPT. 6</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Small</td>
<td>NA</td>
<td>65.5%</td>
</tr>
<tr>
<td>DEPT. 7</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>High</td>
<td>30.0%</td>
</tr>
<tr>
<td>DEPT. 8</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>17.2%</td>
</tr>
<tr>
<td>DEPT. 9</td>
<td>Midwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Medium</td>
<td>23.8%</td>
</tr>
<tr>
<td>DEPT. 10</td>
<td>West</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>30.0%</td>
</tr>
<tr>
<td>DEPT. 11</td>
<td>Northeast</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>11.4%</td>
</tr>
<tr>
<td>DEPT. 12</td>
<td>South</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Low</td>
<td>16.7%</td>
</tr>
<tr>
<td>DEPT. 13</td>
<td>West</td>
<td>M.S.</td>
<td>Medium</td>
<td>NA</td>
<td>28.3%</td>
</tr>
<tr>
<td>DEPT. 14</td>
<td>South</td>
<td>Ph.D.</td>
<td>Large</td>
<td>Medium</td>
<td>17.6%</td>
</tr>
<tr>
<td>DEPT. 15</td>
<td>West</td>
<td>Ph.D.</td>
<td>Large</td>
<td>High</td>
<td>31.5%</td>
</tr>
<tr>
<td>DEPT. 16</td>
<td>West</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>High</td>
<td>26.4%</td>
</tr>
<tr>
<td>DEPT. 17</td>
<td>West</td>
<td>Ph.D.</td>
<td>Small</td>
<td>Medium</td>
<td>35.9%</td>
</tr>
<tr>
<td>DEPT. 18</td>
<td>South</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Low</td>
<td>18.0%</td>
</tr>
<tr>
<td>DEPT. 19</td>
<td>Southwest</td>
<td>Ph.D.</td>
<td>Medium</td>
<td>Medium</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

Note: The average response rate is 23.4%. The response rate is the ratio of the number of students that completed more than 90% of the survey items to the total number of students enrolled in the program. We purposefully do not disclose the exact number of students enrolled at each program to avoid program identification. The size refers to the total number of students enrolled at the program, where: a) ≤ 50: small; b) 51-100: medium; c) ≥ 101: large. Similarly, the program’s ranking is presented in the following categories: a) 1-50: high; b) 51-100: medium; c) ≥ 101: low. Information on the size of each program was obtained from the American Institute of Physics [65], and the ranking from the U.S. News & World Report [77].
Sample of Participants

Of the 396 students who completed more than 90% of the items, 86% seek a Ph.D. degree and 14% a Master’s degree. 61% of the respondents have passed the fourth semester (2nd-year) of their studies, 82.8% have a mentor, and 86.5% belong to a research group. Students were asked to type their gender. 25.4% self-identified as women (or cis-women) and 74.6% as men (or cis-men). One student self-identified as gender nonbinary. We placed the student into the women/nonbinary group because of the low sample size to have a separate gender nonbinary group and the traditionally marginalized aspect of their identity in STEM fields.

72% were U.S. citizens, while 28% were international students. Among only U.S. citizens, 54%, 8%, 2%, 6%, and 2% self-identified as racially white, Asian, black/African American, ethnically Latino/Hispanic, and with more than one race, respectively. Finally, 9% are first-generation college students, 7% are parents, and 6% identified as lesbian, gay, bisexual, transgender, queer, intersex, or asexual (LGBTQIA). According to the national data on physics graduate education of the American Institute of Physics (AIP) [65, 66, 67], students that self-identified as women are slightly over-represented in our sample (25% vs. 20%), non-US citizens are significantly underrepresented (28% vs. 43%). Among the U.S. citizens, Latinx, Black, and Native American students are also slightly over-represented in our sample (8% vs. 5.7%). 18 students identified as Latinx/Hispanic, 8 as black/African American, and 22 identified with more than one race, including one the NSF identified “minoritized” race/ethnicity in STEM.
Quantitative Measures

The quantitative data were obtained through a 15-minute-long survey that elicited students’ demographic information (e.g., gender, race/ethnicity, college-generation status, sexuality), intended degree type, the semester in the program. Students were also asked to provide their responses on a scale to elicit their experience of the departmental support structures, self-efficacy, and their intention to persist. In the following paragraphs, we describe these variables.

Aspects of Student Experience Scale

The Aspects of Student Experience Scale (ASES) was developed for the purposes of this broader study and was reported on a previous publication [142]. It is a four-factor scale including Mentoring and Research Experience (MRE) (n=11, \( \alpha = .87 \)), Professional Development (PD) (n=9, \( \alpha = .85 \)), Social and Academic Integration (SAI) (n=8, \( \alpha = .80 \)), and Financial Support (FS) (n=3, \( \alpha = .76 \)). These four factors are designed to measure students’ experience of departmental support structures on a 5-point Likert scale.

Academic Self-Efficacy

The Academic Self-efficacy scale adopted from Santiago & Einarson [59]. It is a 10-item instrument designed to measure an individual’s perceived ability to perform a series of degree-related tasks. Using the responses of the Fall 1995-96 Graduate Experience Project data of about 234 science and engineering students. While the authors used a 3-point response scale ranging from 2 for very confident, 1 for somewhat confident, and 0 for not confident at all, we modified the scale a 100-point response scale (\( \alpha = .89 \)).
Persistence Intention

We asked the respondents whether they intended to obtain their degree. In particular, students read the statement *I intend to complete my degree program*, and were asked to select their response on an ordinal five-point Likert scale.

Qualitative Data Collection

Student Participants

Interview participant selection was based on students’ survey responses. We aimed to approach three types of students: those who indicated in the survey of intention to leave the program (*neither agree nor disagree, disagree, or strongly disagree*), those who indicated experiencing low supports on the four departmental measures, and finally, Bridge students. All interviews were conducted a year after the survey completion. The interviews were video- and audio-recorded, lasted for about an hour, and were transcribed verbatim.

Based on survey responses, we approached three types of students:

1. **Student who did not intend to persist.** We aimed to understand the experiences and perspectives of these students to gain a deeper understanding of the contributing factors to their intention to leave;

2. **Student who reported experiencing low departmental supports.** We aimed to better understand what aspects of the departmental structures were perceived lacking and how this lack of certain departmental aspects influenced students’ experience at the program;

3. **Bridge students.** We wanted to understand what the Bridge program supports look like according to students and whether (or to what extent) these are important to forming students’ experiences.
Students’ survey responses on persistence intentions indicated that 27 students from Ph.D. granting institutions intended to leave the program. We contacted all 27 students, and 11 students agreed to participate in the interview. We also interviewed 4 Bridge students and 4 students who responded to experiencing low departmental supports. In protecting the confidentiality and anonymity of our participants, we assigned pseudonyms. In the extracts used in this paper, we chose to hide any information regarding unique program characteristics to avoid the risk of participant identification. Finally, before submitting the paper, we shared the manuscript with the student participants to check whether our presentation of the experiences is accurately portrayed, and whether participants felt comfortable with the level of anonymity and the assigned pseudonyms. Table 4.2 presents the student interviewees and demographic information.
Table 4.2: Student Interviewee Demographics

<table>
<thead>
<tr>
<th>Participant pseudonym</th>
<th>Persistence intention</th>
<th>Citizenship status</th>
<th>Demographics</th>
<th>Semester in the program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danny</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: white</td>
<td>4</td>
</tr>
<tr>
<td>Brianna</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Woman, Race/Eth: white, LGBT, first-gen</td>
<td>4</td>
</tr>
<tr>
<td>Michelle</td>
<td>Positive</td>
<td>Visa holder</td>
<td>Gen: Woman, Race/Eth: Asian</td>
<td>6</td>
</tr>
<tr>
<td>Tony</td>
<td>Positive</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: Hispanic/Latino, first-gen</td>
<td>2</td>
</tr>
<tr>
<td>Will</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: white</td>
<td>6</td>
</tr>
<tr>
<td>Juan</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: white</td>
<td>4</td>
</tr>
<tr>
<td>Trivaani</td>
<td>Negative</td>
<td>Visa holder</td>
<td>Gen: Woman, Race/Eth: white</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Raquib</td>
<td>Negative</td>
<td>Visa holder</td>
<td>Gen: Man, Race/Eth: Asian</td>
<td>6</td>
</tr>
<tr>
<td>Jack</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: white</td>
<td>6</td>
</tr>
<tr>
<td>Dimitri</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: white</td>
<td>2</td>
</tr>
<tr>
<td>Harry</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: white</td>
<td>2</td>
</tr>
<tr>
<td>George</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: white</td>
<td>2</td>
</tr>
<tr>
<td>Michael</td>
<td>Positive</td>
<td>Visa holder</td>
<td>Gen: Man, Race/Eth: Hispanic/Latino</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Jason</td>
<td>Positive</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: Black/African American, Bridge student</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Alkis</td>
<td>Positive</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: Hispanic/Latino, first-gen, Bridge student</td>
<td>1</td>
</tr>
<tr>
<td>Anthony</td>
<td>Negative</td>
<td>U.S. citizen</td>
<td>Gen: Non binary, Race/Eth: white, LGBT</td>
<td>2</td>
</tr>
<tr>
<td>Marc</td>
<td>Positive</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: Hispanic/Latino, American Indian/Alaska Native, white; Bridge student</td>
<td>9</td>
</tr>
<tr>
<td>Jose</td>
<td>Positive</td>
<td>U.S. citizen</td>
<td>Gen: Man, Race/Eth: Hispanic/Latino, Bridge student</td>
<td>5</td>
</tr>
</tbody>
</table>

*Note: This table shows students’ demographic information and persistence intentions as indicated in the survey. Semester in the program indicates full-time semester (Spring and Fall). In the following year, students were interviewed. Of the eleven students who indicated an intention to leave, nine students either left the program or were about to announce their decision to leave to the departments at the time of the interview (a year after the survey completion).*
In our first contact with the department leadership, we pointed out that participation in the study includes a follow-up interview at a later stage with the department leadership representative (chair, graduate advisor). We emailed the department leadership at all 19 programs asking them to participate in an hour-long interview that would be video- and audio-recorded. Nine agreed to participate. The interviews were transcribed verbatim. We also assigned pseudonyms to protect participants’ identities and avoided the use of any identifiable department characteristics.

The departments’ leaders interviews captured a wide series of topics. However, in this paper, we chose to focus on the department leaders’ themes on topics that resulted as essential from the graduate students’ interviews. We interviewed nine chairs or graduate advisors; eight were from Ph.D. granting institutions, while one was the graduate advisor of a Master’s program. This paper reports the results from only the chairs/graduate advisors of the Ph.D. granting institutions since we aim to capture the whole Ph.D. spectrum of students’ experiences and because every student interviewee was enrolled at Ph.D. granting institutions.
Interview Protocols

Initial student and department leadership interview protocols were revised after the preliminary analysis of the quantitative data. For example, the preliminary analysis indicated that students experience low support in socioacademic integration and professional development. Moreover, we found that average values of financial support were low for Ph.D. students. Therefore, we updated the interview protocols to emphasize these specific areas of the student experience.

The final student interview protocol captured students’ prior academic experience at the undergrad level and their motivation to pursue doctoral studies in physics to help us understand participants’ backgrounds. Next, we asked the students to give an overview of their experience at the doctoral program. We intended to capture emerging themes that were not necessarily included in the protocol and not direct students in a certain direction. We also asked students who decided to leave the program to describe the reasons that influenced this outcome. Next, the protocol captured themes of departmental support structures (e.g., experience with coursework, peer and faculty support, social integration, financial support, mentoring, and professional development). Finally, the protocol included questions regarding the department’s culture, support of work-life balance, students’ experience of discrimination and harassment, and mental health. The interviews ended by asking for students’ suggestions on issues that could help improve the program to better support students. The complete student interview protocol is available in Appendix B.

The department leadership interview protocol captured the program’s vision for what students ought to get from the program, admission criteria and decision-making processes, practices to support those who struggle in coursework and/or examinations, and the departments’ support structures (mentoring, integration, professional development, financial support). We also elicited leadership views on the department’s culture, how it supports students’ work-life balance, resources for mental health. Finally, the departments’ leadership was asked to reflect on the programs’ aspects that work well and those that
need improvement. The complete department leadership interview protocol is available in Appendix C.

Analytical Approach

This study used a mixed-methods convergent design approach to analyze the data [62]. As such, we separately used and analyzed students’ close-ended quantitative data (survey responses) and then collected and analyzed students’ in-depth personal students’ perspectives and experiences. We selected participants and developed aspects of the interview protocols (departmental support structures) based on the students’ quantitative responses. We also explored emerging aspects of students’ experiences and additional aspects (mental health, work-life balance) that were not included in the quantitative design. We used the qualitative data to explain and interpret the quantitative results and combined both data to draw conclusions based on the combined strengths of both data sets.

The analysis of the hypothesized model follows structural equation modeling, and the qualitative data are analyzed using thematic analysis. In the following paragraphs, we describe in detail the analytical procedure for each type of data.

Quant. Analysis: Structural Equation Modeling

We used both theory and data to inform the creation of our final structural equation model (SEM). Our initial model was based entirely off of our theoretical prediction of the relationship between the variables. We refined the model by adding or removing paths that were both consistent with our theoretical understanding of them and improved the fit of the data. We evaluated the quality of the final model’s fit holistically using five measures of fit. Our analysis was run using the Lavaan package [148] in R v4.1 [149]. Responses from 6% of the students included some amount of missing data. Full information maximum likelihood was used as the estimator and to address missing data [150].
Table 4.4: Model variables

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic variables</td>
<td></td>
</tr>
<tr>
<td>GEN Bin.: 0 -&gt; men, 1 -&gt; women</td>
<td></td>
</tr>
<tr>
<td>NW Bin.: 0 -&gt; race: white, 1 -&gt; race/eth.: non-white</td>
<td></td>
</tr>
<tr>
<td>CITZ Bin.: 0 -&gt; US citizens, 1 -&gt; visa holders</td>
<td></td>
</tr>
<tr>
<td>FGC Bin.: 0 -&gt; first-gen. college, 1 -&gt; cont.-gen. college</td>
<td></td>
</tr>
<tr>
<td>SEM Cont.: Semester that a student was in their program</td>
<td></td>
</tr>
<tr>
<td>Depart. and other variables</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>The level of support from a department</td>
</tr>
<tr>
<td>MRE</td>
<td>Cont.: Mentoring &amp; research experience</td>
</tr>
<tr>
<td>PD</td>
<td>Cont.: Professional development</td>
</tr>
<tr>
<td>SAI</td>
<td>Cont.: Social &amp; academic integration</td>
</tr>
<tr>
<td>FS</td>
<td>Cont.: Financial support</td>
</tr>
<tr>
<td>ASE</td>
<td>Cont.: Academic self-efficacy</td>
</tr>
<tr>
<td>INT Ord.:</td>
<td>Intention to complete the degree program</td>
</tr>
</tbody>
</table>

Note: One student self-identified as gender nonbinary, and we included the student into the women/nonbinary group because of the traditionally marginalized aspect of their identity in STEM fields. We also grouped together Asian American, Latinx, black, Indigenous, and bi/multiracial students into the non-white group as resulted from initial SEM analysis.

likelihood has been shown to be similarly effective in minimizing bias caused by missing data as other modern missing data techniques [151], such as multiple imputation [152, 153]. We explored creating a multi-level SEMs but we lacked the institution-level sample sizes and variations necessary for them to converge. Information about the specific variables are shown in Table 4.4. All 5 of the fit statistics indicate that the model was a strong fit for the data ($\chi^2(18)=34.375$, $p=0.011$; CFI = 0.968; TFI = 0.921; RMSEA =0.049, CI90 = (0.23, 0.74); SRMR= 0.036). The strong model fit indicated that the assumption of linearity was met. Visual inspection of q-q plots indicated that the assumption of data normality was met.

While we had not considered including the variable a priori, the construct of a supportive department emerged from the data. More specifically, social & academic integration, mentoring & research experience, and financial support were found to be covariates. This means that these three measures indicate a construct that was not a variable within the
data. We named this construct *supportive department* SD. Thus, the existence of effective social & academic integration, mentoring & research experience, and financial support are indicators of supportive departments.

Qual. Analysis: Thematic Analysis

We use thematic analysis [55] which is a qualitative method for identifying, analyzing, and reporting patterns in the data [56]. The analysis followed the six phases described by Braun and Clark [55]. These six phases are: familiarizing with data, generalizing initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. Both student and department leadership data were analyzed using thematic analysis.

Results

Model of Graduate Student Retention

Table 4.5 shows the descriptive statistics of students’ responses on the departmental support variables and academic self-efficacy. The structural equation model gives results compatible with the hypothesis of the study. We found that academic self-efficacy is an important variable in predicting students’ persistence intentions ($\beta \text{ std.}=0.477$, $p<0.001$). In
particular, we find that one standard deviation increase in academic self-efficacy leads to a 0.477 standard deviation increase in persistence intentions. We also found that social & academic integration is the only departmental support measure that directly influences persistence intentions ($\beta_{\text{std.}}=0.160$, $p<0.001$). A concerning but expected finding is that women are more likely than men to report lower academic self-efficacy ($\beta_{\text{std.}}=-0.156$, $p<0.001$).

We found that students’ experience of social & academic integration ($\beta_{\text{std.}}=0.294$, $p<0.001$) and mentoring & research experience ($\beta_{\text{std.}}=0.260$, $p<0.001$) directly influence students’ development of academic self-efficacy. Thus, we conclude that mentoring & research experience only indirectly (through academic self-efficacy) influence persistence intentions. While the total influence of social & academic integration in persistence intentions is by 50% direct and by 50% indirect (through academic self-efficacy). Financial support and professional development were not found to be predictors of persistence intentions ($\beta_{\text{std.}}=-0.069$, $p>0.05$).

The results about the model are given in Figure 4.2 and the direct and total effects are summarized in Table 4.6. We should note that Figure 4.2 is a summary of the statistically significant relationships of this model. We did not manage to obtain sufficient data of students’ prior academic preparation and academic standing recording. However, we retain these variables in the model as we deem them important in predicting student persistence and encourage future work that intends to build on this retention model to include these two variables. An expanded model including all the possible connections tested in this analysis is presented in Appendix D.

All Students were Excited and Motivated to Pursue Research in Physics

The motivation for the development of this study was driven by the assumption that doctoral students are highly motivated individuals to pursue studies in their chosen fields. The doctoral student population is also different from the undergraduate one because they have experienced an academic environment and pursued research work. Thus, they
Table 4.6: Parameter estimates resulted from SEM

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>SE/\beta</th>
<th>p</th>
<th>$\beta$ std.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dir. Effect on INT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASE</td>
<td>0.024</td>
<td>0.003</td>
<td>0.000</td>
<td>0.477</td>
</tr>
<tr>
<td>SAI</td>
<td>0.173</td>
<td>0.063</td>
<td>0.006</td>
<td>0.160</td>
</tr>
<tr>
<td><strong>Ind. Effect on INT though ASE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAI</td>
<td>0.151</td>
<td>0.032</td>
<td>0.000</td>
<td>0.140</td>
</tr>
<tr>
<td>MRE</td>
<td>0.161</td>
<td>0.031</td>
<td>0.000</td>
<td>0.147</td>
</tr>
<tr>
<td>PD</td>
<td>0.067</td>
<td>0.016</td>
<td>0.000</td>
<td>0.064</td>
</tr>
<tr>
<td>FS</td>
<td>0.014</td>
<td>0.018</td>
<td>0.442</td>
<td>0.018</td>
</tr>
<tr>
<td><strong>Tot. Effect on INT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAI</td>
<td>0.324</td>
<td>0.065</td>
<td>0.000</td>
<td>0.300</td>
</tr>
<tr>
<td>MRE</td>
<td>0.157</td>
<td>0.034</td>
<td>0.000</td>
<td>0.143</td>
</tr>
<tr>
<td>PD</td>
<td>0.079</td>
<td>0.043</td>
<td>0.065</td>
<td>0.050</td>
</tr>
<tr>
<td>FS</td>
<td>-0.052</td>
<td>0.039</td>
<td>0.177</td>
<td>-0.069</td>
</tr>
</tbody>
</table>

*Note:* The full table with every tested relationship is shown in Appendix E.

are at a decent extent familiar with the academic environment and expectations; pursuing a doctoral degree is more likely to be an informed decision than an exploration. Therefore, we hypothesized that the unexpected to the student aspects of graduate school could be behind the national high attrition rates.

Student interview data supported our hypothesis. In particular, we found that every student interviewee described their excitement and motivation to pursue research in physics, a feeling that was developed because of their positive undergraduate experience. For example, Juan describes with excitement his motivation to pursue doctoral studies in physics because of his interest in a particular research area:

*I decided to pursue [a PhD in physics], basically because I loved my research project there [at the undergraduate program]. I thought I had found that research I wanted to do for the rest of my life. It was fun to figure out new things and to basically choose my own direction. [...] There is [this research area] that I very much care about. - Juan*
Figure 4.2: The resulted retention model in graduate education. This model is the summarized version displaying only the significant relationships. The black lines indicate the effect of each variable to the other. The yellow lines indicate the three covariates of social & academic integration, mentoring & research experience, and financial support that are indicators of supportive departments. The full-version model is shown in Appendix D.
The above quotation indicates the motivation that drives students to apply to graduate programs. Similarly, Harry describes that the combination of having experienced a supportive and friendly undergraduate program and the motivation for a career in academia urged him into going after a doctoral degree in physics:

I got into the Ph.D. program because I wanted to go into academia. I had a really good experience with my undergrad degree. I really enjoyed the department. I really enjoyed the culture. I enjoyed studying physics. [...] I would say the department as a whole [encouraged me to pursue further studies in physics], in particular my advisor. My advisor was fantastic and he was very encouraging. He would do anything to try to help you achieve what you wanted. - Harry

Similar to Harry’s experience of interacting with a supportive and caring advisor, Marc, a Bridge student, describes how he loved the physics subject matter and wanted to pursue further studies, but lacked the necessary resources to guide him in the process of getting into graduate school:

I really liked math and science most of my life. [...] I like the understanding of physics and understanding of the universe. [...] I like the knowledge, I like science, getting a PhD was on my mind. [...] So I chose physics. I love the understanding. I can’t explain it, the numbers to constants, I just loved that. It is so organized. It’s so beautiful. [...] so I chose physics and eventually I just, I knew that was what I was going to, was going to happen. But I didn’t know the way. I didn’t know that I had to take my GRE to get to grad school. So even though I knew I was going to graduate, I didn’t know the steps. So like it was the spring of my graduation and I still hadn’t applied to grad school. Didn’t do the GRE. So like in my mind I was like, yeah, for sure I’m going to do this, but I didn’t do anything. - Marc

Marc becomes emotional when he starts describing the interaction with a professor at this undergraduate institution who guided him towards the APS-BP:
I was leaving campus one time and I was walking toward the physics building and we crossed (a professor and Marc), and she was like, “Hey Marc did you apply to grad school?” And now I was like, “uh, no, not really.” She’s like, “you should look into the bridge program. It’s pretty good. Like if they’ll look at your application” and I was like, “okay, I can do that.” And so I did, and it’s funny, I’m being overwhelmed by the emotions that I wasn’t going to.

These narratives of students’ experience prior starting at the graduate programs showcase the increased motivation and excitement towards physics and for pursuing a Ph.D. In particular, we saw that positive (supportive, caring, and friendly) undergraduate departments influence students’ decisions and lives. We should note that every student who left their program described similar motivation and excitement towards physics and pursuing a Ph.D. degree when graduating from their undergraduate institution. In the following paragraphs, we explore the reasons students gave for intentions to leave their studies.

Intenotions to Leave are Predictive of Leaving

Persistence intentions were predictive of actual students’ persistence decisions. We interviewed eleven students who indicated in the survey not intending to persist. In the follow-up interview a year later, nine students had either left the program or were about to make it formal by announcing their decision to their departments. Of the six interviewed students who indicated they had intended to persist on the survey, two described how at some point during their programs were determined to leave.
Reasons for Leaving the Program

We found one overarching theme that describes the reasons for leaving the program. This theme is the department culture in terms of social and academic support. In the following paragraphs, we present students’ experiences of how a lack of social & academic support influenced their progress in the program. We also show the importance of experiencing strong social & academic support for students who persisted in the program in spite of perceived academic and/or personal struggles.

Lack of social & academic support was the most common reason students gave for not persisting

Lack of social & academic support was the most common factor stated among students who did not persist. However, the importance of this aspect is also reflected in the stories of students’ who changed their mind about not persisting and those who always intended to persist, as is described later. Students perceive social & academic support mainly from their cohorts (peers) with whom they spend their time studying for coursework and socializing. Secondly, students find social & academic support from mentors who are supportive and caring about students needs (personal and academic). The reason we add lack of social & academic support under the umbrella of departmental culture is because in the cases of students who left the program, lack of social & academic support was mainly initiated by faculty members in the form of academic discrimination or lack of empathy towards students’ academic needs.

Brianna, describes her experience being at the program. She emphasizes that there was this notion that if the student needs to seek for academic assistance is not worthy being in a Ph.D. program.

*If I had to make the choice again [to go to grad school], I don’t think I would’ve gone to [this program]. Because the environment, knowing what I know now, the environment was not very supportive. And, it made it more difficult than it*
needed to be. For anybody to be successful, not just myself, it was difficult. Not necessarily just because of the content of the courses, but because of the culture around being a physics grad student at [this program]. There was very much this idea that if you needed to ask for help, you weren’t able to do it and you weren’t worthy of continuing. […] And it’s that sort of idea that if you need extra help, you’re not good enough. That makes it incredibly difficult to motivate yourself to succeed. - Brianna

Other students from Brianna’s program emphasized that the lack of social & academic support was influential in their experience as graduate students. For example, Michelle, also emphasized that the department as a whole (with one exception from a faculty member) promoted the notion that students should make it on their own without assistance. She particularly gave this example:

They [faculty members/instructors] never come and meet you to appreciate you or to ask “are you struggling?” You know, I saw many of my classmates getting dismissed from the department for low grades, for being very anxious and not showing up to the final exam, or something like that. And that is also a trauma because you feel that you could be the next one. And then in my fourth semester, I was taking a class with [this] professor. […] I went to the office hours, he tells me, “you are a grad student, you should figure it out on your own.” I felt very weird because I thought office hours were for going and asking the questions, but if you were not going to answer the questions, then why do you have office hours? – Michelle

However, in the case of Brianna, this lack of support took a discriminatory form by the instructor of the graduate course(s). According to Brianna, this professor had formed a negative impression of Brianna’s academic abilities because she was asking questions in and/or outside of the class. When Brianna asked for accommodations with her disabilities
when taking the examinations, the professor not only refused to accommodate her needs, but also mistreated her, as described below.

The main reason [I chose not to continue at the program] was because of one specific professor who I ended up having to talk to institutional equity about discrimination. I’m being treated unfairly in the classroom and that professor is on the graduate committee. So I knew that this person would never have let me continue to get my Ph.D. [...] I had accommodations through Disability Services for Students. [...] I was supposed to have permission to leave and return on tests and I ended up getting accused of cheating on the final because of taking advantage of that. [...] That’s something the university has decided is fair. And for someone to say, because of you having this accommodation, I think you’re cheating is the same thing as somebody saying, because of you having this disability, I think you’re cheating. That’s the same thing and it’s discriminatory and it’s very unfair. Then just being called out in class in a way that my peers were never called out in that way. [...] Just the getting picked on basically, and called out and getting singled out and discriminated against. I couldn’t do it. Like I couldn’t deal with that and you shouldn’t have to, no one should have to deal with that. – Brianna

In the above quotation, Brianna described how not having the social & academic support from her program, not having the liberty to seek help demotivated her to continue in the program. Moreover, later on, the notion that the department promotes in the sense that students should be able to figure the answers to their questions on their own led a professor to discriminate against Brianna’s academic abilities. In that context, the professor neglected Brianna’s accommodation needs and started tokenizing her in front of her class.

Anthony, a student from another department, shared a similar experience. When describing his overall experience at the program, Anthony described that although he expected the program to be demanding in terms of difficulty and time-commitment, the extent of the
lack of work-life balance was something he could not imagine. However, he emphasized that if he had experienced the same social network support as in his undergraduate experience, he could have handled the workload.

“*My experience at [this program] was very challenging in a lot of different ways.* Whenever you apply to graduate school and you begin in the graduate program, everyone tells you, and you think you understand, that there is nothing else like it, and that you’re going to be working more than you have ever worked before in your life and blah, blah, blah. But I didn’t really understand that until I got to [this program] and it was insane how much work they expected you to do. And it was a struggle for me to adapt to that. Certainly a struggle for me to adapt whenever there wasn’t really a support network like I had in my undergraduate. I had a support network of a lot of different professors who I felt like I could rely on during my undergraduate. That was not the case in my graduate program. Ultimately led to my decision to leave my graduate program. – Anthony

Anthony continued describing the aspects of the graduate program that led to his decision to leave the program. He mentioned that the social support that was lacking from the program was translated in a lack of empathy for students’ needs. The program was structured in a way where students had to work more than 80 hours per week and whoever could not make it on their own, they could just leave the program. Anthony emphasized that the program’s structure and the professors were disconnected from the students’ experiences.

The reason I didn’t finish my degree was because the professors were unwilling to put students’ needs first. [...] I feel like I could have handled the workload, working 80 hours a week and that is no exaggeration. I feel like I could have handled the workload if I had the support necessary, but the support didn’t exist. [...] Nobody likes working 80 hours per week, so that was something that I did not want do, but I feel like I could have done it. [...] I feel like it was more like a lack of empathy. They felt like it was a write or die situation. Like if you
could do it, if you could cut it, that was it. And you would make it through the graduate program, but if you couldn’t cut it and half the class was going to drop out, that was okay too. It was very disconnected from the students’ experiences.

– Anthony

Later on Anthony added that an aspect of the lack of social & academic support was the fact that incoming students did not had anyone to talk to (e.g., academic advisor, mentors). He emphasized that the fact that “the professors were not reaching out to students was pretty bad. [...] I feel like the support system was just completely lacking.” Moreover, as in Brianna’s case, Anthony described how his academic background was degraded from one professor (instructor of grad course(s)), which was also a contributing factor to his decision to leave. Anthony reported this experience to the equity office at his institution and was given the opportunity to be removed from this professor’s class.

I regret my decision coming to [this program]. I don’t know if would have been any different at any other university, because I think most departments in physics are filled with a bunch of jerks. It was the main decision why I left. [...] I was treated differently because I had a gap year and because I was a bit rusty, like professors absolutely treated you differently if they knew that. [...] The professor whose class I was removed from before he actually threatened me personally, he asked me what university I came from. He was like, “what university did you go to as an undergraduate?” And I was like “[the name of the program].” And he’s like, “Oh, that makes sense.” That professor was a horrible human being.

– Anthony

As mentioned earlier, the most common reason for not continuing in the program was the lack of social & academic support. We see that the lack of social & academic support is reflected in the department’s culture of urging students make it on their own (without offering assistance if needed) and from discriminatory behavior against students’ academic abilities and background. In Brianna’s and Anthony’s experiences the discriminatory be-
behavior against students’ academic abilities was performed from their instructors. However, similar behaviors were reported coming from students’ mentors. For example, Michael described how his advisor’s reactions during their meetings influenced his experience and mental health in the program.

[I felt] I’m an idiot because it [the solution] should be obvious, and this is what I gathered from my advisor’s expressions. From the yelling, from the extremely hand gesturing, you know, and that’s typically not in the beginning, but when a lot of advisors have this thing, if you’ve asked the same thing twice, that’s already kind of like you’re on thin ice, like you’re starting to look like an idiot. Whereas I think it shouldn’t be that bad that you don’t get it the first time. But so those are the kinds of experiences that like drill us, drove a lot of us to drinking a lot and others to a lot of other drugs. – Michael

Michael graduated with a Ph.D. however, he mentioned that there were several points in this journey where he was determined to leave because of the tense negative nature of his graduate experience.

Strong social & academic support can help students persist in their program

The essential role the presence of social & academic support has on students’ experiences is found in the interviews of students who changed their mind on persistence intention from the time of the survey until the interview. For example, Raquib describes a completely different departmental nature from what was described earlier. Raquib emphasized the support students were offered on the coursework from the faculty members both social and academic, as described below:

Basically he [the professor] solved like 40 to 50% of the problems in the recitation session. So he was really nice. And I know that he cares for each, every one of us because I remember, he called me to his office when I did not as good in the
midterm. And he just wanted to know, what’s going on, like why I didn’t do well, things like that. Of course I improved after that. – Raquib

Raquib was struggling with mental health ever since his undergraduate, but the stressful graduate environment exacerbated further his stress and anxiety. When Raquib was hospitalized and had to pause his progress in the program, the department made the necessary accommodations to support Raquib through this struggle. At that time Raquib had a teaching assistantship, so the department assigned another teaching assistant to cover for him and continued to financially support him until he was able to return on his position:

So I started my program in 2016, uh, fall 2016, and then all stuff went down in spring 2018 when I failed my classes. And then I got into depression, but the department is really nice. The people are kind enough to let me persist in it. I mean they try to help me out of it. They are alright with me going to a program for coping up with depression. So, I’m really grateful for them, for the department head, for the program. They’ve been really supportive along the way. 

 [...] The department was very supportive. The head of undergrad labs let me take the semester off basically, and just let me focus on my health. So I did get help. I went to a hospital with a mental health center and did a program there. [...] So I was still paid as a TA [teaching assistant], even though I was not teaching for the whole semester, so they were trying to get me to get help. That’s the level of support that they give. They didn’t pull out the funding. – Raquib

At the time of the interview, Raquib was back in his program making good progress and sounding excited about his research, and recently publishing his first journal article. Another student who initially intended to leave the program, but at the time of the interview was making good progress, was Dimitri.

Dimitri started in his program with [according to the graduate advisor] a weak academic background. The department had a practice of making recommendations to the students for taking individualized coursework plan based on their academic background
(undergraduate transcripts). This first meeting discouraged Dimitri in his ability to do well in the program because of the way that this conversation was framed. Dimitri struggled with the coursework, but early on he understood that he needs to integrate in a community of his cohort to support each other. He emphasized how the fact that he was part of this network of students, made him feel that he belonged in the department. He also joined a research group which was very supportive towards his needs:

> There were a couple people in the department who I felt very comfortable going to, to talk about things to sort of improve my understanding of material. One of those people and both of the people are [in this research group]. And so I was sort of familiar with them because I started going to group meetings just sort of becoming a part of that research environment. So when I took my first quantum midterm, I went to one of these folks in the group and I talked about it. It was like, “Hey, you know, it looks like I’m struggling here. I’m trying to figure out what are some things that I can do to sort of improve.” And so we had a conversation about that. I took away some sort of tips that could be helpful and implemented those tips. And in that sense I felt pretty supported. I felt like somebody was hearing my circles and trying to offer constructive solutions. So that was good. That’d be another faculty member in the group who would occasionally just check in and say, “Hey, how are you doing” versus “going to flip that?” So that was a really nice thing to have because I know that if there was something going on, I would be comfortable approaching her and saying, “Hey, can we talk about this?” I still have that sort of relationship with these people. – Dimitri

At the time of the interview, Dimitri was determined and very confident that he would get his Ph.D. degree. He had completed the coursework and passed the comprehensive examination. He was starting to form his dissertation committee.

The experiences of Raquib and Dimitri reinforce the argument that a strong social & academic support is influential to students’ outcomes. In particular, we see how students
with potential can turn out to leave or stay and be successful at their programs because of the support (or lack of) (psychological, academic, motivational) offered by their departments. Interestingly, we found that students who reported in the survey of not intending to persist, several of them were within certain departments. There were only a few students who were the only ones within their programs who did not intend to persist. This outcome also supports the idea that departments’ actions can alter attrition rates.

Similarly, Alkis, a Bridge student described how the perceived departmental environment and discriminatory comments from certain faculty members influenced his mental health and enforced a sense of imposter syndrome. At the same time, as a Bridge student, Alkis received mentoring from several other faculty members. During this informal mentoring environment, Alkis could talk to them about his struggles (academic, personal, social). This support was finally influential in Alkis’ persistence in the program.

It’s [graduate school] been very difficult. [...] I feel like it has definitely affected my mental health. [...] I had a lot of trouble when I was failing courses and so on. My experience in graduate school kind of enforced, some imposter syndrome mindset. It’s not to say that the whole department that there’s something wrong with the whole department, but there has been a difference in the culture in graduate school than what I perceived in undergrad. This culture makes me feel like, my worth is based upon my evaluations upon like reaching certain deadlines, performing well on tests and so on. But I see a larger problem with the department and the physics culture at large, that I was kind of, not as aware of before graduate school. – Alkis

Alkis continued describing his experience at the graduate program, in particular how being a Bridge student put him on spot of one of his instructors’ conversation about Bridge students’ academic abilities.

There’s been some conflict in terms of the bridge program at this site with some key faculty actors [...] For instance, I was getting lunch and my instructor
happened to be sitting five feet away from me. And I overheard talking about the bridge program and she said, basically, quote, that like “the people in the bridge program are at the lowest of low, that whatever comes into the program because of the bridge program, they aren’t prepared. They couldn’t get in anywhere else. So they are very weak physics students basically.” So that was a pretty strong statement and it stuck with me for years now. Just to make it clear, I mean, her viewpoint doesn’t necessarily reflect the viewpoint of the entire department, but it reflects some of the opinions held within the graduate committee culture overall.

– Alkis

However, as mentioned earlier, Alkis persistence in the program was enforced by a sense of social & academic support that he received from his mentors and advisors. He particularly stated that without their support he could not have remained in the program.

But there have been certain professors and my current research advisors that have been very supportive and helped me persist in the face of these struggles. [...] Like if I’m having difficulty with like navigating aspects of like teaching or problems with the coursework or something, I can reach out to him [mentor] also. [...] And the bridge faculty, those two professors feel like they can help, they will try to. So it’s just supposed to be a resource to start a dialogue. [...] it’s helpful for sure. It does feel like a safe space. [...] I think without them, I might have quit by now, because they’re one of the very few sources of support that I feel in the graduate program. So without it would be difficult to persist. There would just be me struggling in the dark with no one to talk to. – Alkis

In the above paragraphs, we showed how students’ quotations support that social & academic support (effective communication with faculty members and mentors, working with peers on coursework, socializing) influences students’ decision to persist. In particular, this relationship between social & academic support and persistence is supported by students who left the program and those who initially intended to leave. In particular, students who
reported experiencing a lack of social & academic support left the program. In contrast, students who were at risk of leaving while experiencing a lack of social & academic support, when that support became available, persisted by making good progress in the next steps at the programs.

As mentioned earlier, social & academic support was the most commonly stated factor for influencing students’ persistence decision. However, we also found other primary reasons that were uniquely stated by individual students. For example, Jack, mentioned that the main reason he left the program in his 7th semester was because the department lacked funding (R1 institution, highly ranked). The department hired too many students at some point and couldn’t support financially the senior ones. According to Jack, twelve other students left the program at the same time due to lack of funding. As a solution, the department forced these students to switch field of research that was incompatible with their background. Another student from a different department, Juan, also passed his comprehensive examination and started research. He reported experiencing poor mentoring and a lack of interest in the assigned research project, which was the main reason he decided to eventually leave the program.

Influential Aspects to the Student Experience

In the previous subsections, we extensively discussed the aspect of the student experience that influenced most students’ decision to leave the program, social & academic support. When talking about the social & academic support, students’ quotations showcased other essential aspects to their experience that in one way or another were linked to social & academic integration and their decision to persist. In particular, Anthony referred to the increased workload where students work around 80 hours per week; Michael and Raquib touched on the influence of the graduate school requirements and relationships with professors on their mental health. Finally, several students described experiencing discriminatory behavior by certain faculty members. Unfortunately, several graduate students widely
described these negative aspects (those who persisted and those who did not). The fact that these themes were so common across our participants, we deem it important to expand on them and bring awareness to the experience of physics graduate students.

Department culture of lack of work-life balance

Several students emphasized that the biggest struggle they encountered in their graduate programs is that the department culture supports a lack of work-life balance. Students work at least 60 hours per week (some students mentioned 70 and 80 hours), which is encouraged by the departments that also promote the notion that being a graduate student means that their life is oriented around the student role.

Tasia stated exactly the aspect that the lack of work-life balance is encouraged by the department as a whole in the way that the graduate program is structured, as shown below:

*I definitely feel like the department on the whole, [...] it feels like you should be a grad student, 24 hours, seven days a week, that that’s your priority 100% and that you don’t need a personal life. You can have a personal life when you’re not a grad student anymore. That’s, that’s kind of how I feel like the department treats its grad students.* – Tasia

Similarly, as vividly described by Michael it is the department’s expectation that the student should focus only on the graduate program and that this is the main and only priority. “[The] expectation is that your only priority in life is to finish the program and that nothing else matters to you. [...] Like you’re expected to like live, breathe and eat physics.” Anthony corroborated on this argument explaining that the department actively promotes this notion/expectation by encouraging students to work late nights:

*There was an active campaign in the department to get you to not have a work-life balance is how I would put it. One of the first things in orientation that I remember the department telling us, was that you need to go and get a key to*
the physics department because you are absolutely going to be working here after hours. I mean, I consider that to be an active campaign, to get students not to have work-life balance. [...] I don’t think a single professor told me to take time off because I was stressed. – Anthony

Finally, Michelle and Trivaani described what a graduate student with a lack of work-life looks like. They both emphasized that this aspect is reflected in students’ working all day long, skipping meals all day, and skipping socializing opportunities. Michelle in particular refers to students’ whom she observed in her department ending up not completing their degree:

For students whom I have seen failing, I know that they work for hours and hours and they skip their meals. They skip sleeping. They skip socializing moments, skip everything and just work. But they fail probably because they don’t know which direction to work. And the department judges you that you are not working enough. – Michelle

While Michelle specifically described above students’ life of those who she saw not persisting in her department, Trivaani described the most successful type of student. As shown below, Michelle’s and Trivaani’ descriptions of those students do not differ:

The most successful people in my department, one guy, like he wakes up in the morning, he eats an apple, he comes to the office, works all day, goes home, eats dinner. So he doesn’t eat all day. [...] He goes home, he eats an entire chicken and he works some more. And that’s all, that’s all his life. And there is no workplace balance. There’s just work. I don’t know a single person having a personal life along with PhD. – Trivaani

As expected, a lack of work-life does not come without consequences on one’s emotional and physical well-being. In this case, students reported that the lack of work-life balance, especially the intense workload during the first two years of coursework resulted in
mental health issues.

The structure and culture of graduate school can lead to mental health issues

Students reported that graduate school’s intense workload and competitive nature resulted in either developing or exacerbating preexisting mental health conditions, such as anxiety, depression, and panic attacks. Unfortunately, every single interviewee but two stated that their mental health had been affected negatively since they started in the graduate program. Students agreed that the aspect of graduate school that negatively affected their mental health was the coursework and the increased workload they were called to carry out. Several mentioned that constantly working 70 to 80 hours per week on problem-solving, teaching, grading, and in the end, having the feeling that they did not accomplish anything significant contributed to the development of mental health issues. In many cases, problematic student-faculty interactions added to these negative experiences that students endured. Students who at the time of the interview had left the program stated that their mental health had been significantly improved since they left.

Micheal described the graduate experience and how it contributed to his mental health issues:

One thing is that some of the courses are pretty demanding, but that’s to be expected in physics grad school. But then you pile your TA duties on top of that. So you already have a pretty full plate, but you’re expected to already be exploring research, right? Because you’re expected that at the end of year two, you will settle with an advisor. So that means that during your first two years, when you’re taking three, maybe even four courses per semester plus teaching, and going to seminars that you will find an advisor. And that means that it’s not only like, “Hey, can I start working with you?” That means you have already proven yourself to the point that they will hire you. [...] Usually [you work] more
like 60 with the expectation for getting paid only 20 hours a week to do something that’s not research. So that’s just, it’s too much. – Michael

As Michael described later, he was diagnosed with depression during the years he was in graduate school. He particularly described how these issues evolved over time and reached a point where he was not able to be functional anymore. He then started drinking a lot.

There had been some mental issues that I just had never realized were there. I guess probably like on and off throughout my life, but here is where they really just were very exacerbated. And what would have been like a mild depression. But that would let you still be functional and go to class and do your homework and go to your teaching duties and whatnot. But it very quickly became very hard to be functional. I’m in my second semester, I stopped going to class. I turned in probably about a third of homework assignments. […] I mean I developed the classic symptoms of depression that most students here have developed, which is complete apathy for what you’re doing. A complete disdain for what you’re doing, a total lack of motivation, the stuff that you were interested in. […] And I started drinking a lot, a lot, a lot. […] That was actually several of my friends that also went through that. Like a lot of us were just drunk most of the day, most of the time because we just couldn’t handle the department culture. – Michael

Unfortunately, every other student reported experiencing similar situations that negatively influenced their mental health. In many cases, students mentioned taking advantage of the university’s resources for counseling. However, there were cases where even though these opportunities existed, students reported that they were inadequate (e.g., appointments available only once in three weeks, only first session was free of charge).

There were only two students who reported that when they felt that their mental health was affected by the increased workload and stress, they immediately stopped working
prioritizing their mental health. For example, Trivaani who eventually left her program, stated:

*There are many people who really work, work and they get depressed. I usually stay away from situations like that. I ended up not working because of that. [...] The program did not affect my mental health because I did not let it affect, I did not spend more time on it than I was comfortable with. But I have seen so many people struggling with mental health in my department. So many, almost everybody. So if you definitely give yourself completely to the program and sacrifice your private life or personal life, you will face mental health challenges. I did not because I did not sacrifice my personal life.* – Trivaani

Trivaani, being an international student, struggled with the transition to a new culture and the increased workload of balancing coursework, teaching, and research. She emphasized that the stressful environment resulting from the graduate program requirements influenced her creativity and enjoyment of research. Over time, she realized that the academic environment, as portrayed by her personal experience and the faculty members’ at her department, is not the environment that would allow her to live her life in the way she wanted.

*I enjoyed research because research allowed me to explore and do free thinking, be creative, but under high stress condition, like you can be creative for like eight hours a day or something and then not be creative if you have tried to be in that zone or not. If I’m struggling to make ends meet [...] It all becomes extremely stressful and it’s not an environment that you can be creative. [...] And if I’m not enjoying it, I don’t think it’s worth it. It’s not worth the struggle. [...] I have career goals, I love research, but I also want a good future. I want to have a family, I want to be happy [...] And all the professors in the department seem unhappy and seem struggling with their lives. So I don’t want to be one of them.* – Trivaani
Maintaining mental health is essential for students’ growth and learning. As we saw earlier, an imbalance in mental health that can result from increased workload and frustration can influence students’ learning and progress in the program. But most importantly, mental health affects one’s life and happiness. As Trivaani stated above, “if I’m not enjoying it, I don’t think it’s worth it. It’s not worth the struggle.” Some students mentioned that the faculty members at their programs are not different in terms of stress and struggle and associate the disconnect between themselves (as a student body) and the professors because professors already have their problems to deal with. Students emphasize that the mental health problems that are widely observed among their peers result from the departmental culture.

Sexism and discriminatory behaviors are common in physics graduate programs

We found that sexism and discriminatory behavior against women students were present across several of the departments from which our interviewees are/were enrolled. Every woman participant reported having experienced sexist behavior in the program, and several men reported having observed and learned about sexist incidents against their women peers. The incidents reported in these interviews were conducted by the instructor(s) of the graduate courses. In particular, the sexist and discriminatory behaviors were either in the form of intensely staring at women students while making comments about their appearances or treating women students’ exams differently than men’s while making discriminatory comments against women’s academic abilities and role in physics. For example, Tasia, below described how the instructor constantly treated herself and other women students differently than their men peers:

[This professor] has been known to say very sexist things about how women are just not as good at physics as men. He never said anything directly to me, but he essentially said that like [a woman student] because she was a woman, she was not qualified to be doing physics. I know he said something similar to [another woman

131
student a couple of years ago. [...] So there were two men and three women in my cohort and consistently the three women would get worse grades than the two men on tests and homework. I mean, we’d have not identical, but very similar answers because typically we talked to each other and we worked together on these problems. [This woman student] and I have points taken away on problems that [two other men students] didn’t have points taken away. [...] And that we noticed that trend. And we definitely felt like, like if [this woman student] and I had a question, and at the same time [these two other men students] were raising their hand; we, women tended to get passed over for one of the men. So if she [or I] had a question, sometimes [we] would just write it down and give it to [a man student] to ask for us just because it was the only way to get like a civil answer sometimes. – Tasia

Other women and men students from the same department corroborated Tasia’s quotation. This particular, professor often exhibited sexist and discriminatory behavior against the women students to a point where the students (women and men) reported him to the department’s chair but nothing came out since this discriminatory sexist behavior continued. Then students reported the professor’s behavior to the institutional equity office.

Michael, described another form of sexist behavior where a professor would constantly make inappropriate comments to women students:

He’s [the professor] an extremely extroverted a person that just doesn’t really care about any social norms at all. And so he would normally make female students feel very uncomfortable. [...] [He would] like stare [them] way too long. Look up and down or sometimes even just comment on their bodies or something like to that very direct extent. [...] So what would happen is that for incoming female students, the other female students would like kind of take them [incoming students] aside and tell them like, you know, look out for this professor, you know, listen to that. – Michael
Instances as the ones described by Tasia and Michael were experienced by several graduate students’ participants. Michelle vividly described her interaction with a professor when she failed the first attempt on the comprehensive examination and went to seek for assistance to increase her chances in succeeding on the second attempt. Below she described the dialogue between the two:

“At the time there were only three or four chapters. But right now I’m supposed to learn like 32 chapters. It’s difficult. Can you please help me?” And he’s like, “it’s always difficult and plus you are a woman, you know?” And I was like, “what?” And I’m like, “yeah, I know I’m a woman and it could be difficult, but I just want to try. Can you please help me?” And he then points out that I’m from India, [...] I don’t know what he actually meant it, but to me it sounded like he was judging that people from India are weak and cannot do it or something. And I was like, “it’s the matter of interest and passion and willingness to do and willingness to learn. And that should not matter whether I’m a male or a female or I’m from Asia or I’m from America or somewhere else.” And it was very very traumatizing. [...] But they were very non-supportive. [...] I’ve seen some male students suffering and dropping out, but I’ve seen every, pay attention to this word, every female student in the department suffering. – Michelle

Michelle’s quotation above emphasized the impact that key faculty members’ mind-sets have on students. In particular, in this department, the professor-instructor of the graduate course(s) exhibits sexist behavior against the women students at a point where Michelle said: “I’ve seen some male students suffering and dropping out, but I’ve seen every, pay attention to this word, every female student in the department suffering.”
Structures for Social & Academic Support

The interviews with departments’ leadership across the eight Ph.D. granting institutions indicate that there is heterogeneity to some extent in the practices that the departments’ organize to support students’ socialization and academic progress. These differences mainly lie among APS-BP affiliated and non-affiliated programs. The APS-BP affiliated programs have more formal structures to support students’ social and academic integration. While every program reported having orientation sessions for incoming students, the bridge affiliated programs also match incoming with senior students such that senior mentors provide mentoring and guidance to the newcomers. The bridge affiliated programs also reported having graduate student associations, offering communal spaces where students (and in some cases faculty members) get frequently together. Finally, some programs (both bridge- and non-bridge affiliated) hold teaching assistant (TA) training and provide resources for TA mentoring.

In terms of specifically academic support, we found a greater heterogeneity among the graduate programs in our dataset. We found that some programs offer recitation sessions related to homework and preparing students for the comprehensive/qualifying examinations, where in some of these programs these sessions are facilitated by senior students and in other by faculty members. For example, Morgan below described this formal departmental structure in assisting students with the coursework requirements:

We have those recitations and for each course there’s some recitation for problem solving. Some as the senior students help with the problem solving. [...] Some professors worked with the students to prepare them the qualifier. So there is plenty of mentoring. – Morgan

In one particular program, students were struggling with coursework and the general graduate student duties. As described by Maria, one graduate student wrote a letter to
the department leadership explaining the struggle students face with the transition and adjustment to the program and its intense requirements. In particular, Maria stated: “So that was what we were doing, in reaction to there was actually a very excellent heartfelt letter by one of the students. We had a town hall meeting, and one of the students couldn’t make it, but he wrote a very heartfelt letter, which another student read, which talked about his experience as a first-year student and the stresses that he had been under. And I mean, we listened to that one.” As later described by Maria, that letter initiated a whole discussion within the program that led to several reforms (at the time of the interview, the program was undergoing these reforms). As shown in Maria’s quotation below, in response to students’ stress caused by the intense coursework load and to ease the transition into the program, the department offered socializing opportunities to incoming students by offering a common area and replaced one of the core courses in the first quarter with a pedagogy course.

The students in particular said that the first quarter was exceedingly difficult for them because they come in, they have a GTA, they have to teach, they have to find an apartment. They have to adapt to a new town. And then they’re taking three very difficult courses at once. So one of the things we started doing was putting all this first year students in an office together. So they at least had a support system. They had been in two person offices in somewhat socially isolated. We require that they come to the colloquia and we serve food before that. So that there’s a place for people to meet and talk to each other with the speaker before the colloquium. [...] And so one of the things we’re doing is we’re replacing one of the first quarter graduate courses with essentially a pedagogy class. [...] And we hope that we’ll integrate them more into the department. – Maria

Later, Maria continued describing how it is difficult for the old generation of faculty members who made it through the old system (which offered limited integration and social support) to think of new ways to support students and effectively adapt and implement them. She emphasized the importance of initiating this open student-faculty conversation
Faculty Perspectives on Student Attrition

Students’ interview results showed that the most common reason for students’ departure from the program was the departmental culture regarding the lack of social and academic support. However, departments’ leadership attributed students’ attrition to student personal factors. For example, Noah stated that students at his department usually leave because they find another career interest besides physics.

What happens is in a few years in, they decided they want to do something else. Like my TA at present, he’s decided he doesn’t want to do physics. He wants to go to law school. [...] I was gonna say that sometimes they say, “Oh, I’ve got this really great opportunity in this company in industry. Um, I don’t want to be hanging around on this pathetic paper for some years.” – Noah

Other commonly stated reason was students’ weak performance on the qualifying examinations and/or the core courses. For example, Morgan stated: “[The reason students do not obtain a Ph.D.] is the qualifier exam. Or if they didn’t perform in the core courses.” These two reasons – change of career interest and weak performance on academic requirements – were the reasons to which departments’ leadership attributed student attrition. As noted earlier, we also encountered students who left for personal reasons. For example, not finding interest in the research project (also stated poor mentoring relationship) and one student who left because he failed in the comprehensive examination. However, most of our participants stated reasons related to the departmental culture.
Supporting Work-Life Balance

In students’ interviews, we saw them emphasize the lack of work-life balance and how the department culture pushes towards focusing mainly on the graduate student role, neglecting other aspects of one’s life. Department leaderships’ interviews corroborate this notion. Several chairs/graduate advisors stated that the students’ main priority should be centered around working on research. In particular, Morgan stated that he (as a research advisor) encourages his students to view their graduate work as an investment for the future. The more students work during these years, the higher chances for obtaining a job after graduation:

*We require students to work 20 hours, but we tell them that 20 hours are not enough to do a Ph.D., you have to work more. And it depends on the faculty. Personally, [my students] should know what to do and how much effort they should put and without any pressure from anyone that, “Oh, you’re not working.” Now they’re building their feet. That’s what I tell my students. “You’re putting money in the bank, right? [The more] you put in the bank, the more return you will get later. If you want to work and get two papers in your Ph.D., you will have hard time finding a job. If you want to work harder and get seven or eight papers, everybody would want to hire you. [...] You want to be one of the competitive people. You have to decide how much you want. You should be pushing me to go through the papers that you write and make it, ‘Oh, we’re not moving fast and publishing these papers.’ Not me pushing [you].” – Morgan*

Along the same lines, Jason stated that while the department culture around work-life balance sends the message of only work unless “you’re sleeping or eating,” there is an understanding for students who ask for accommodations to balance their lives better. Jason specifically stated that such accommodations usually apply to students who have families.

*Our current chair actually talks about it [work-life balance] a lot. So that’s more of there is understanding, I wouldn’t necessarily say it’s built into the cul-


ture. I would say the culture is kind of “focus on research sort of, unless you’re sleeping or eating.” […] I wouldn’t say it’s built into the culture necessarily, but I’m not aware of a problem. […] I do think there is enough consciousness about it. If a student is willing to say that they don’t feel that their life is balanced enough and they need to make some adjustments. I do think there is enough understanding to allow for that. – Jason

Finally, Keith emphasized that student work-life balance is heavily dependent upon the advisor’s mentality. The department has no control over what advisors communicate to their students and the workload they require from them.

*Students have their research advisors and research advisors can be all kinds of research advisors. They’re the ones that treat the students really harshly. They would, if you work 60 hours –you’re not working enough- type of advisors. And there are more understanding advisors. There are advisors who would leave you alone. And of course we have no control over that, so every advisor has the group, has their subculture, but we do try to come up with excuses to bring our students for social activities.* - Keith

As shown above and from students’ interviews, we found that the culture around work-life balance is unhealthy, promoting an unreasonably increased workload on students’ shoulders. While the departments’ leadership mainly emphasized the aspect of research that students should be focusing on, we saw that students also add in the picture the increased workload during the first two years of coursework. In many cases, this was the most challenging time in the graduate program. Overall, the situation of working around 60 hours a week in a competitive environment lasts at least five years of the students’ experience (assuming students graduate at the shortest time to degree).
Resources for Mental Health

As we saw in students’ interviews, every student but two mentioned that they struggled with mental health issues. However, everybody stated that it is an important problem at their programs since most of their peers also experience the struggle. Moreover, it is essential to note that every single department leader stated that students’ mental health issues are an ongoing problem at their programs. The agreement among all the participants (students and department leaders) indicates that mental health issues are present at graduate programs. Noah’s quotation below showed the extent of this issue:

Oh, tell me about it. [Sighs] My wife’s a psychologist and I think I see more of the seriously mentally ill than she does. [Sighs] [...] We refer them to the appropriate services in the university. I try help them as best I can, like leaves of absence, whatever it takes. [...] Sometimes you just don’t get to hear of it until it’s too late. Last year we had a suicide from a graduate student. Other times I’ve had students who have been so worried when they come in. During a meeting, I’ve had a policeman in the room next door. I mean, that’s in the whole range. I just say that every one or two of them might have mental health issues. [...] The guy who committed suicide, it was just happened suddenly. It wasn’t really his advisor. He was doing research with a very easygoing faculty member. I mean, just wasn’t showing up. And so she kind of asked, where was he, what was he doing? And then he was supposed to be going to his classes, and he hadn’t been shown for up for one or two of them. So we thought we should send somebody to do a wellness check. And that’s when he was found. – Noah

Noah and Stavros (as shown below) as well as other department leaders showed awareness of students’ struggle with mental health issues. As Stavros described below the department called the health services to educate faculty members on how to recognize such problems and be aware of appropriate ways to respond.
I’ve been pretty surprised in recent years as that [mental health issues] have become more and more and more of an issue. I assume that 10 years ago we were just completely oblivious to it. We’d notice it when it was severe enough that a student sort of drop off the face of the earth and we’d have to hunt them down and find out what’s wrong. But even now I’ve talked with our college and I’ve had people from health services come to faculty meetings to try to help us as faculty recognize problems and be equipped with how to respond. We’ve had instances of suicide watch of students as sometimes as even involved undergraduates, not just graduate students. We know the way we usually find out about problems is somebody overhears, someone say something in desperation or says something that alarms us. [...] We then contact health services. Occasionally we’ve had to contact police if somebody told us something that concerned us enough. [...] So the students that you work with closely every day those are the faculty members that are usually in best position to notice when something’s wrong. And when they do what they usually do is they come talk to me. – Stavros

Although, as mentioned earlier, there is a wide and clear agreement that mental health issues are an important ongoing problem at every department, the approach to support students seemed disconnected between department leaders and students. While department leaders focus on helping students with existing mental health issues, none mentioned ways to prevent them. This argument particularly lies in the fact that students attributed the development or exacerbation of preexisting mental health issues to the stress and pressure caused by the structure of their graduate programs, especially during the two years of coursework. On the other hand, some department leaders attributed students’ mental health to personal reasons (e.g., family relationships).
Discussion

This study aimed to provide an understanding of the reasons that contribute to physics graduate students’ persistence and aspects of their experience in their programs. We used a mixed methods convergent design approach by first collecting quantitative student data to test a hypothesized retention model. Then we gained a deeper understanding of students’ experiences through their interviews. In particular, the interviews explored emergent aspects of students’ experiences, elicited their experiences of key departmental support structures, their mental health, and work-life balance. Finally, we used department leaders’ interviews to understand their perspectives on aspects that contributed to the student experience.

In the following paragraphs, we first note important limitations that could have influenced the study results. We then combine quantitative and qualitative results to interpret the results of this study.

Limitations

In this work, we collected and analyzed student survey responses and interview data. However, before we draw conclusions on the results to the research questions, some limitations must be noted.

The average response rate is low, although typical for survey administration. However, a larger concern is the large fluctuation in students’ response rates among various departments. This outcome suggests a response bias where students from certain programs are more likely than others to participate in our study. An implication of this potential limitation could be reflected in students’ survey responses of persistence intentions. More specifically, we found that 27 students expressed concerns about not completing their degree. 14 of these were enrolled at 2 programs (8 students in one and 6 in the other). Students’ interviews also indicated that certain programs (besides these two) have high attrition rates.
As noted in the results section, one student mentioned that 12 students left the program within a year because of funding cuts and lack of departmental support, but only 3 who intended to leave took the survey and one accepted the invitation to the interview. This leads to the following two rationales. First, although intention persistence predicted actual persistence (or attrition), our records of students’ intending to leave the program are an underestimate of the actual departmental attrition records. Second, different programs contribute at varying extent to the average national attrition rates. Some programs have significantly higher attrition rates than others (in our study this was independent of rank and department size). This is also supported by the department leaders’ interviews who report significant fluctuations in attrition rates across programs.

Moreover, although we intentionally chose to select programs with certain characteristics (large programs in terms of size and rank), the range of programs included is not representative of Ph.D. programs in the country. Moreover, we consider non-response bias for students who were concerned about the possibility of identity exposure. These students may have avoided to share negative aspects of their experience (either on the survey and/or the interviews) in light of concerns about identity exposure.

The response rate from department leaders to participate in the follow-up interviews is low (9/19), given the fact that they agreed to participate in a follow-up interview by having their program be part of the study. Department leaders were invited for the interviews during the Spring semester of 2020. The invitations started in early Spring, paused during the peak of the COVID-19 pandemic (around March to mid-April), and continued until the end of the semester. We sent up to reminder emails as was accounted from the initial study design and the IRB approval. Moreover, while inviting department leaders to participate in the interviews, we also asked for students’ academic records (undergraduate GPA, GRE, and graduate GPA). (We had obtained approval from the IRB and students’ consent to access these records. Moreover, this information about later requests of these records were included in the first contact with department leaders as part of the study.
design.) However, only four department leaders provided us with these records, resulting in a very small sample size. Therefore, we did not include these data in the retention model as was initially planned. This lack of department leader participation and access to students’ academic records, most likely was a result of the pandemic and the resulted implications.

Why Students do not Persist?

This study examined the reasons that influence students’ persistence by testing a retention model based on students’ survey responses and following-up with in-depth interviews of students’ perspectives and experiences. We designed this study under the hypothesis that departmental support structures influence students’ persistence intentions. Our quantitative and qualitative results are in accordance with each other and partially support our initial hypothesis.

Retention Model

We found that the social & academic integration was the only departmental support structure that was a direct predictor of persistence intentions. Consistent with our hypothesis and prior undergraduate literature, self-efficacy was a strong predictor of persistence (intentions) [40, 41, 42, 43, 44]. However, we found that women are significantly more likely to report lower academic self-efficacy than men. We also found that both social & academic integration and mentoring & research experience indirectly influenced persistence intentions through academic self-efficacy. We found that financial support was not a predictor of self-efficacy or persistence intentions. However, financial support was found in our qualitative data to be important for student persistence. Most physics graduate programs provide financial support to students, however some departments struggled with providing this support. In these programs, students discontinued their studies. Finally, the three variables of social & academic support, mentoring & research experience, and financial support were
indicators of supportive departments.

Students’ In depth Perspectives

Students’ interview data corroborated the quantitative findings that social & academic support is a critical aspect of the student experience that influences their persistence. In particular, we found evidence that suggests that students who experience a lack of social & academic support (inapproachable faculty members, intense workload, working in isolation) tend to leave the program without completing their intended degree. We should note here that in our results, we specifically found that social & academic support is critical during the first two years of coursework. The adverse outcomes on students’ experiences from a lack of social & academic support are exacerbated when they are unfamiliar with the graduate school requirements, the transition to a new place, and the intense workload (balancing graduate assistantship, coursework, and sometimes research).

Although we also found students who cited other reasons for their decision to leave the program (lack of interest in the research project, weak performance on coursework), those were stated by only a few participants. Lack of interest in the research project was also associated with poor student-mentor relationships. Regarding poor performance on coursework or comprehensive examination, we found it is an aspect that is influenced by social & academic support. Students who left the program because they failed on the comprehensive examination also experienced a lack of social & academic support. On the other hand, the two students who intended to leave due to poor performance on coursework, a year later, when they found a support network (especially from faculty members and department leaders) managed to catch up, do well on their coursework, and passed the comprehensive examination.

Another important note is that department leaders only stated two reasons for students’ attrition – poor performance and personal reasons (family- or career interests). We believe that students who leave for personal reasons are more likely to communicate to fac-
ulty members why they leave. Students who leave because of the negative experience or lack of support from their program are significantly less likely to express these reasons to the faculty members.

In weaving together our qualitative and quantitative data, we can conclude that social & academic support is the most important aspect of students’ experience that influences their decision to stay in the program. Social & academic support can also influence students’ academic self-efficacy (the beliefs of their abilities to perform academic-related tasks), which influences students’ persistence.

Aspects of the Student Experience

Two other critical aspects of the students’ experiences were found to be a lack of work-life balance and mental health problems. Students emphasized that they work more than 60 hours a week, focusing on teaching, completing the coursework and meeting deadlines, and sometimes trying to progress their research projects. This lifestyle results in only focusing on the graduate program’s requirements neglecting any other aspects of personal or social life. The lack of work-life balance is also part of the departmental culture. Many students and faculty members mentioned that mentors expect students to work more than 60 hours a week to increase their chances of finding a job after graduation. When discussed work-life balance, the department leaders focused on the time that students are primarily involved in research. On the other hand, every student mentioned that the lack of work-life balance starts from the first day in the program and reaches a peak during the first two years (when taking the coursework).

The lack of work-life balance and the intense workload was the reason that student cited as negatively influencing their mental health. Unfortunately, every single graduate student talked about how their mental health worsened since they started in the program. The only two students who stated that they had a mechanism to prevent that made a step back from work until they felt better. Department leaders corroborate that mental health
is an ongoing and severe matter in their graduate programs, citing several heartbreaking incidents. As a response, department leaders are taking steps to help identify students who struggle and direct them to the appropriate resources. Some leaders cited personal reasons behind students’ mental health (family or personal relationships). On the other hand, every student cited the lack of work-life balance and intense workload as the primary reasons which either developed or exacerbated preexisting mental health conditions.

Finally, we found that students reported several incidents of sexist and discriminatory behavior against women students. These types of behaviors were performed mainly by one of the graduate course instructors.

Implications for Practice and Research

Practice

The results of the present study indicate that physics departments need to shift their departmental structures and cultures towards supporting graduate students’ learning, growth, and well-being. More specifically, departments need to develop concrete and formal departmental social and academic support structures and shift faculty members’ perspectives for working with students (either on coursework and research) to support student success. Below, we elaborate, suggesting specific initiatives. Every recommendation point resulted from students’ interviews. The following first four recommendations are also consistent with the APS-BP to better help support students (practices for social & academic integration and mentoring).

1. *Supporting student academic progress.* We found that one of the largest students’ struggles involved a lack of support to cope with the coursework. We encourage department leaders to develop a climate that promotes and supports student learning and growth rather than forcing students to continually prove that they deserve to be
in the program. For example, offer formal recitation sessions for core courses that are facilitated by senior graduate students.

2. **Supporting student daily socialization.** Students’ socialization was found to be an important aspect of their integration in the program. We found that socialization opportunities helped develop a support network that supported students cope with the degree requirements (e.g., coursework). Moreover, socialization was an essential aspect in supporting student work-life balance. We encourage departments to create a communal space to promote daily student socialization. Encourage daily lunch and/or coffee break times in the communal space. Assign an individual (staff, faculty member, senior students) to organize weekly socializing events. Students are unlikely to consider events that take place on a rare basis as socializing opportunities (e.g., potluck, which takes place twice a year).

3. **Supporting student-faculty communication.** We found that department leaders are largely unaware of students’ struggles and the reasons that lead them to depart. We encourage department leader to design and incorporate practices to create a safe environment where students are welcomed to communicate (formally or informally) their concerns and struggles to the department leaders or trusted faculty members, as well as have the university student union conduct exit student interviews.

4. **Peer mentoring.** Mentoring is found to increase to student self-efficacy and in turn persistence intentions. We encourage department leaders to assigned a peer mentor (e.g., a senior graduate student) to each incoming student from the first day in the program. Evaluate peer mentoring (mentees evaluate mentors) and create incentives for effective peer mentoring (e.g., peer mentoring award at the end of the year).

5. **Supporting student work-life balance.** Every interviewee reported experiencing a lack of work-life balance. Students’ suggested that faculty members promote the notion that student life must solely revolve around the student role. Students also associ-
ated the lack of work-life with experiencing mental health programs. We encourage departments to educate faculty members on the struggles and concerns students report experiencing. Help promote the development of a shared understanding among the faculty members that prioritizes students’ psychosocial well-being. Promote the practice/policy of expecting students to have some leisure time.

6. Consider instructors’ approach to diversity and equity. Students’ widely reported discriminatory and sexist behavior from instructors towards women students. We recommend department leaders to carefully assign instructors to core courses considering their approach of respect to diversity and inclusion, as well as offering training in diversity and equity for faculty members at the department. In most cases, the instructor of the core courses is the department representative to the graduate student. When taking the coursework, students interact and depend on the instructor (academically and psychologically). It is important that students and instructors develop a respectful interaction.

7. Consider instructors’ pedagogical approach and/or training. We asked students to recommend intervention that could improve their departments in better supporting students. Several students pointed out the need to have instructors in the core courses with good pedagogical skills and interest in teaching. Many students stated that the level of teaching skills and interest they received declined significantly from their undergraduate experience since graduate course instructors are mainly focused on their research, neglecting their teaching approach and effectiveness. Therefore, we recommend department leaders to carefully choose instructors for core courses considering their pedagogical approach to teaching graduate students and offer training focused on teaching and pedagogy for faculty members at the departments.

Such reforms, as recommended above, require work-power, time, and resources. Such large-scale changes should be approached holistically, including faculty members, administrators, and students. We avoid suggesting ways to approach such large-scale changes
that include multiple stakeholders and aim for sustained reforms. There is literature on institutional change that should be the appropriate direction that interested parties should look into.

Research

Our results suggests future work on graduate retention to approach the subject matter using mixed methods design. In particular, we find that besides the benefits of using mixed methods to comprehensively interpret the results, a mixed-methods design helps identify students’ persistence intentions. One of the most challenging aspects of retention studies is identifying and contacting students who discontinued their programs. The use of surveys can be useful in identifying students’ intentions, and follow-up interviews can be used to elicit their experiences and their reasons to leave the program. Next, we call for more studies to use a sociological approach (focusing on the surrounding environment) to investigate retention in other STEM programs focusing on a single discipline across multiple programs. It is worth examining whether students in other STEM disciplines experience similar structures and climate at their programs or if the results of this study are particular (or more intense) in physics graduate programs. Finally, we invite future research to adapt the expectancy-value theory in shaping the design and interpretation of the results. We see that expectancy-value theory is an suitable approach in analyzing students’ qualitative data of their experience at their programs. Finally, as mentioned earlier, self-efficacy is a significant predictor of persistence intentions, however, women students are more likely to have significantly lower self-efficacy than men students. The reported discriminatory and sexist behavior towards women students could be correlated with lower self-efficacy. Students self-efficacy was captured as a snapshot of their experience at the program. It is worth looking further into how women students’ self-efficacy evolves at different stages in the program (before starting, during the coursework years, progress towards dissertation)
and understand what particular factors contribute to this outcome.

Conclusions

Graduate attrition is a persistent problem in higher education that negatively affects students and institutions. Although students exert an overwhelming amount of time and resources to get accepted into graduate programs, some aspects during their experience at the program contribute to their premature departure from the program.

Graduate retention studies started more than 30 years ago; however, our understanding of the reasons behind attrition was limited for two main reasons – it is very difficult to track students who left and elicit the reasons that contributed to their departure and prior studies focused across several disciplines with distinct characteristics [30] making difficult to identify program elements that influence student experience. The present study used a sociological approach to understand what and how program characteristics influence students’ experience and retention. We found that the most critical aspect is the lack of social & academic support. This finding is in agreement with prior studies that suggest that social isolation and lack of academic integration are related to attrition [10, 25, 26, 27]. Using students’ perspectives, we highlighted how this lack of support looks specifically in physics graduate programs. We also found that students reported experiencing a lack of work-life balance that resulted in mental health problems. Moreover, department leaders corroborated students’ reports that mental health problems are a significant and ongoing issue at their programs. Department leaders focused on identifying early students who struggle with mental health to direct them to the appropriate resources. Still, there was no mention on taking action to help prevent the development of mental health problems. The results of this study suggest an immediate need for change in departmental culture that revolves around supporting students’ learning, growth, and well-being. There is a need for a parallel reform to graduate program requirements and structure with improving the department climate towards a shift from work-focused to well-being-focused priorities.
CHAPTER V
CONCLUSIONS

This dissertation aimed in contributing towards our understanding of doctoral attrition from the lens of the social cognitive theory. In particular, our approach was to understand departmental-related contexts that influence the graduate student experience and cognitive factors that shape student persistence intentions. In doing so, we encountered a lack of validated instruments to measure students’ experience of departmental support structures. We also identified that there is a lack of up-to-date validate instruments of student self-efficacy in STEM graduate education. The first two articles of this dissertation focused in addressing these limitations. Finally, using the developed Aspects of Student Experience Scale (ASES) and the validated academic self-efficacy measure, we tested a model of graduate retention and used in-depth student and department leadership data to gain further insight into the student experience and how departments can support student progress and success in the program. In the following paragraphs, we summarize the main findings of each article and discuss how these results contribute to the literature. Moreover, we discuss the limitations and future research direction.

Summary of Findings

The development and validation of the psychometric properties of the ASES instrument showed that the instrument is comprised of four ASES components mentoring & research experience, professional development, social & academic integration, and financial support and exhibited acceptable construct validity and substantial internal consistency. The structural equation modeling analysis in Article 3, further suggested that the components of mentoring & research experience, social & academic integration, and financial support are covariates, meaning that these measures indicate the extent of a supportive department.

In Article 2, we adopted two self-efficacy instruments [57, 59] that have been designed for graduate education and have been validated across several disciplines. The psychometric
evaluation indicated four factors *self-efficacy for initiating a research project, self-efficacy for experimental procedures, academic self-efficacy,* and *self-efficacy for computer usage*. Similarly to the ASES, the self-efficacy measures exhibited acceptable construct and substantial internal consistency.

The primary goal of the present dissertation was to test of hypothesized model of graduate retention and explore students’ experience and reasons that contributed to their decision to depart. The structural equation modeling of the retention model partially confirmed our hypothesis. We found that academic self-efficacy is an important variable in predicting students’ persistence intentions. We also found that social & academic integration is the only departmental support measure that directly influenced persistence intentions. We also found that students’ experience of social & academic integration and mentoring & research experience indirectly influenced persistence intention through the mediating role of academic self-efficacy. Financial support and professional development did not predict persistence intentions.

Student in-depth interview data are consistent with the results of the retention model. First, we must note that intention to leave the program predicted actual attrition. Next, we found that the lack of social & academic support was the most common reason students gave for not persisting and that a strong social & academic support helped students persist in their program. A lack of social & academic support was evident to students through inapproachable faculty members, intense workload, and working in isolation. Other influential aspects of student experience (not directly related to persistence) were lack of work-life balance and mental health. Students reported that they work (and are encouraged by the departmental culture to work) more than 60 hours per week. They described that their lives revolved around meeting program requirements, essentially neglecting any personal or social aspects. Every student also stated that this lack of work-life balance, intense stress posed by meeting deadlines, and increased workload resulted in the development or exacerbation of preexisting mental health issues. The extent of the phenomenon of student mental health is
also described by the department leaders. In summary, according to students, the graduate program requirements (as designed) and the departmental climate encourage students’ lack of work-life balance. Finally, we found that sexism and discriminatory behaviors are common in physics graduate programs.

As mentioned earlier, academic self-efficacy resulted from the structural equation modeling as a significant predictor of intention persistence. In particular, the effect size between students who intend and do not intend to persist is large and meaningful suggesting that students with higher self-efficacy are more likely to intent to persist than students with lower self-efficacy.

The strong and meaningful effect of academic self-efficacy on persistence intentions poses a concern about the development of women students’ self-efficacy. In examining demographic differences in student self-efficacy, we found that a gender gap for self-efficacy exists, with men having higher self-efficacy than women/nonbinary students. This gap is further exacerbated in favor of men of white and Asian American descents, but the opposite existed for students from racial/ethnic minoritized backgrounds. Racially/ethnically minoritized women students have higher self-efficacy measures than men in the same racial/ethnic group. We also found a large, meaningful difference between LGBTQIA and straight students on academic self-efficacy, with LGBTQIA students reporting lower self-efficacy than straight students. We also found that women with additional minoritized identities (in this case, sexuality) had even lower self-efficacy than LGBTQIA men. Finally, we found meaningful differences for the first-generation college status. First-generation college students had lower self-efficacy than continued-generation college students.
Limitations

Before we move to the discussion and contribution of this dissertation results to the literature, we should note the limitations to the study designs and results. First, common limitations across the three articles are the low average response rates and the large fluctuation in students’ response rates among various departments (ranging from 11% to 60%). This outcome suggests a response bias where students from certain programs are more likely than others to participate in our study. A significant limitation is the low sample size of individual subgroups (racially/ethnically minoritized students, LGBTQIA, first-generation college students), especially when we examine the intersectionality of these identities with gender.

In addition, the selected programs (rank and size), do not represent the range of Ph.D. programs in the country, limiting the generalizability of the study results. Moreover, we consider a non-response bias for students who were concerned about the possibility of identity exposure. These students may have avoided to share negative aspects of their experience (either on the survey and/or the interviews) because of concerns of identity exposure.

The study design included the collection of students’ academic records (undergraduate GPA, GRE, and graduate GPA). However, only four department leaders provided us with these records, resulting in a very small sample size, which we decided not to include in the retention model, as initially planned. We believe that these data would had further informed the retention model.

Next, the development and validation of the ASES instrument suggested that ASES exhibited acceptable construct validity and substantial internal consistency. However, the process of instrument development is an ongoing process and future work is needed to administer ASES to a different population of physics graduate students and use confirmatory factor analysis to test whether measures of the four identified constructs in this study are consistent with the new data. A test-retest is also needed to establish the internal consistency of the constructs further.
Finally, we applied the social cognitive theory as a framework to design the study and analyze our data. However, the expectancy-value theory is an alternative and possibly a more appropriate approach to approach graduate retention study. We view the expectancy-value theory to be more suitable in analyzing student interviews of their experience in graduate programs, especially in light of the discriminatory experiences and low self-efficacy of women students. According to the expectancy-value theory, students exert increased effort into tasks that they perceive to have value and at which they expect to succeed [154]. We also suggest that future research considers the role of motivation (in addition to expectancy, value, and cost) and how it evolves as students progress through the program.

Discussion

The graduate retention model results and the qualitative student interview data converge into the increased importance of social & academic integration in shaping students’ experiences and influencing persistence intentions. This finding is in agreement with prior work that argued the role of social isolation and lack of academic integration in doctoral students attrition [25, 26, 27, 28]. Although prior studies examined this aspect across several disciplines, this study shows how social & academic support (or lack of it) is particularly evident in physics graduate programs. Students described that inapproachable faculty members (instructors), intense workload, and isolation were the most common aspects of the lack of social & academic support. On the other hand, students who reported experiencing social & academic support emphasized its crucial role in their persistence. These students described experiencing social & academic support by working with their peers on coursework, being offered and participating in recitation sessions, having a social support network to discuss their concerns and struggles (peers, mentors). Student and department leaders’ interview data suggested that the departments’ investment into supporting student social & academic integration is correlated with the departments’ (faculty members’) perspectives on the role of graduate student (proving worth being in the program vs. being in the program to learn and
grow as academics). We found that APS-BP departments have more rigid structures in place to support students’ social & academic integration as opposed to non-APS-BP departments.

We found that the lack of social & academic support was the most common reason for leaving the program; other reasons included poor mentoring and lack of interest in the research project. This was also evident in the students’ quantitative data. We found that mentoring & research experience only indirectly influenced persistence intention through academic self-efficacy. Paglis et al. 2006 and Santiago & Einarson 1998 showed that a positive correlation between mentoring and self-efficacy exists. In particular, the psychosocial aspect of mentoring (role modeling, counseling in crises, informal friendship) positively predicted graduate students’ research self-efficacy on the 5th year of the longitudinal study [131]. Similarly, [59] found that the most significant positive predictors of student ratings of academic self-efficacy positive student expectations about faculty/student interactions positively predicted academic self-efficacy.

Finally, our results highlighted the importance of academic self-efficacy in predicting persistence intentions. However, a concerning finding is the gender gap in students’ self-efficacy. Women are more likely to have lower self-efficacy than men. This finding is consistent with the literature which detected gender gaps in student self-efficacy, with women reporting lower self-efficacy of their science-related abilities than men despite having similar levels of prior achievement and outcomes [99, 100]. This study showed that this outcome is large and meaningful. The gender gap is exacerbated further for women with additional minoritized identities, such as sexuality and college generation status (except for racial/ethnic minoritized women). It is found that gender role socialization is an important aspect of self-efficacy development, resulting in higher and lower self-efficacy for men and women, respectively [97, 101]. These results, in combination with students’ interviews suggesting that sexism and discriminatory behavior are common in physics graduate programs, support several scholars’ arguments on the impact of systemic inequalities posed by institutional actors on student educational outcomes [95, 96].
This study’s results urge the need to open a discussion for the lack of work-life balance in physics graduate programs that is found to be correlated with the departmental culture. Students’ and department leaders’ interviews suggested that while in the graduate program, students dedicate their lives (and are encouraged and expected to) to meeting the program requirements by working more than 60 hours per week. This is a culture that promotes the notion of the “survival of the fittest” and the constantly competitive nature of the working environment in academia. Students reported that the lack of work-life balance, intense workload, and social isolation led to their development or exacerbation of preexisting mental health issues. It is difficult to emphasize the extent of students’ struggle with mental health issues without the risk of “sounding” excessive. Department leaders’ interviews agreed with the picture presented by students on the extent that mental health issues are present in physics graduate programs. However, every department leader stated that they are focused on helping students cope with these issues when they identify them by directing them to the appropriate resources. Some department leaders attributed students’ mental health to personal issues (e.g., family situations, personal relationships). None of the leaders stated on aspects that the departments could do to help prevent the development of mental health, mainly because we believe that they are unaware of the struggles students experience that result from the program design and department culture.

Recommendations for Practice and Research

Research

The results of this dissertation supported the notion that departmental support structures are predictors of student persistence and are crucial in forming students’ experiences (both for those who do and do not persist). Therefore, we invite future work on graduate retention to continue building on this study results by focusing on single disciplines across multiple departments to identify other departmental-context elements that influence student experience and outcomes. Retention studies are usually longitudinal since there is a
need to identify students’ sample as they progress in the program and record their academic progress. This need for a longitudinal approach results in a slow rate at which research in this field is expanding. This study results indicated that intentions to leave predict actual attrition. Therefore, we invite future work to use persistence intentions and follow-up with these students to further explore the reasons for their departure. Moreover, we see an emerging need to focus on retention and the experiences of all students (those who do and do not persist), especially focusing on how department culture influences student experience.

One of the most challenging aspects of retention studies is identifying and contacting students who discontinued their programs. The use of surveys can be useful in identifying students’ intentions, and follow-up interviews can be used to elicit their experiences and their reasons to leave the program. Next, we encourage future work to adapt the expectancy-value theory. The study results further supported the notion that expectancy-value theory is the appropriate approach in exploring student retention. In particular, the aspect of “cost and value” could be tested in whether the lack of work-life balance and its consequences are perceived as “cost” and whether the research-focus aspect of graduate education and the prestigious potential faculty role are perceived as “value.” In this study, we saw evidence from a few students who reported to leave because their experience of the academic environment (faculty role, lack of work-life balance) demotivated them from pursuing the graduate degree.

As mentioned in the limitations, survey development is a complicated and ongoing process. Therefore, we invite future work to continue building on the ASES instrument to further refine and improve it. In particular, we suggest future research to add aspects related to students’ experience of coursework and instructor-student relationship and aspects related to students’ work-life balance experience.

Finally, self-efficacy is a significant predictor of persistence intentions. We found that consistent with the literature, women students are more likely to have significantly lower self-efficacy than men students. The reported discriminatory and sexist behavior (often directed by the instructor of the course(s)) towards women students could be correlated
with lower self-efficacy. We invite future work to examine women students’ self-efficacy and how it evolves as students progress in the program. More specifically, we suggest more work to help understand the experiences of women students with additional minoritized identities in STEM fields and how those contribute to their academic self-efficacy, specifically.

Practice

Recommendations for practice are directed towards two aspects: developing formal departmental structures to support students’ social & academic integration, and a cultural change in physics graduate programs towards prioritizing students’ learning and well-being. Below, we discuss the specific actions that department leaders and other stakeholders should take to help reach these goals and ways to assess the effectiveness of these reforms.

1. **Supporting student academic progress.** We found that one of the largest students’ struggles involved a lack of support to cope with the coursework. We encourage department leaders to develop a climate that promotes and supports student learning and growth rather than forcing students to continually prove that they deserve to be in the program. For example, offer formal recitation sessions for core courses that are facilitated by senior graduate students.

2. **Supporting student daily socialization.** Students’ socialization was found to be an important aspect of their integration in the program. We found that socialization opportunities helped develop a support network that supported students cope with the degree requirements (e.g., coursework). Moreover, socialization was an essential aspect in supporting student work-life balance. We encourage departments to create a communal space to promote daily student socialization. Encourage daily lunch and/or coffee break times in the communal space. Assign an individual (staff, faculty member, senior students) to organize weekly socializing events. Students are unlikely to consider
events that take place on a rare basis as socializing opportunities (e.g., potluck, which takes place twice a year).

3. **Supporting student-faculty communication.** We found that department leaders are largely unaware of students’ struggles and the reasons that lead them to depart. We encourage department leader to design and incorporate practices to create a safe environment where students are welcomed to communicate (formally or informally) their concerns and struggles to the department leaders or trusted faculty members, as well as have the university student union conduct exit student interviews.

4. **Peer mentoring.** Mentoring is found to increase to student self-efficacy and in turn persistence intentions. We encourage department leaders to assigned a peer mentor (e.g., a senior graduate student) to each incoming student from the first day in the program. Evaluate peer mentoring (mentees evaluate mentors) and create incentives for effective peer mentoring (e.g., peer mentoring award at the end of the year).

5. **Supporting student work-life balance.** Every interviewee reported experiencing a lack of work-life balance. Students’ suggested that faculty members promote the notion that student life must solely revolve around the student role. Students also associated the lack of work-life with experiencing mental health programs. We encourage departments to educate faculty members on the struggles and concerns students report experiencing. Help promote the development of a shared understanding among the faculty members that prioritizes students’ psychosocial well-being. Promote the practice/policy of expecting students to have some leisure time.

6. **Consider instructors’ approach to diversity and equity.** Students’ widely reported discriminatory and sexist behavior from instructors towards women students. We recommend department leaders to carefully assign instructors to core courses considering their approach of respect to diversity and inclusion, as well as offering training in diversity and equity for faculty members at the department. In most cases, the instructor
of the core courses is the department representative to the graduate student. When taking the coursework, students interact and depend on the instructor (academically and psychologically). It is important that students and instructors develop a respectful interaction.

7. Consider instructors’ pedagogical approach and/or training. We asked students to recommend intervention that could improve their departments in better supporting students. Several students pointed out the need to have instructors in the core courses with good pedagogical skills and interest in teaching. Many students stated that the level of teaching skills and interest they received declined significantly from their undergraduate experience since graduate course instructors are mainly focused on their research, neglecting their teaching approach and effectiveness. Therefore, we recommend department leaders to carefully choose instructors for core courses considering their pedagogical approach to teaching graduate students and offer training focused on teaching and pedagogy for faculty members at the departments.

8. Evaluate student experience. Use the ASES instrument to annually evaluate students’ experience of the supports offered at the departmental level. Pay particular attention to the individual items on the social & academic integration.

The above recommendations are particularly focused on aspects that resulted as essential in influencing students’ experience in the graduate programs. The change of departmental culture, which requires bringing on the same page faculty members within the department, is the most challenging of the above recommendations. We encourage department leaders and other stakeholders in the program to start making the changes from the ones that require the least risk of tension (e.g., offering a communal space to promote student socialization) and slowly expanding towards the most challenging areas for change.
REFERENCES


[69] Climate for graduate students in science and engineering departments (2005), proceedings of the 2005 American Society for Engineering Education annual conference exposition.


APPENDIX A: HSIRB Approval Form
Date: January 8, 2019

To: Charles Henderson, Principal Investigator
Diana Sachmpazidi, Student Investigator for dissertation

From: Amy Naugle, Ph.D., Chair

Re: IRB Project Number 18-12-32

This letter will serve as confirmation that your research project titled “Investigating the Process of How Individual Attributes and Departmental Structures are Related to Doctoral Students' Persistence: An Analysis of Characteristics from 18 Physics Graduate Programs” has been approved under the expedited category of review by the Western Michigan University Institutional Review Board (IRB). The conditions and duration of this approval are specified in the policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may only be conducted exactly in the form it was approved. You must seek specific board approval for any changes to this project (e.g., you must request a post-approval change to enroll subjects beyond the number stated in your application under “Number of subjects you want to complete the study”). Failure to obtain approval for changes will result in a protocol deviation. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the IRB for consultation.

Reappraisal of the project is required if it extends beyond the termination date stated below.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: January 7, 2020
Thank you so much for joining me today. As you know, this study is entitled: Investigating the process of how aspects of physics graduate students’ experiences affect their self-efficacy and intention to persist.

As stated on the title, the purpose of this study is to understand the experiences of physics graduate students at their programs and how these experiences affect their performance and persistence.

In today’s interview, which will last about an hour, I will be asking about your personal and academic backgrounds, experiences in the graduate program, work-life balance, and your future career plans.

I will treat the content of this interview, including the recordings, all notes, and any other documents with the strictest confidentiality. The data will be kept in a safe location that is not accessible to anyone except me. Your name will never appear in the dissertation of this study. If I should use your words in my dissertation, I will refer to you only with a pseudonym. I also will never reveal the names of individuals whom you should mention.

Only I, as the interviewer, will have access to your real name. The results of the study will be used for the main investigator dissertation, in conferences, meetings, publications in journals, and used for educational purposes. As we proceed through the interview today, I would like to invite you to stop me at any time to point out issues or concerns that you want me to mask or otherwise to keep “off the record.”

Finally, I want to be sure that you know that your participation in this study is completely free and voluntary. You may refuse to respond to any questions. You also may discontinue the study at any time.

With your permission, I would like to record this interview in order to have a comprehensive record of our conversation. Is that acceptable to you? YES ____ NO ____.
If YES: If at any time you would like to stop the recorder, you can ask me to do so. If NO: If you would prefer not to be recorded I’ll be happy to take notes by hand as you speak.

Do you have any questions at this time?  
Do you agree to participate? YES ____ NO ____.

Okay, thank you – do you have any questions for me at this point?

1. I’d like to start by confirming some of your information.
   (a) Are you pursuing a ____ [degree type] at ____________ [institution name]?
   (b) At which stage of your graduate program are you currently at?
   (c) if appropriate: I understand that you are affiliated with the APS-BP, is that right?

   ACADEMIC BACKGROUND

2. Can you start by telling me a little bit about your experience in the undergraduate program you were enrolled?
   (a) In what area was your undergraduate degree?
   (b) Were you involved on any research projects?
   (c) Did you have mentors as an undergraduate student? [IF YES:]
      i. Could you describe for me the relationship you had with your mentors?
      ii. What influence do you think they had, if any, in how you navigated in academia, or in finishing your degree?
   (d) Who or what most encouraged you to pursue graduate studies?
   (e) How strong, do you feel, your physics background was when you finished your undergraduate degree?

   EXPERIENCES AT THE GRADUATE PROGRAM

   Great! Now, before we get into more detail about your experiences can you start by giving me a brief description of your experience in the graduate program?

   [Welcoming at the program]

3. Can you describe your experience of moving to the town and starting your program?
   (a) How supportive were people at your program with your accommodation needs when you first moved in to town?
   (b) How was your experience of blending into your department’s culture?

   [Departmental diversity and culture]

4. How would you describe your department’s diversity?
   (a) How do you feel this affects your experience in the department in general?
(b) Can you reflect on how you fit or do not fit in your program?
   i. Do you mind elaborate on that?
   ii. (if applicable) How does this make you feel?
(c) What would make you feel more included?

5. In what ways do you feel that your program could support you better?
   (a) What kind of changes would you like to see?

[Work-life balance]

6. How does the department’s culture support work life balance?

7. How well do/did you balance your graduate duties such as teaching assignments with
   your research work [if engaged in research] or coursework [if still taking coursework]?

8. How intensive is your weekly workload on average? How you allocate your time
during a typical day?

[Coursework and the first two years]

9. When you first started graduate school, did you take the courses that most of the
   other graduate students took? [IF NO:]
   (a) How was the coursework plan that you took different from the one most of
      your peers take and how did this plan suit your preparation?

10. When you have experienced challenges in your coursework, how responsive were
    people in your program in identifying and in helping you overcome them?

[Mentoring and research experience]

11. Do you have a mentor at your graduate/doctoral program? [IF YES:]
   (a) How many mentors do you have?
   (b) Can you describe the relationship you have with your mentor?
   (c) What influence do you think they had, if any, in how you navigated in your
       program?
   (d) How frequently do you meet with your mentor? Can you describe a typical
       meeting that you have with them?

12. Can you tell me a little bit about your experience in your research group?
   (a) Who or what influenced you to join this [research group] or [research project]?
   (b) Does your research group hold meetings on a regularly basis [or do you meet
       with your research advisor on a regular basis]? If so, can you describe how a
       typical meeting runs?
   (c) How satisfied do you feel with your choice on joining the research group/project?

[Professional development]
13. What kind of opportunities you have had through your program for professional development for effective networking and outreach (e.g., attending conferences)?

(a) How satisfied are you with the opportunities you have had through your program for professional development for effective networking and outreach (e.g., attending conferences)?

14. What kind of opportunities you have had through your program for professional development as a scientist and a scholar (e.g., writing for grants, publishing papers)?

(a) How satisfied are you with the opportunities you have had through your program for professional development as a scientist and a scholar (e.g., writing for grants, publishing papers)?

[Financial support]

15. What kind of financial support did you receive for the most period of time at your program?

(a) Is this support adequate to help you meet your financial needs?
(b) Do you have to explore other paths to help you meet financial needs?

16. When you first entered the program, were you aware for the financial situation that will support you until you complete the degree?

[Expectations and mental health]

17. How does your expectation of graduate school compare with your experience?

18. How do you think graduate school has affected your mental health?

(a) What aspects of graduate school do you feel cause you [e.g., stress]? Do you mind elaborate that?
(b) Do you feel that there are sufficient resources for you to take care of your mental health?
(c) How likely are you to use them? [if student is not using them: What are the factors inhibiting you from them?]?

19. Is there anything else that you would like to add/share about your experience as a graduate student that we haven’t talked about?

[Persistence in the program]

20. Do you have any concerns (e.g., financial, personal, academic) that might impede your completion of the program? If so, do you mind elaborate on that?

21. Do you feel like you will be successful in your graduate program?

22. Do you plan to complete your intended degree?

(a) Do you feel that your overall experience in your graduate program has changed your intention to complete your degree?

[Career goals and future plans]
23. Do you feel supported in planning your next steps after graduate school?
   
   (a) How does this support look like?
   
   (b) Have your initial career goals shifted since you started your graduate/doctorate program? [IF YES:]
       
       i. What aspects in your doctoral experience influenced you change in your career goals?
   
   (c) How confident you feel in fulfilling your career goals?

24. If you had to go back in time when you were applying for graduate school, is there anything that you would do differently?

   (a) Would you still choose to pursue a graduate degree and in the same program? Why or why not?

25. Is there anything else you would like to add in this interview, any information you think might help me to understand more about your experience at your graduate program?

THANK YOU VERY MUCH FOR PARTICIPATING IN THIS INTERVIEW AND SHARING ALL THOSE EXPERIENCES.
APPENDIX C: Department Leader Interview Protocol
Interview Protocol for Departments’ Administration

Investigating the process of how aspects of physics graduate students’ departmental experiences affect students’ self-efficacy and intention to persist.

Ntiana (Diana) Sachmpazidi

Interviewee Name: ____________________________
Interviewee’s affiliation: ____________________________
Interviewee’s position: ____________________________
Date of interview: ____________________________
Time of interview: ____________________________

Notes on identifiability:

Setting description:
Thank you so much for joining me today. As you know, this study is entitled: Investigating the process of how aspects of physics graduate students’ experiences affect their self-efficacy and intention to persist.

As stated on the title, the purpose of this study is to understand the experiences of physics graduate students at their programs and how these experiences affect their performance and persistence.

In today’s interview, which will last about an hour, I will be asking about your graduate program’s policy, goals, and outcomes. These questions are based on the recommendation of the APS-BP.

I will treat the content of this interview, including the recordings, all notes, and any other documents with the strictest confidentiality. The data will be kept in a safe location that is not accessible to anyone except me. Your name will never appear in the class report of this study. If I should use your words in my class report, I will refer to you and your department only with a pseudonym. I also will never reveal the names of individuals whom you should mention.

Only I, as the interviewer, will have access to your real name. The results of the study will be used for the main investigator dissertation, in conferences, meetings, publications in journals, and used for educational purposes. As we proceed through the interview today, I would like to invite you to stop me at any time to point out issues or concerns that you want me to mask or otherwise to keep “off the record.”

Finally, I want to be sure that you know that your participation in this study is completely free and voluntary. You may refuse to respond to any questions. You also may discontinue the study at any time.

With your permission, I would like to record this interview in order to have a comprehensive record of our conversation. Is that acceptable to you? YES ____ NO ____.
If YES: If at any time you would like to stop the recorder, you can ask me to do so.
If NO: If you would prefer not to be recorded I’ll be happy to take notes by hand as you speak.

Do you have any questions at this time?
Do you agree to participate? YES ____ NO ____.

Okay, thank you – do you have any questions for me at this point?

1. I’d like to start by confirming some of your information.
   (a) Are you the _____ [role at the department (e.g., chair, graduate advisor] at
       _________[institution name]?
   (b) How many years have you been working at this institution?
   (c) How many years have you served at this position?

**OVERVIEW OF GRADUATE PROGRAM**

2. Have you had a chance to read the summary report of students’ survey? I am
   interested in learning about what you feel about the report.

3. Overall, what do you think are working really well and what areas would you wish
   to improve?

4. What is your vision for what graduate students will take out of this program?

5. How diverse is the body of faculty and staff at your department?
   Okay, great! I’ll continue now with questions related to your program’s admission
   criteria.

**ADMISSION CRITERIA**

6. What are the main criteria that your program has to admit students?

7. Who comprises the committee on admissions?

8. How does the committee decide how many offers to make to potential graduate
   students?

9. How many students start with teaching and research positions and how does that
   happen?

10. Can you describe the graduate admissions’ process?
   (a) On your website it is mentioned that physics GRE is [NOT] a requirement on
       admission.
       i. If an applicant has a low GRE, how heavily does it factor in your decision?
       ii. How does the committee navigate these situations to make a decision?
       iii. How important are general GRE scores on the admission decision?
(b) How financial support and health benefits being determined? Are you satisfied with the amount of financial support that students receive?

(c) When you have applicants that will increase the diversity in the department, how does that factor in your decision?
   i. How does admission criteria differ for applicants that fall into the diversity and inclusion policy?
   ii. What kind of financial support does your program offer to those applicants? [IF FELLOWSHIP:]
   iii. What kind of strategy does your program has to ensure financial support to those students after their fellowship expires?

Great! Now, I would like to continue with your graduate/doctoral program’s policy upon admission.

WHILE AT THE PROGRAM

11. Can you tell what does it look like to graduate student starting at the program?

12. What kind of mentoring is available?
   (a) Are there specific practices that the department has to ensure a multi mentoring model?

13. Are students required to take the qualifying exams? To what extent do these exams determine students’ progress in the program?
   (a) Does your program has any supports to prepare students’ for the exams?
   (b) What happens if someone fails?

14. How often and based on what criteria does your program monitor and evaluate students’ progress in the program?
   (a) Do you communicate the results of those evaluations to the students?
   (b) What practices does your graduate program have to support students’ "at risk?"

15. What practices does your program have to match students with research advisors?

16. What kind of financial support do students have when they start working on their thesis/dissertation?
   (a) How many hours per week do you think that students actually spend on their duties as TAs/RAs?

17. If a student is working with a research advisor that does not have a research funding to financially support the student, what kind of support does this students receive?

18. What practices does your program have to help students frequently attend conferences and to develop an effective networking at their research field?
   (a) At which stage of their progress at the program does the student receive these opportunities?
(b) How do the opportunities that students receive for outreach and networking differ?

19. What practices does your program have to help students develop professionally and be prepared for their future role at their field of focus?

20. How often do students that intend to leave with a PhD degree, instead leave with a MS degree? What do you think are the main reasons for this?

21. What practices does your program have in place to identify students that are experiencing stress and anxiety? What practices or resources are there to help those students?

22. Is there anything else you would like to add in this interview, any information you think it might help me to understand more about your graduate program and its practices to support students?

THANK YOU VERY MUCH FOR PARTICIPATING IN THIS INTERVIEW AND SHARING ALL THIS INFORMATION!
APPENDIX D: Full Structural Equation Model
Our final model took the form:

\[
\begin{pmatrix}
\eta_{MREi} \\
\eta_{PDi} \\
\eta_{SAIi} \\
\eta_{FSi} \\
\eta_{ASEi} \\
\eta_{INTi}
\end{pmatrix} =
\begin{pmatrix}
\alpha_1 \\
\beta_{2,1} \\
\alpha_3 \\
\beta_{3,2} \\
\alpha_5 \\
\beta_{5,1}
\end{pmatrix} +
\begin{pmatrix}
0 \\
0 \\
0 \\
0 \\
0 \\
0
\end{pmatrix}
\begin{pmatrix}
\eta_{MREi} \\
\eta_{PDi} \\
\eta_{SAIi} \\
\eta_{FSi} \\
\eta_{ASEi} \\
\eta_{INTi}
\end{pmatrix} +
\begin{pmatrix}
\gamma_{1,1} \\
\gamma_{1,2} \\
\gamma_{1,3} \\
\gamma_{3,1} \\
\gamma_{5,1} \\
0
\end{pmatrix}
\begin{pmatrix}
\zeta_{MREi} \\
\zeta_{PDi} \\
\zeta_{SAIi} \\
\zeta_{FSi} \\
\zeta_{ASEi} \\
\zeta_{INTi}
\end{pmatrix}
\]

where \( \text{VAR}(\zeta_i) = \begin{pmatrix}
\Psi_{MRE} \\
0 \\
0 \\
0 \\
0 \\
0
\end{pmatrix} \)

In the model, \( \eta \) variables represent endogenous variables (value determined by the model) and \( x \) variables represent exogenous variables (value not influenced by another variable in the model). The \( i \) subscript represents the \( i \)th student. The \( \zeta \) variables represent the error terms for the endogenous variables. The full model including all tested connections is shown below.
APPENDIX E: Full Table of SEM
| Latent Variables: | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|------------------|----------|---------|---------|---------|--------|---------|
| **Sup.Dept. =**  |          |         |         |         |        |         |
| MRE              | 1.000    | 0.388   | 0.547   |         |        |         |
| SAI              | 0.840    | 0.210   | 3.997   | 0.000   | 0.326  | 0.453   |
| FS               | 1.241    | 0.296   | 4.193   | 0.000   | 0.481  | 0.466   |

| Regressions:     |          |         |         |         |        |         |
| INT ~            |          |         |         |         |        |         |
| ASE (A_I)        | 0.024    | 0.003   | 9.347   | 0.000   | 0.024  | 0.477   |
| FS (F_I)         | -0.066   | 0.035   | -1.875  | 0.061   | -0.066 | -0.087  |
| SAI (S_I)        | 0.173    | 0.063   | 2.736   | 0.006   | 0.173  | 0.160   |
| PD (P_I)         | -0.088   | 0.057   | -1.548  | 0.122   | -0.088 | -0.084  |
| VISA             | -0.108   | 0.079   | -1.379  | 0.168   | -0.108 | -0.062  |
| ASE ~            |          |         |         |         |        |         |
| FS (F_A)         | 0.583    | 0.757   | 0.770   | 0.441   | 0.583  | 0.039   |
| SAI (S_A)        | 6.342    | 1.156   | 5.487   | 0.000   | 6.342  | 0.294   |
| MRE (M_A)        | 5.708    | 1.136   | 5.025   | 0.000   | 5.708  | 0.260   |
| GENDER           | -5.493   | 1.605   | -3.422  | 0.001   | -5.493 | -0.156  |
| NW               | 2.647    | 1.886   | 1.404   | 0.160   | 2.647  | 0.069   |
| VISA             | 1.398    | 1.669   | 0.837   | 0.402   | 1.398  | 0.040   |
| FG               | -3.145   | 2.514   | -1.251  | 0.211   | -3.145 | -0.058  |
| SEMESTER         | 0.430    | 0.205   | 2.092   | 0.036   | 0.430  | 0.095   |
| SAI ~            |          |         |         |         |        |         |
| FG               | -0.096   | 0.105   | -0.918  | 0.359   | -0.096 | -0.038  |
| NW               | 0.081    | 0.077   | 1.052   | 0.293   | 0.081  | 0.046   |
| GENDER           | -0.091   | 0.069   | -1.326  | 0.185   | -0.091 | -0.056  |
| PD (P_S)         | 0.445    | 0.043   | 10.360  | 0.000   | 0.445  | 0.457   |
| PD ~             |          |         |         |         |        |         |
| SEMESTER         | -0.017   | 0.010   | -1.679  | 0.093   | -0.017 | -0.079  |
| NW               | 0.312    | 0.090   | 3.473   | 0.001   | 0.312  | 0.170   |
| MRE (M_P)        | 0.376    | 0.049   | 7.715   | 0.000   | 0.376  | 0.361   |
| VISA             | 0.314    | 0.082   | 3.833   | 0.000   | 0.314  | 0.189   |
| MRE ~            |          |         |         |         |        |         |
| GENDER           | -0.095   | 0.081   | -1.174  | 0.240   | -0.095 | -0.059  |
| NW               | 0.133    | 0.092   | 1.439   | 0.150   | 0.133  | 0.075   |
| VISA             | 0.136    | 0.082   | 1.668   | 0.095   | 0.136  | 0.085   |
### Table 0.2: Full SEM Table - Intercepts

|       | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|-------|----------|---------|---------|--------|--------|---------|
| MRE   | 3.671    | 0.054   | 68.375  | 0.000  | 3.671  | 5.180   |
| SAI   | 2.162    | 0.106   | 20.384  | 0.000  | 2.162  | 3.006   |
| FS    | 3.918    | 0.054   | 73.074  | 0.000  | 3.918  | 3.798   |
| INT   | 2.743    | 0.217   | 12.647  | 0.000  | 2.743  | 3.526   |
| ASE   | 32.466   | 4.917   | 6.603   | 0.000  | 32.466 | 2.090   |
| PD    | 0.866    | 0.197   | 4.397   | 0.000  | 0.866  | 1.173   |
| Sup.Dept. | 0.000 |      |         |        | 0.000  | 0.000   |

### Table 0.3: Full SEM Table - Variances

|       | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|-------|----------|---------|---------|--------|--------|---------|
| MRE   | 0.346    | 0.046   | 7.509   | 0.000  | 0.346  | 0.688   |
| SAI   | 0.254    | 0.033   | 7.688   | 0.000  | 0.254  | 0.491   |
| FS    | 0.833    | 0.085   | 9.804   | 0.000  | 0.833  | 0.782   |
| INT   | 0.438    | 0.033   | 13.332  | 0.000  | 0.438  | 0.723   |
| ASE   | 171.677  | 13.106  | 13.099  | 0.000  | 171.677| 0.712   |
| PD    | 0.437    | 0.032   | 13.606  | 0.000  | 0.437  | 0.802   |
| Sup.Dept. | 0.150 |      | 3.230   | 0.001  | 1.000  | 1.000   |

### Table 0.4: Full SEM Table - Defined Parameters

|                  | Estimate | Std.Err | z-value | P(>|z|) | Std.lv | Std.all |
|------------------|----------|---------|---------|--------|--------|---------|
| Direct Effect    |          |         |         |        |        |         |
| PD               | -0.088   | 0.057   | -1.548  | 0.122  | -0.088 | -0.084  |
| SAI              | 0.173    | 0.063   | 2.736   | 0.006  | 0.173  | 0.160   |
| FS               | -0.066   | 0.035   | -1.875  | 0.061  | -0.066 | -0.087  |
| Total Indirect Effect |        |         |         |        |        |         |
| MRE              | 0.157    | 0.034   | 4.666   | 0.000  | 0.157  | 0.143   |
| PD 0.144         | 0.032    | 4.514   | 0.000   | 0.144  | 0.137  | 0.140   |
| SAI              | 0.151    | 0.032   | 4.658   | 0.000  | 0.151  | 0.140   |
| FS               | 0.014    | 0.018   | 0.768   | 0.442  | 0.014  | 0.018   |
| Indirect Through ASE |         |         |         |        |        |         |
| MRE              | 0.162    | 0.031   | 5.249   | 0.000  | 0.162  | 0.147   |
| PD               | 0.067    | 0.016   | 4.246   | 0.000  | 0.067  | 0.064   |
| SAI              | 0.151    | 0.032   | 4.658   | 0.000  | 0.151  | 0.140   |
| FS               | 0.014    | 0.018   | 0.768   | 0.442  | 0.014  | 0.018   |
| Total Effect     |          |         |         |        |        |         |
| MRE              | 0.157    | 0.034   | 4.666   | 0.000  | 0.157  | 0.143   |
| PD               | 0.079    | 0.043   | 1.843   | 0.065  | 0.079  | 0.050   |
| SAI              | 0.324    | 0.065   | 5.015   | 0.000  | 0.324  | 0.300   |
| FS               | -0.052   | 0.039   | -1.350  | 0.177  | -0.052 | -0.069  |