THESIS

ALONE AGAIN, NATURALLY? LONELINESS AND PERFORMANCE AMONG STEM GRADUATE STUDENTS

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ABSTRACT

ALONE AGAIN, NATURALLY? LONELINESS AND PERFORMANCE AMONG STEM GRADUATE STUDENTS

Graduate student mental health is a trending topic of research, and rightfully so considering the growing number of graduate students, high rate of mental health concerns particularly among young adults, and the high rate of attrition from graduate programs. Qualitative research has consistently raised isolation and loneliness as concerns for many doctoral students. Not only is loneliness an issue for mental health and wellbeing, but loneliness may have serious consequences for students' motivation, satisfaction, intentions to stay in school, and the current and future productivity of these scholars. Based on the tenets of self-determination theory and the model of workplace loneliness, I hypothesized that perceived loneliness in doctoral students would be negatively related to motivation, satisfaction, productivity and intent to quit. The current study extends previous research by exploring loneliness in doctoral students in a large-scale (N = 1117) quantitative survey to investigate perceptions of loneliness, motivation, engagement, satisfaction, and productivity among doctoral students in STEM fields. Using structural equation modeling (SEM) to test hypotheses, results demonstrated that loneliness was negatively related to satisfaction with program, motivation, and productivity, and explained 49% of the variance of intent to quit. Relationship with advisor mediated the relationship between loneliness and motivation, but not satisfaction with program or productivity. Results may inform graduate programs with students who may be at higher risk

of loneliness and/or attrition and may guide future interventions to prevent or reduce loneliness in graduate students.

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INTRODUCTION

Gilbert O'Sullivan, the singer-songwriter of "Alone Again (Naturally)," never went to graduate school, but he may have well written the tale of a graduate student, telling the story of a "cheerful, bright, gay" student looking forward to graduate school, but "as if to knock [the student] down, reality came around" and the student is now "alone again, naturally." Despite a growing push for collaboration, graduate school can be a notoriously lonely and isolating experience (Cantor, 2020; Janta et al., 2014), with over half of students reporting feeling lonely or isolated in the academic year (American College Health Association, 2019; MIT Institutional Research, n.d.).

Isolation and loneliness may be common experiences for graduate students because of the nature of research to be open-ended and uncertain and the push for graduate students to become independent researchers. The relationships between loneliness and mental health and wellbeing have been extensively studied (See Hawkley & Cacioppo, 2010 for a review), but very little has explored the relationship between loneliness and performance in graduate school. The current study seeks to investigate the relationship between loneliness and productivity, motivation, satisfaction with the academic program, and intentions to quit their graduate program in STEM (science, technology, engineering, and mathematics) doctoral graduate students'.

Defining Isolation and Loneliness

There are many ways that we conceptualize isolation and loneliness. Often, loneliness is a broad term that encompasses a perception of social isolation or the subjective feeling of being alone without the company of others and feeling upset about it (National Academies of Sciences, Engineering, and Medicine, 2020). Social isolation is commonly defined along the lines of the

"inadequate quality and quantity of social relations with other people at different levels where human interaction takes place (individual, group, community, and the larger social environment)" (Zavaleta et al., 2014, p. 5). Although social isolation and loneliness are theoretically different, they are similar and thus positively associated with each other (Ray et al., 2019) and often defined in similar ways or used interchangeably (Veazie et al., 2019; Zavaleta et al., 2014). By the given definition, social isolation encompasses professional isolation (experiencing a sense of isolation in the workplace) and may be related to concepts such as physical isolation (being physically separated from others), all of which can be related to negative affect, decreased wellbeing, and increased psychological stress (Golden et al., 2008; Hawkley & Cacioppo, 2010; Ingram & London, 2015). However, loneliness, social isolation, and professional isolation tend to be of bigger concern than physical isolation, most likely because physical isolation is not necessarily indicative of a lack of social support or social connections (Weinstein & Nguyen, 2020). In this paper, loneliness encompasses, but is not limited to, social isolation, physical isolation, and professional isolation. Therefore, I rely upon use of the term loneliness throughout this paper.

Although isolation is common and at times welcome, it does not always benefit the graduate student and can lead to an induced sense of disconnectedness to others and is related to negative consequences relating to mental wellbeing (Barry et al., 2018; Mushtaq et al., 2014). In fact, many recent typologies describing stress among graduate students rate concerns about social support as a top five category (Mackie & Bates, 2019). Social isolation is associated with the imposter phenomenon (Cohen & McConnell, 2019), increased stress (Grady et al., 2014), and can lead to a lack of professional opportunities and connections critical to career development and growth (Golden et al., 2008). In general, isolation and loneliness are of concern to graduate

students because they inhibit a sense of belonging and may be linked to lower feelings of competence (Cantor, 2020; Cohen & McConnell, 2019). Isolation and loneliness can act as additional stressors on graduate students, harm overall wellbeing, and be a catalyst of attrition, particularly among women and underrepresented groups (Ali & Kohun, 2006; Cantor, 2020).

Theoretical Framework

Much of the research regarding graduate student experiences has examined well-being through exploratory semi-structured interviews, often identifying isolation and loneliness as a common factor of poor well-being (e.g., Alexander & Hermann, 2016; Erichsen & Bolliger, 2011; Gay, 2004; Le & Gardner, 2010). Thus, there is little existing research that draws on theory to explain findings. However, theories of loneliness and motivation may explain a link to performance.

Loneliness

Within social and cognitive psychology, loneliness and social isolation are not an island of research, but rather a large continent. Theories derived from social and cognitive psychology focus on interactions between a person and others around them and how the person interprets interactions. A dynamic duo of loneliness research, Cacioppo and Hawkley (2009), developed the *regulatory loop model of loneliness* to describe the psychological mechanisms occurring within lonely people. In the regulatory loop model, Cacioppo and Hawkley (2009) propose that perceived social isolation equates to feelings of insecurity that lead the person to perceive greater social threat in their environments, expect more negative interactions with others, and remember more negative interactions with others. The person now expects negative social interactions from others and behaves accordingly to protect themselves, but often push away those who may be harmlessly socializing. Thus, those stuck in the regulatory loop of loneliness settle into a self-

fulfilling prophecy where they do not believe others want to interact with them and therefore actively distance themselves from others (Hawkley & Cacioppo, 2010). This sets in motion a cycle of avoiding others as to not encounter more negative events, but this behavior often isolates the person further and continues the belief that others do not like them.

In the long term, being caught in the regulatory loop of loneliness can increase cognitive load and decrease executive functioning, as well as have negative consequences on physical and mental health and well-being (Masi et al., 2011). Thus, keeping graduate students out of the regulatory loop of loneliness should be of utmost priority to graduate programs, as increasing cognitive load and decreasing executive functioning may affect performance outcomes (Kirschner, 2002; Masi et al., 2011).

Theories regarding loneliness specific to the field of industrial-organizational (I-O) are few and far in between. Much of the I-O literature draws from social and cognitive theories to explain loneliness in the workplace (see Gabriel et al., 2020; Ozcelik & Barsade, 2018; Wright, 2015; Wright et al., 2006). This is not to say that loneliness is understudied in I-O psychology, but rather that commonly recognized I-O outcomes (e.g., job commitment, socialization, performance, productivity, culture) might not be wholly represented through a social or cognitive lens. To address this gap in theory, Ozcelik and Barsade (2018) created the *model of workplace loneliness*, where affective commitment to organization (one's attachment to social environments) and employee approachability (how approachable others perceive an employee) mediate the effect of loneliness on job performance. In a study of 672 employees, Ozcelik and Barsade (2018) found support for their model in a time lagged study where greater workplace loneliness was related to lower job performance and lonelier employees tended to be less approachable and have lowered affective commitment. Although the researchers cannot claim

causality, their research adds support for the model of workplace behavior and integrates a previously social and cognitive construct into I-O literature, tying loneliness to work performance outcomes.

Taking into account the model of workplace loneliness and the following literature, many of my hypotheses are visualized in Figure 1.

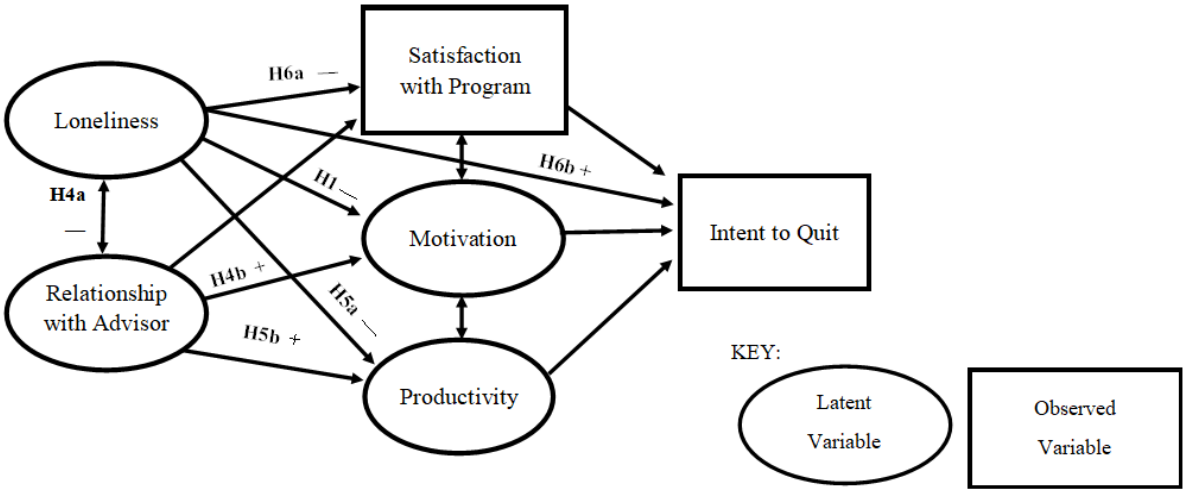

Figure 1: Hypothesized Model

Determinants of Job Performance

Campbell (1990) stated that there are three components to job performance: declarative knowledge, procedural knowledge, and motivation. Graduate programs may have control over the amount of declarative and procedural knowledge that a student gains but have relatively less control over the motivation of a student. Through Campbell's determinants of job performance, it is important to understand how motivation exists within a graduate student to understand how that may affect levels of performance in graduate school. One such model of motivation is *self-determination theory* (Deci & Ryan, 1985) and the *basic psychological needs theory* (BPNT) where motivation and psychological well-being are predicted by autonomy, competence, and

relatedness (Deci & Ryan, 2000; Ryan & Deci, 2000a; Vansteenkiste et al., 2020). Autonomy is the ability to make choices about one's life, competence is the perception of having the skills and ability to complete a goal, and relatedness is the sense of belonging and connectedness to others (Deci & Ryan, 2000). Satisfying the three basic needs leads to optimal development and functioning, including higher well-being, job satisfaction, organizational commitment, collaborative behaviors, and performance (Van Den Broeck et al., 2019).

Some research has suggested that applied properly, the fulfillment of the three basic needs may reduce loneliness. For example, Chong et al. (2020) examined the satisfaction of the three basic needs of MBA interns through socialization tactics and found that providing an environment that will fulfill the three basic needs is associated with higher organizational commitment and lower withdrawal cognitions. Translated to graduate students, it is highly likely that satisfying the needs of autonomy, competence, and relatedness early on in the graduate program will have similar results. However, as graduate school tends to be unstructured and have a great deal of autonomy, it is possible that the needs of competence and relatedness require more attention to fulfill. A lack of relatedness may be associated with a lack of belonging and thus be an ingredient leading to loneliness. Similarly, perceiving the imposter phenomenon, or a sense of incompetence, can have detrimental effects to a graduate student, wherein the student may isolate from peers to avoid exposing themselves as "the imposter."

Another reason why social isolation and loneliness may lead to poor performance may be explained through social comparison theory (Festinger, 1954). Social comparison theory is rooted in uncertainty reduction theory, where the ability to compare oneself to others reduces uncertainty about the norms of a situation. Within the social comparison theory framework, Festinger (1954) proposes that we as humans have a drive to evaluate ourselves, and one such

way of doing so is by comparing ourselves to others around us. By comparing ourselves to those around us, we can gauge our level of performance relative to the norm. Thus, through social comparison theory, it is plausible that isolation hurts performance because isolation means that the individual is not exposed to the performance norm and may have a decreased sense of relatedness to others, and have a distorted view of competence, potentially leading to the imposter phenomenon and/or lowered performance.

H1: *Loneliness will be negatively related to motivation in STEM doctoral students.*

Factors Contributing to Isolation and Loneliness

Aligning with the regulatory loop model and basic needs theory, several factors such as mental health, imposter phenomenon, inter-personal relationship difficulties (such as lacking a sense of relatedness to others), and organization of program have been linked to perceived isolation and loneliness in graduate students (Cantor, 2020; Janta et al., 2014; Ray et al., 2019). Some research has categorized risk factors into groups: individual (personality, feeling different from peers, employment), interpersonal (exclusionary atmosphere, faculty relationship concerns, competitiveness), community (relocation reduces social support), and organization (too busy with coursework, program increases isolation) (Ali & Kohun, 2006; Grady et al., 2014; Ray et al., 2019). Perceptions of loneliness may reach peak points upon entry into graduate school and after finishing coursework and working toward PhD (Grady et al., 2014). Upon beginning graduate school, students are balancing workload and often are adjusting to relocation and have limited pre-established social networks (Grady et al., 2014; Ray et al., 2019). However, after finishing coursework and working on dissertations, graduate students often face a different type of isolation, where they may have a social network built within the program, but may not be as active within it, thus feeling isolated (Ali & Kohun, 2006).

Loneliness and Mental Health

Loneliness can be detrimental to a graduate student's mental health and ultimately graduate school performance. Previous studies have found loneliness to be associated with depression (Bradley, 2000), anxiety (Yang & Clum, 1995), alcohol abuse, sleep problems (Mushtaq et al., 2014), and overall poor mental health and wellbeing in graduate students (Ali & Kohun, 2009; Barry et al., 2018; Cacioppo et al., 2006; Hamza et al., 2020). Having a mental health issue can further increase a student's sense of isolation, making them feel as though they must face their issues alone, creating a cycle of perpetuating situations where feelings of loneliness can grow (Cantor, 2020). Additionally, within the regulatory loop model, individuals who become isolated due to mental health issues may continue to perceive more threat in social interactions and be less likely to attempt to exit the loop.

Some research shows that it may not be students with pre-existing mental health concerns that graduate programs should be worried about, but rather, students with no pre-existing mental health concerns who experience an increase in loneliness as they transition into graduate school (Hamza et al., 2020). This may be because the transition to graduate school can bring a sudden onset of social isolation without the knowledge of coping resources to deal with this new experience; whereas a student who has a known mental health concern may be more aware of resources to mitigate worsening their condition. According to the regulatory loop model, if the student is unable to get out of social isolation, they may find themselves in the loneliness loop, and further harm their mental well-being (Masi et al., 2011). However, graduate students who experience mental health issues and report a good relationship with their advisor are more likely to seek help for mental health issues (Hyun et al., 2006). Even this one relationship can help to mitigate the negative effects of loneliness and increase help seeking for mental health issues.

Regardless, the likely impact of poor mental health on graduate student productivity is notable. Mental health issues are likely to reduce research productivity, and increase likelihood of attrition (Guthrie et al., 2017; Mackie & Bates, 2019). Therefore, less loneliness is likely to be associated with better mental health and research productivity as a result of the graduate student being more engaged and completing their studies.

Loneliness and the Imposter Phenomenon

A woe that many graduate students struggle with, imposter phenomenon, is associated with and can be a predictor of isolation and loneliness (Cohen & McConnell, 2019). Imposter phenomenon is defined as the feeling in high-achieving individuals who fail to recognize their competence in the field, often attributing success to luck or external factors (Bravata et al., 2019). Imposter phenomenon plagues graduate students, with some programs reporting up to 80% of students experiencing at least moderate imposter phenomenon (Sims & Cassidy, 2020). However, reducing isolation may be one way to decrease imposter phenomenon in graduate students. Cohen and McConnell (2019) found through a national survey of graduate students that a one-point increase in perceived isolation from faculty (on a five-point scale) was equal to an 18% increase in a student's imposter phenomenon score, while a one-point increase in perceived isolation from other students corresponded to a 7% increase in the student's imposter phenomenon score. It is possible that the relationship between imposter phenomenon and isolation could be explained through social comparison theory (Festinger, 1954), wherein imposter phenomenon is the result of isolated students lacking exposure to peers as to evaluate their experiences in comparison to their peers. Feeling isolated or lonely means that graduate students are not exposed to other students' experiences and are unable to put their own experiences into perspective (Lovitts, 2001). An inability to make social comparisons can lead to

experiences of imposter phenomenon and further isolation because of a perceived lack of fit with others and the program (Cohen & McConnell, 2019). Imposter phenomenon proves itself to be a double edge sword - should one be inflicted by it, one may draw away from social connections, but by isolating oneself, one might be digging an imposter phenomenon grave. However, it is possible that this spiral works backwards. Reducing social isolation exposes graduate students to the experiences of their peers, creating a form of social comparison, where each can understand the performance norms of the program, feel a sense of belonging and identity, and avoid loneliness. Further, exposure to the performance norm through peer interactions may increase perceived competence, both reducing imposter phenomenon and satisfying a basic need. Reducing imposter phenomenon by reducing social isolation could alleviate some anxiety in graduate students (Thompson et al., 1998), decreasing mental health concerns for some.

Loneliness and Underrepresented Groups

Graduate students from underrepresented groups may find it difficult to satisfy the basic need of relatedness, which could affect motivation and performance outcomes (Ryan & Deci, 2000b). International students and students from underrepresented groups such as women and/or people of color report higher levels of social isolation and loneliness, and lower levels of commitment to graduate school, particularly in the STEM fields (Anderson, 2017; Charleston et al., 2014). These students, who may not feel a sense of inclusion or relatedness to their peers, are at higher risk of attrition (Anderson, 2017) which further homogenizes the STEM fields.

Students of color in graduate schools often perceive graduate school to be unwelcoming, and experience many microaggressions that increase a sense of exclusion (Alexander & Hermann, 2016; Harris & Linder, 2018; Torres et al., 2010). Not only are students of color experiencing common graduate school stressors, but also tend to be the minority, and may feel

cultural isolation (Gay, 2004) and lack a sense of peer support (Harris & Linder, 2018), lending to increased loneliness. This may be in part because students of color tend to be invited to fewer out of the classroom social events by their white peers (Schwartz et al., 2003), and in turn are "systematically denied the rich social experiences and informal learning opportunities" that are attended by white peers (Johnson-Bailey et al., 2008, p. 188) further spiraling the lack of belonging, inability to participate in social comparison, and increased sense of loneliness.

International students often experience high levels of isolation and loneliness, perhaps because of differences in academic and social culture (Erichsen et al., 2014), as well as being a minority group. However, the relationship between perceptions of isolation and reporting isolation is complicated for international students. Erichsen et al (2014) interviewed graduate students and found that when asked directly if they feel isolated, many will report not at all, but would talk about isolation as a personal concern as a response to other questions. This might be because international students often have a strong sense of purpose being in a graduate program and focus less on relationship outcomes and more on career outlooks. Hence, forming relationships is not perceived to be a primary issue with graduate studies themselves, but it does still affect the student personally. Forming support networks within a chosen program helps international students to debrief on emotional or academic topics (Le & Gardner, 2010).

Women are often out-grouped in STEM fields, outnumbered by male counterparts (Murphy et al., 2007), fighting a male-centric environment (Cheryan et al., 2009), and often facing gender bias and sexual harassment, which can lead to lower levels of motivation for students in STEM fields (Leaper & Starr, 2019; Smith et al., 2012), decreased sense of belonging (Smith et al., 2012), and potential increased loneliness. In some studies, up to 70% of undergraduate women experienced at least one instance of gender related bias in a STEM course

(Leaper & Starr, 2019), which can lead to a decreased sense of belonging (Smith et al., 2012), and lead to attrition from the STEM pipeline (Robnett, 2016). In these cases, having strong encouragement from friends, not necessarily peers, can increase motivation for work in STEM fields and mitigate some of the negative effects of gender bias (Leaper & Starr, 2019), perhaps because of an increased sense of relatedness and competence. Many women in STEM graduate programs find social interactions to be larger obstacles to achievement than organizational policy, suggesting that they face unwritten culture and climate issues rather than written program regulations or classroom rigor (Amon, 2017). Experiencing loneliness in STEM fields as a woman may interfere with research productivity, which can have negative effects on career outcomes (Pinheiro et al., 2012). Thus, it is important for women to build and maintain a social network to satisfy relatedness and competence needs, mitigate the negative effects of gender bias and to discourage loneliness and attrition from the program. Therefore, Hypothesis 2 states:

H2: *Students who identify with underrepresented, minority groups (e.g., non-binary, non-white) will report higher levels of loneliness and lower levels of motivation, satisfaction, and productivity, and higher intention to quit their graduate program compared to students from majority groups.*

Loneliness in STEM Graduate Programs

Some research found that isolation and loneliness varies by field of study. For example, within science, math, engineering, and technology, graduate students in the social sciences may have an increased risk for loneliness compared to graduate students in the natural sciences and technology (Janta et al., 2014). This may be due to the different methods of training by program. Students in social sciences are often taught to build and work on their own projects, while those in natural sciences may work together in labs or on projects overseen by the advisor (Chiang,

2003). Even within science fields, graduate students report different levels of satisfaction with peer interaction that may lead to changes in perceived isolation and loneliness. One study found that students in engineering and technology graduate programs rated lower satisfaction with peer interactions than students in exact and natural science or health and medical (Zhang et al., 2019). Again, this may be because of differences in lab interactions. It is possible that the difference in experiences of loneliness lead to higher completion rates in the natural sciences than social sciences (Wright & Cochrane, 2000). Therefore, Hypothesis 3 states:

H3: *Doctoral students in natural sciences will report less loneliness than those in social sciences.*

The Role of the Advisor

A graduate student's advisor plays an important part in the graduate school experience. The advisor has great responsibility, as many studies show how this relationship can contribute to student satisfaction, persistence, and academic achievement (see Sverdlik & Hall, 2018 for a full review). Most notably, the advisor plays a large role in the socialization process of a graduate student, not only academically and professionally, but also with others, which can either contribute to the students sense of belongingness and relatedness or hollow the hole for loneliness (Le & Gardner, 2010; Pinheiro et al., 2012; Sverdlik et al., 2018). Building a relationship between a new student and faculty and peers early in the transition to graduate school may be a vying factor in reducing loneliness for a graduate student (Goplerud, 1980). Thus, the relationship between an advisor and a graduate student is important to preempt feelings of loneliness in a graduate student and to program outcomes. Because previous research has already provided empirical support for the relationship between satisfaction and productivity

with relationship with advisor, I sought to test two additional hypotheses about the links between a student's relationship with their advisor and loneliness:

H4a: *Relationship with advisor and loneliness will be negatively associated.*

H4b: *Relationship with advisor will mediate the relationship between loneliness and motivation.*

Potential Outcomes of Loneliness and Isolation

Performance

Based on the model of workplace loneliness and the cognitive effects of the regulatory loops of loneliness, it is likely that loneliness in graduate students can predict performance outcomes. As noted previously, loneliness can increase cognitive load and decrease executive functioning (Masi et al., 2011), and lead to lowered affective commitment and performance (Ozcelik & Barsade, 2018). In addition, satisfying the needs of relatedness and competence may lead to higher motivation, which in turn will have a positive outcome on performance (Campbell, 1990; Deci & Ryan, 2000). Therefore, mitigating loneliness may have an impact on performance.

Previous research suggests that isolation and loneliness may mediate graduate school outcomes such as productivity, engagement, motivation, attrition, and satisfaction with the program (Ali & Kohun, 2006, 2009; Ozcelik & Barsade, 2018). The perception of loneliness suggests a lack of connection with others, possibly others who would help advance the students' career. Within the workforce, professional isolation is associated with lower perceived competence, lower performance, and fewer opportunities for career growth (Anderson et al., 2015; Golden et al., 2008). Extrapolated to graduate programs, this might mean that a student

who feels lonely or isolated may not be offered as many opportunities to perform, and experience imposter phenomenon, which may affect their performance.

When one lacks connections in general, it may be harder to gain and use professional connections leading to stronger performance. For example, collaborations are one of top strategies of highly productive scholars to publish research (Martínez et al., 2011). Collaboration increases confidence, reduces loneliness, and encourages graduate students to perform research (Hemmings, 2012). Collaboration can be used to negate loneliness by creating networks and reducing imposter phenomenon (Hemmings, 2012). In a study of bibliometric publication data compared to survey data from academic scientists, graduate student publication and collaboration were found to be predictors of later career success and productivity (Pinheiro et al., 2012). What is most notable, however, is that those who published with their advisor at least once before attaining their PhD reported more than 30% more publications per year than those who did not (Pinheiro et al., 2012). Further, highly productive scholars note building relationships and collaborating as the most common strategy for high productivity (Martínez et al., 2011). This includes collaborating with peers, mentors, and other students (Martínez et al., 2011). Certainly, knowing other people and being able to work with them successfully contributes to productivity in research.

One might ask, is collaboration with an advisor not expected in graduate school? For some students, it is less likely. Underrepresented groups (i.e., not white males) are less likely to publish with an advisor, perhaps because of the issues they face relating to social isolation where a strong working relationship was not established with the advisor (Pinheiro et al., 2012). Thus, the opportunities for collaboration are severely limited and impact future productivity. Being socially isolated limits collaboration opportunities, while having collaboration opportunities

rebuts social isolation, particularly in underrepresented groups (Amon, 2017; Jones, 2016). Collaboration is a form of networking and can be a strategy to form relationships with faculty and peers (Jones, 2016), thus mitigating perceptions of social isolation and potentially increasing performance.

H5a: *Loneliness will be negatively related to productivity.*

Based on the same rationale described earlier regarding the importance of the quality of a student's relationship with their advisor, I also hypothesize that the association between loneliness and productivity will be mediated by relationship with advisor.

H5b: *Relationship with advisor will partially mediate the relationship between loneliness and productivity.*

Attrition

At a time when graduate students may need encouragement to continue, they may feel alone and with little support from peers, contributing to feelings of loneliness and isolation. In fact, doctoral students find the experience of social isolation so troubling that feeling socially isolated is one of the top reasons that doctoral students drop out of their graduate program (Ali & Kohun, 2006). In multiple qualitative studies, isolation and loneliness are reported as a contributing factor to attrition from doctoral programs (Ali & Kohun, 2009; Lott et al., 2009; Ruud et al., 2018). Feeling separated from the institution and peers is related to higher attrition rates from graduate programs (Herbert, 2006; Morgan & Tam, 1999). Ultimately, the association between social isolation, loneliness, and attrition from graduate programs makes the aforementioned constructs critical to understand and prevent.

H6a: *Loneliness will be negatively related to satisfaction with program.*

Due to the cross-sectional nature of the current study, intent to quit is measured instead of attrition. According to the theory of planned behavior which states that attitudes or beliefs lead to behavioral intentions which in turn lead to behavior, an individual who has a greater intention to quit would be at higher risk of attrition (Ajzen, 1991). Having an intention to quit does not necessarily mean that the student has or will drop out, but measuring intentions to quit is as close as we can do without measuring actual attrition.

H6b: *Satisfaction with program will partially mediate the relationship between loneliness and intent to quit.*

Contributions of the Current Study

Loneliness affects many graduate students to different degrees and in different capacities (American College Health Association, 2018; Ray et al., 2019; MIT Institutional Research, n.d.). It is particularly harmful for those in underrepresented groups, and it is one of the top named factors in attrition for all groups. Thus, it is clear that to some extent, loneliness hinders performance. Obviously, dropping out of a graduate program brings research productivity to nearly none. But what is the extent of the relationship between loneliness and performance outcomes for graduate students in doctoral programs? Many of the previous studies about loneliness and social isolation have been conducted via interviews. Although informative and beneficial for in-depth understanding, qualitative research often limits a researcher's ability to generalize to a broad population and study trends over time. Additionally, much of the current research focuses on mental health and wellness outcomes, but less on performance outcomes, despite empirical evidence indicating that graduate student productivity is linked to later career success and productivity (Pinheiro et al., 2012). Recognizing the lack of literature in this area, Feldon et al. (2010) called for an increase in research on doctoral education in the STEM fields

focusing on performance-based research examining individual differences that affect doctoral students' development. Understanding how loneliness relates to important graduate school outcomes may inform behaviors to develop interventions to improve satisfaction, motivation, and productivity, and decrease attrition.

Noting what Feldon et al., (2010) suggested, this study will investigate how loneliness relates to outcomes relevant to performance in STEM doctoral programs in the United States, using a cross-sectional study. A cross-sectional study can be used to gather baseline data at a single time point. For this study, a cross-sectional study is appropriate because it will gather data from a national U.S. participant pool and be able to make comparisons across fields of study, year in program, and across constructs.

METHOD

Participants

I recruited N =1117 doctoral graduate students in any year of degree program in STEM fields across the United States. To be eligible for participation, students must be over the age of 18 and must be a current doctoral student in any year of degree program within a STEM field.

Participants were recruited through several avenues. First, participants were invited via the regional and national network of the Colorado State University STEM Center. Second, I reached out to graduate student groups on social media and on university campuses such as the Society for Advancement Chicanos/Hispanics & Native Americans in Science (SACNAS) at Colorado State University and nationally and the National Black Graduate Students Association (NBGSA) to diversify my participant pool. Third, my advisor and I reached out to our network of faculty at other colleges and universities in the U.S. to share my invitation to doctoral graduate students at their school. Finally, I collected publicly available emails from STEM graduate departments and emailed participants my screening survey directly after confirming with the IRB that this would be acceptable.

Design

This is a cross-sectional study in which participants were asked to complete an online survey at the beginning of the semester (September 2021), and an objective productivity measure in November 2021. Dependent measures included motivation, satisfaction with program, productivity, and intent to quit. Specific details about measures are listed in the next section.

Measures

A complete list of survey measures included in this study are available in Appendix A. Prior to finalizing the measures used in my study, I followed up with individual committee members based on our discussion at the thesis proposal meeting.

Demographics

Participants were asked to report their gender, race, ethnicity, whether they are a first-generation student, sexual orientation, age, where they heard about the study (club, social media, through your department), field of study, year in program, level of lab interaction, and current level of COVID-19 restrictions (e.g., mask mandate, limited capacities, vaccine requirement).

Loneliness Scales

Because there are many different approaches to loneliness, this study included three scales to assess perceptions of loneliness. The three scales are the Loneliness and Belonging Scale, the Professional Isolation Scale (Golden et al., 2008), and the UCLA Loneliness Scale (Russell et al., 1978)

The Loneliness and Belonging Scale

The Loneliness and Belonging Scale a 6-item measure. Three of the items relate to a sense of belonging to the graduate program (e.g., "I feel a sense of belonging to my graduate program.") ($\alpha = .94$), whereas another three items relate to general isolation and loneliness frequency (e.g., "how often do you feel isolated from others?") ($\alpha = .86$). The items relating to frequency were derived from Hughes et al. (2004), whereas the other items were created based off the findings of Baumeister and Leary (1995). The response scale for items was 1 (*hardly ever*) to 5 (*most of the time*) scale.

Professional Isolation Scale

The Professional Isolation Scale (Golden et al., 2008) is designed to measure professional isolation. This scale was chosen because it has shown to have convergent validity with the UCLA Loneliness Scale (Version 3; Russell, 1996) and content validity fitting professional isolation. The Professional Isolation Scale measures the perception that one is out of touch with others in the workplace. This scale was adapted to fit the study population. Participants were asked to rate the extent that they experience each item on a scale of 1 (*rarely*) to 5 (*most of the time*). This scale showed acceptable internal consistency with my sample ($\alpha = .81$). This scale has been negatively associated with job performance and turnover intentions (Golden et al., 2008).

The UCLA Loneliness Scale

The UCLA Loneliness Scale measures subjective feelings of loneliness and isolation (Russell et al., 1978). Participants were asked to rate 20 items relating to how often they experience each item on a scale of 1 (*not at all*) to 4 (*often*). An example item is "I lack companionship." This scale showed acceptable internal consistency with my sample ($\alpha = .81$). The UCLA Loneliness scale has demonstrated test-retest reliability, convergent validity with other loneliness scales, construct validity with relationships with other individuals and measures of health and well-being (Russell, 1996).

Objective Productivity

A measure of objective productivity was adapted from Barrick et al. (2011). Participants were asked to report the number of research presentations, publications before and after enrollment, previous experience or plans to participate in formal instruction, practice, or development training, and teaching experiences. Number of experiences were summed to

measure objective productivity. This measure was used priorly by the National Research Council to measure the productivity of graduate students (Barrick et al., 2011).

Subjective Productivity

I modified the Health and Work Questionnaire (HWQ; Shikiar et al., 2004) to be a 25-item scale to measure subjective productivity and work satisfaction. Items relating to topics such as feelings of personal reward, control and communication, and negative emotions with others were dropped. Items were modified to reflect graduate program experience (i.e., advisor instead of supervisor, peers instead of coworkers). Three items asked participants to rate their satisfaction with the graduate program, relationship with fellow students, and relationship with professors ($\alpha = .75$). Three items asked participants to rate the difficulty of completing tasks ($\alpha = .78$). Three questions included rating productivity in terms of efficiency ($\alpha = .78$), quality ($\alpha = .85$), and amount of work completed ($\alpha = .82$). In these questions, participants were asked to rate how productive 1) they rate themselves, 2) an advisor might rate them, and 3) how peers might rate them. Participants were asked to respond on a ten-point scale tailored to each question (e.g., "very dissatisfied" to "very satisfied" for questions dealing with work satisfaction; "my worst ever" to "my best ever" for questions dealing with rating quantity, quality and efficiency for work). The HWQ has been shown to have strong internal consistency and criterion validity against other measures of productivity such as hours lost.

Additionally, participants completed the Health-Related Quality of Life and Work Productivity Questionnaire (HQWP; Huang, 2008). This 8-item scale asked participants to rate the frequency of productivity issues at work (e.g., how much of the time was the speed of work or productivity higher than expected?). Participants rated these items on a 1 (*never*) to 5 (*always*) scale. This scale has previously demonstrated construct validity with presenteeism and

productivity measures (Huang, 2008). Running psychometrics revealed that two items loaded poorly in this sample and were dropped in future analyses (i.e., Did you have trouble controlling your emotions when you were around people at work?; Did you get along well with others at work?). Internal consistency for the used scale was α = .81.

The Basic Psychological Need Satisfaction and Frustration Scale

To measure motivation, I used the Basic Psychological Need Satisfaction and Frustration Scale (BPNSFS; Chen et al., 2015). Rooted in self-determination theory, the BPNSFS captures both satisfaction and frustration of the three basic needs to conceptualize motivation: autonomy, competence, and relatedness. The BPNSFS is a 24-item scale where participants are asked to rate the extent of which they agree with each statement on a scale of 1 (*not true at all*) to 5 (*completely true*). This scale was scored as six subscales: autonomy satisfaction (α = .83), autonomy frustration (α = .81), relatedness satisfaction (α = .87), relatedness frustration (α = .79), competence satisfaction (α = .92), and competence frustration (α = .84). This scale has demonstrated construct validity through associations with life satisfaction, vitality, and depressive symptoms (Chen et al., 2015).

Relationship with Advisor

Relationship with advisor was measured using the Advisory Working Alliance Inventory (AWAI; Schlosser & Gelso, 2001). The AWAI is a 30-item measure where respondents are asked to indicate their level of agreement on a 5-point Likert type scale from 1 (*strongly disagree*) to 5 (*strongly agree*). The AWAI has 3 subscales: rapport, apprenticeship, and identification-individuation. Rapport is defined as how well the advisor and advisee get along interpersonally (e.g., My advisor welcomes my input into our discussions). Apprenticeship is defined as the amount to which the advisor has aided in the professional development of the

advisee (e.g., I learn from my advisor by watching them). Identification-Individuation is the amount to which the advisee wants or does not want to be like their advisor (e.g., I tend to see things differently than my advisor). Scores are summed and high scores are indicative of a strong sense of each construct. The AWAI has high internal consistency interrater reliability and convergent validity when compared to the Counselor Rating Form (a measure of perceived expertness, attractiveness, and trustworthiness of a counselor, although the word advisor was substituted for counselor). In this sample, all subscales showed high internal consistency (rapport: $\alpha = .93$; apprenticeship: $\alpha = .88$; identification-individuation: $\alpha = .85$).

Satisfaction with Program

A satisfaction with program measure was adapted from the University of Kansas Graduate Student Satisfaction Survey (University of Kansas, 2016). The scale measures overall satisfaction with three items based on the statement "Overall, how would you rate the quality of:" (1) your academic experience at the university, (2) your student life experience at your university, and (3) your overall experience at your university. Participants were asked to rate these items on a scale of 1 (*poor*) to 5 (*excellent*). This scale showed high internal consistency, $\alpha = .85$.

Intention to Quit

Intention to quit (ITQ) one's graduate program was measured with a three-item measure adapted from Dresel and Grassinger (2013). An example question is, "I often think about dropping out of my current graduate program." Participants responded on a 1 (*strongly disagree*) to 5 (*strongly agree*) scale. This scale was previously used to measure intent to drop out of university and examine its relationship between school achievement and performance. This scale

showed a somewhat low level of internal consistency, α = .66, possibly due to the variation in reasons for responses in item content across the three items.

Positive and Negative Affect

The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) is a 20-item scale to assess positive and negative affect. Participants indicated the extent to which they have felt the item in the past week (e.g., interested, distressed, irritable, determined) on a 1 (*very slightly* or *not at all*) to 5 (*extremely*) scale. Separate scores were constructed for positive affect (α = .93) and negative affect (α = .89). This scale has been correlated with other positive and negative affect scales, as well as the Beck Depression Inventory and STAI State Anxiety Scale (Watson et al., 1988).

Procedure

Participants were invited via email in September 2021 to participate in the study. Participants were asked to read and sign an informed consent. After completing the informed consent, participants were asked to complete general demographics, satisfaction with program, the ITQ, the Professional Isolation Scale, the Loneliness and Belonging Scale, the UCLA Loneliness Scale, measures of objective productivity (asked only in the second survey), the Health and Work Questionnaire, the Health-Related Quality of Life and Work Productivity Questionnaire, the Basic Psychological Needs Satisfaction and Frustration Scale, the Advisor Working Alliance Inventory, and the Positive and Negative Affect Scale. The entire survey took approximately 20 minutes. The entire study was completed online. Data were collected through the month of September. A second survey, containing the objective productivity scale was sent and completed in November. This survey is a part of a larger, three-year study. Data will be

collected and stored until the completion of the entire longitudinal study and will be destroyed on or before December of 2026.

Data Analyses

I exported the data from Qualtrics directly into an SPSS file. Data cleaning, including analyzing missing data, running psychometrics, and creating scale scores were completed in SPSS. The hybrid path analysis and SEM model was completed in Mplus Version 8.7. All other analyses were completed in SPSS.

Data cleaning

After uploading the data into SPSS, I ran frequencies to check for abnormal and missing data. Some abnormal data was identified (e.g., incorrect scale coding) and corrected. Individuals who did not complete past the demographics were removed. I checked normality and skewedness. Most variables were not skewed, nor were they moderately skewed. Assessing kurtosis revealed similar findings. Only two variables were of concern, the UCLA Loneliness Scale, which reported high positive skew and high kurtosis, and the AWAI Rapport, which reported high negative skew and high kurtosis. Variable transformation of UCLA Loneliness Scale and AWAI Rapport showed no difference in correlations, so skewedness was not a concern in future data analyses. See Table 1 for scale descriptive statistics, including means, standard deviations, skewness and kurtosis.

To investigate missing data, I began with assessing item level missing data. Individuals who did not complete more than 50% of the loneliness scales were removed from analysis. This gave me a final sample of 1043, with an acceptable average missing data percentage of 2.9% per scale (min = 0, max = 6.5%, Advisor Relationship Identification-Individuation). Further analyses were run with pairwise deletion to retain as many participants in the analyses as possible.

Psychometrics

Using SPSS, I conducted a principal components analysis to evaluate the factor structure of the scales and assess that they measure what they proport to measure. I used a principal components analysis to identify general evidence that the scales fit their expected factors, as all scales are existing, validated scales. Nearly all scales and subscales were appropriate and reliable within my sample. Two items were dropped from the HWQP ("Did you have trouble controlling your emotions when you were around people at work?" and "Did you get along well with others at work?"), which loaded onto a second factor. Theoretically, it made sense to drop these items, as they addressed relationships with other people, not work productivity. Removing those items resulted in a single factor scale.

Table 1.

Descriptive Statistics, Skewness and Kurtosis

	N	Mean	SD	Skewness		Kurtosis	
				Statistic	S. E.	Statistic	S. E.
Year started graduate program	1043	2018.49	1.75	-0.50	0.08	-0.03	0.15
Age	1041	27.14	4.08	2.35	0.08	10.17	0.15
Lab Interactions	1043	3.40	2.01	0.37	0.08	-1.64	0.15
Intent to Quit	1043	2.05	0.90	0.72	0.08	-0.19	0.15
PIS	1043	2.53	0.81	0.40	0.08	-0.12	0.15
LBS	1041	3.48	1.14	-0.59	0.08	-0.58	0.15
LBS Frequency	1043	2.29	0.91	0.87	0.08	0.34	0.15
UCLA	1043	1.88	0.76	1.33	0.08	1.77	0.15
Satisfaction	1043	3.71	0.93	-0.88	0.08	0.42	0.15
Work Relationships	1036	3.62	0.89	-0.64	0.08	-0.07	0.15
Work Efficiency	1021	6.07	1.81	-0.58	0.08	0.46	0.15
Work Quality	1015	6.35	1.89	-0.47	0.08	-0.05	0.15
Work Amount	1018	5.93	2.05	-0.32	0.08	-0.28	0.15
Work Frequency	1020	2.52	0.91	0.75	0.08	-0.03	0.15
Autonomy Satisfaction	1005	3.64	0.86	-0.68	0.08	-0.07	0.15
Autonomy Frustration	1005	3.05	0.96	0.00	0.08	-0.79	0.15

Relatedness Satisfaction	1005	3.96	0.83	-0.86	0.08	0.53	0.15
Relatedness Frustration	1005	2.08	0.86	0.74	0.08	-0.05	0.15
Competence Satisfaction	1005	3.66	0.94	-0.83	0.08	0.22	0.15
Competence Frustration	1005	2.94	1.05	0.03	0.08	-0.89	0.15
AWAI Rapport	977	4.14	0.88	-1.28	0.08	1.12	0.16
AWAI Apprenticeship	977	3.50	0.76	-0.57	0.08	-0.22	0.16
AWAI Identification-Individuation	975	3.39	0.98	-0.39	0.08	-0.47	0.16
Positive Affect	976	2.86	0.94	0.04	0.08	-0.78	0.16
Negative Affect	976	2.11	0.84	0.80	0.08	-0.05	0.16
HWQP	1018	2.68	0.72	0.78	0.08	0.40	0.15
Objective Productivity	888	37.67	35.59	1.55	0.08	3.27	0.16

Note: Lab interactions: Frequency of interactions with others in the lab, PIS = Professional Isolation Scale, LBS = Loneliness and Belonging Scale, UCLA = UCLA Loneliness Scale, Satisfaction = Satisfaction with program, AWAI = Advisor Working Alliance Inventory, HWQP = Health-Related Quality of Life and Work Productivity Questionnaire

RESULTS

Descriptive Statistics

1117 participants completed the online survey. Of this sample, 74 were removed from the sample because they were missing more than half the data on key variables of either intent to quit or loneliness. Our final usable sample consisted of 1043 participants, ranging in age from 19 to 62, with a mean of 27.1 (*SD* = 4.08). The majority of participants were White (58.5%) followed by Asian (13.2%), Hispanic (7.7%), and Biracial/Multiracial (indicated by reporting two or more races) (5.0%). These percentages are similar to the national distribution of race and ethnicity of postbaccalaureate enrollment of 2019 (White: 62%; Asian: 8%; Hispanic:12%; Multiracial: 3%; NCES, 2020). Participants who identified themselves as Hispanic may have indicated variability in race, but they remain their own group because their ethnicity may have stronger influence on responses than biological race, as commonly distinguished in health services research (Ford & Kelly, 2005). Additionally, this is how it is measured by the National Center for Education Statistics. Men comprised 31.7% of the sample, whereas women comprised 53.2% of the sample, and 3.7% identified as non-binary. The sample was split almost evenly between being a first-generation graduate student (40.6%) and having one or more parent or guardians having at least started graduate school (48.6%). Field of study was sorted into science (57.8%), technology (.2%), engineering (7.0%), math (7.1%), or other (e.g., students did not identify a distinct STEM category or field) (17.4%). Frequencies for all demographic variables can be found in Table 2.

Table 2

Demographics

	N	%
Race		
White	683	58.5
Hispanic	90	7.7
Black/African American	31	2.7
Asian	156	13.4
Other	24	2.1
Biracial/Multiracial	58	5.0
Year in Program		
1	133	11.4
2	223	19.1
3	187	16.0
4	192	16.5
5	171	14.7
6+	137	11.7
Gender		
Man	370	31.7
Woman	621	53.2
Non-binary	43	3.7
Other/Prefer not to answer	9	.8
Transgender		
No	1018	87.2
Yes	23	2.0
First Generation Graduate Student		
No	567	48.6
Yes	474	40.6
International Student		
No	831	71.2
Yes	211	18.1
Sexual Orientation		
Asexual	32	2.7
Bisexual	137	11.7
Gay	28	2.4
Heterosexual or straight	703	60.2
Lesbian	23	2.0
Pansexual	26	2.2

Queer	60	5.1
None of the above/prefer not to answer	33	2.8
STEM Grouping		
Science	674	57.8
Technology	2	.2
Engineering	82	7.0
Math	83	7.1
Other	203	17.4

Note. Biracial/Multiracial determined based on participants selecting more than one race. Percentages may not sum to 100.0% due to missing data.

Correlation Matrix

A correlation matrix with all variables revealed significant relationships at the $p < .01$ level between all variables, indicating high multicollinearity. See Table 3 for correlation coefficients among all study variables.

Model Testing

To test hypotheses H1 (loneliness will be negatively related to motivation in STEM doctoral students), H4a (relationship with advisor and loneliness will be negatively associated) H4b (relationship with advisor will mediate the relationship between loneliness and motivation), H5a (students who report a stronger sense of loneliness will also report lower subjective productivity), H6a (perceptions of loneliness will be negatively associated with satisfaction with program), H6b (satisfaction with program will partially mediate the relationship between loneliness and intent to quit), I computed a structural equation model in which some of the variables were modeled as latent variables and others were modeled as observed variables; more specific details about the models I computed are presented below. SEM is superior to regression analysis because it allows the researcher to test multiple associations simultaneously, compute mediation models, and adjust for unreliability in measures among latent variables (Schumacker & Lomax, 2010). However, for my purposes, SEM was not necessary to test all hypotheses, but rather, important for creating latent variables. A latent variable is a variable that is not directly

Table 3.

Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11
1. Satisfaction	--										
2. ITQ	-.50**	--									
3. PIS	-.40**	.31**	--								
4. LBS	.54**	-.38**	-.31**	--							
5. LBS Frequency	-.41**	.31**	.56**	-.39**	--						
6. UCLA	-.44**	.35**	.57**	-.43**	.82**	--					
7. Work Relationship	.68**	-.53**	-.46**	.61**	-.48**	-.52**	--				
8. Work Efficiency	.25**	-.35**	-.28**	.21**	-.25**	-.28**	.32**	--			
9. Work Quality	.21**	-.34**	-.25**	.20**	-.23**	-.25**	.31**	.79**	--		
10. Work Amount	.18**	-.29**	-.20**	.18**	-.19**	-.22**	.26**	.76**	.72**	--	
11. Work Frequency	-.34**	.41**	.39**	-.23**	.34**	.40**	-.38**	-.46**	-.45**	-.39**	--
12. HQWP	-.31**	.38**	.35**	-.19**	.34**	.38**	-.31**	-.53**	-.53**	-.47**	.69**
13. Autonomy Satisfaction	.51**	-.57**	-.33**	.41**	-.35**	-.41**	.57**	.39**	.39**	.33**	-.43**
14. Autonomy Frustration	-.40**	.47**	.32**	-.31**	.35**	.39**	-.44**	-.25**	-.23**	-.18**	.42**
15. Relatedness Satisfaction	.40**	-.29**	-.30**	.43**	-.54**	-.61**	.49**	.24**	.24**	.19**	-.28**
16. Relatedness Frustration	-.37**	.32**	.40**	-.43**	.58**	.67**	-.48**	-.23**	-.22**	-.18**	.32**
17. Competence Satisfaction	.34**	-.47**	-.33**	.26**	-.36**	-.40**	.40**	.49**	.54**	.45**	-.51**
18. Competence Frustration	-.30**	.45**	.38**	-.24**	.38**	.44**	-.39**	-.46**	-.47**	-.41**	.51**
19. Advisor Rapport	.47**	-.47**	-.39**	.35**	-.30**	-.37**	.56**	.25**	.27**	.20**	-.30**
20. Advisor Apprenticeship	.47**	-.43**	-.37**	.35**	-.27**	-.35**	.57**	.28**	.29**	.26**	-.31**
21. Advisor Identification - Individuation	.44**	-.44**	-.30**	.30**	-.25**	-.29**	.52**	.20**	.20**	.14**	-.27**
22. Positive Affect	.37**	-.42**	-.24**	.32**	-.28**	-.31**	.46**	.50**	.47**	.46**	-.44**
23. Negative Affect	-.32**	.41**	.36**	-.26**	.37**	.42**	-.38**	-.28**	-.31**	-.21**	.49**

	12	13	14	15	16	17	18	19	20	21	22	23
13. Autonomy Satisfaction	-.42**	--										
14. Autonomy Frustration	.37**	-.62**	--									
15. Relatedness Satisfaction	-.27**	.43**	-.28**	--								
16. Relatedness Frustration	.30**	-.40**	.40**	-.65**	--							
17. Competence Satisfaction	-.49**	.57**	-.38**	.39**	-.39**	--						
18. Competence Frustration	.47**	-.49**	.48**	-.31**	.46**	-.74**	--					
19. Advisor Rapport	-.27**	.49**	-.44**	.32**	-.41**	.37**	-.37**	--				
20. Advisor Apprenticeship	-.28**	.48**	-.35**	.33**	-.33**	.36**	-.31**	.73**	--			
21. Advisor Identification - Individuation	-.23**	.45**	-.47**	.22**	-.31**	.27**	-.29**	.70**	.68**	--		
22. Positive Affect	-.42**	.56**	-.39**	.34**	-.30**	.53**	-.49**	.29**	.41**	.33**	--	
23. Negative Affect	.42**	-.40**	.43**	-.32**	.41**	-.48**	.56**	-.40**	-.29**	-.30**	-.20**	--

Note: Satisfaction = Satisfaction with program, ITQ = intent to quit, PIS = Professional Isolation Scale, LBS = Loneliness and Belonging Scale, UCLA = UCLA Loneliness Scale, HWQP = Health-Related Quality of Life and Work Productivity Questionnaire

measured but inferred from a set of observed variables. For example, motivation is a latent variable that can be created using the observed variables and items measuring competence, relatedness, and autonomy. I created a latent variable for motivation using the basic needs satisfaction and frustration subscales, a latent variable for relationship with advisor by using the three components of the Advisory Working Alliance Inventory, a latent variable for loneliness using the Professional Isolation Scale, the Loneliness and Belonging Scale, and the UCLA loneliness scale, and a latent variable for productivity using the subscales of the Health and Work Questionnaire including relationship with program, difficulty of completing tasks, work efficiency, work quality, and amount of work completed, the Health Related Quality of Life and Work Productivity Questionnaire, and a sum of objective productivity. The SEM models for these variables indicated that there was an underlying relationship with most expected scales. Objective productivity did not significantly relate to other productivity variables (Estimate = -2.44 (SE = 3.59, p = .50), and was dropped to increase model fit.

Hypothesized Model.

I conducted a path analysis using Mplus 8.7 (Muthén & Muthén, 2017) to test my hypothesized model, that ITQ is predicted by loneliness indirectly via satisfaction, motivation, and productivity, controlling for relationship with advisor. See Figure 2 for the complete path model.

Overall Model Fit

The path analysis resulted in moderate fit of the model to the data. I used multiple fit statistics to decide the acceptability of model fit, as fit indices may report contradicting acceptability based on sample size and degrees of freedom (McDonald & Ho, 2002). The Chi-square test of model fit is commonly examined, where nonstatistical significance displays good

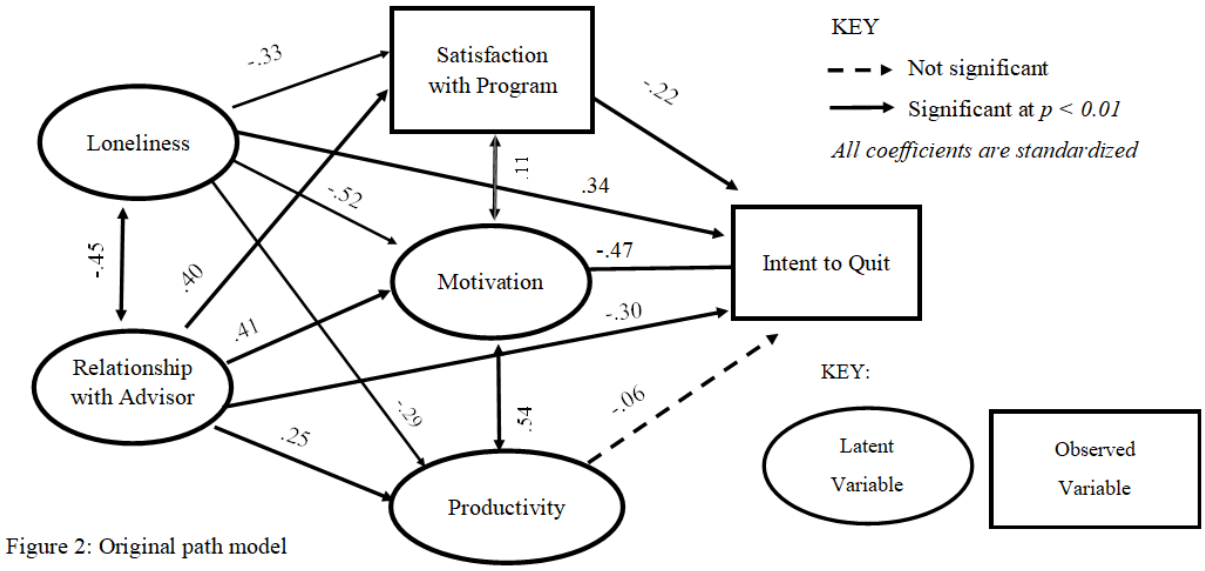

Figure 2: Original path model

fit. However, the chi-square test is not a useful test when sample size is large because of its sensitivity to sample size (Schumacker & Lomax, 2010; Raykov & Marcoulides, 2011). Chi-square fit statistics are reported here to show change in indices across models. Additional reported fit indices include the Comparative Fit Index (CFI) and Tucker Lewis Index (TLI) which range from 0 to 1, wherein a value above 0.9 is considered good fit (McDonald & Ho, 2002; Raykov & Marcoulides, 2011). The root mean square error of approximation (RMSEA) is another commonly used fit statistic that measures error (Raykov & Marcoulides, 2011). Ideally, this value would be 0, but values under 0.10 are considered acceptable. The RMSEA statistic tends to be larger in models with high degrees of freedom, meaning that this is not the strongest indicator of fit for my sample (Raykov & Marcoulides, 2011). Finally, the standardized root mean square residual (SRMR) complements the chi-square test, as it similarly measures the SEM model, but is not sensitive to sample size (Hu & Bentler, 1999; Asparouhov & Muthen, 2018). SRMR can range from 0 to 1.0, with values equal or less than 0.08 being acceptable model fit (Asparouhov & Muthen, 2018). The chi-square test of model fit in my original model was significant ($\chi^2(179) = 3456.16$, $p < .001$). Overall fit indices were somewhat acceptable, although not indicative of good fit (RMSEA = .13; CFI = .76; TLI = .72; SRMR = .13).

Models with Control Variables.

Because the original model resulted in poor fit, I tested the same model, but included control variables of use of mentoring, first generation graduate student, positive and negative affect, and COVID restrictions.

Controlling for COVID

I ran a point biserial correlation between all COVID restrictions and all measures in the study to assess the necessity of controlling for COVID restrictions. Most relationships were insignificant ($p > .05$), although that statistically significant relationships were small (ranging between -.14 to .10), and likely due to large sample size. Two restrictions showed the most significant correlations with other measures: limited capacity indoors and classes mostly online or hybrid. Thus, I created a dichotomous variable where participants had either limited capacity indoors and/or classes mostly online or hybrid or neither of these restrictions were present. I used this dichotomous variable to control for COVID restrictions.

Path model

I conducted a path analysis to test the hypotheses that ITQ is predicted by loneliness indirectly via satisfaction, motivation, and productivity, controlling for relationship with advisor, first generation, mentoring, positive affect, negative affect, and COVID restrictions. This model differs from the hypothesized model by including the variables first generation, mentoring, positive affect, negative affect, and COVID restrictions.

Overall Model Fit

The path analysis resulted in moderate fit of the model to the data. The Chi-Square test of model fit was significant ($\chi^2(281) = 4124.29$, $p < .001$). Overall fit indices were slightly worse than the original model (RMSEA = .12; CFI = .74; TLI = .69; SRMR = .17).

Modification Indices

Next, I investigated modification indices to identify empirical recommendations for improving model fit. Modification indices suggested changes to the SEM model and path analysis and I pursued those that were also theoretically appropriate. First, it suggested that the Health and Work Questionnaire – Relationship subscale be moved to the loneliness latent variable. This theoretically makes sense, as the relationship questions were very similar to the loneliness and belongingness questions. Second, it recommended that relatedness satisfaction and frustration be moved to loneliness. Again, this makes sense, as relatedness would be satisfied or frustrated when experiencing loneliness. Third, it suggested that competence satisfaction and frustration be moved to the productivity latent variable (See Figure 3 for final latent variables). Although competence was anticipated to be a component of motivation, it is possible that it

Loneliness	**Motivation**
• Work Relationship • Relatedness Satisfaction/Frustration • Professional Isolation Scale • Loneliness & Belonging • Loneliness & Belonging Frequency	• Autonomy Satisfaction/Frustration • Competence Satisfaction/Frustration
Productivity	**Relationship with Advisor**
• Work Efficiency • Work Quality • Work Amount • Work Frequency • HQWP • Competence Satisfaction/Frustration	• Rapport • Apprenticeship • Identification - Individuation

Figure 3. Final Latent Variables

aligns more strongly with productivity, as competence may be needed to perform (Bravata et al., 2019). Fourth, it suggested correlations between relatedness satisfaction and frustration with each other and with UCLA Loneliness Scale, competence frustration with competence satisfaction, the HQWP with the Health and Work Questionnaire- Frequency, the Health and

Work Questionnaire- Relationship with the Loneliness and Belonging Scale, and the UCLA Loneliness Scale with Loneliness and Belonging Frequency.

Optimal Model Fit

Taking into account the suggestions made by the modification indices, I analyzed another path model to test the hypotheses that ITQ is predicted by loneliness indirectly via satisfaction, motivation, and productivity, controlling for relationship with advisor.

Overall Model Fit

The path analysis after the aforementioned changes resulted in moderate fit of the model to the data, and model fit that was better than the previously tested model. The Chi-Square test of model fit was significant ($\chi^2(170) = 1317.01$, $p < .001$). Overall fit indices were acceptable (RMSEA = .08; CFI = .92; TLI = .90; SRMR = .08).

Direct Effects

Path estimates for the optimal model are shown in Figure 4. Several direct effects

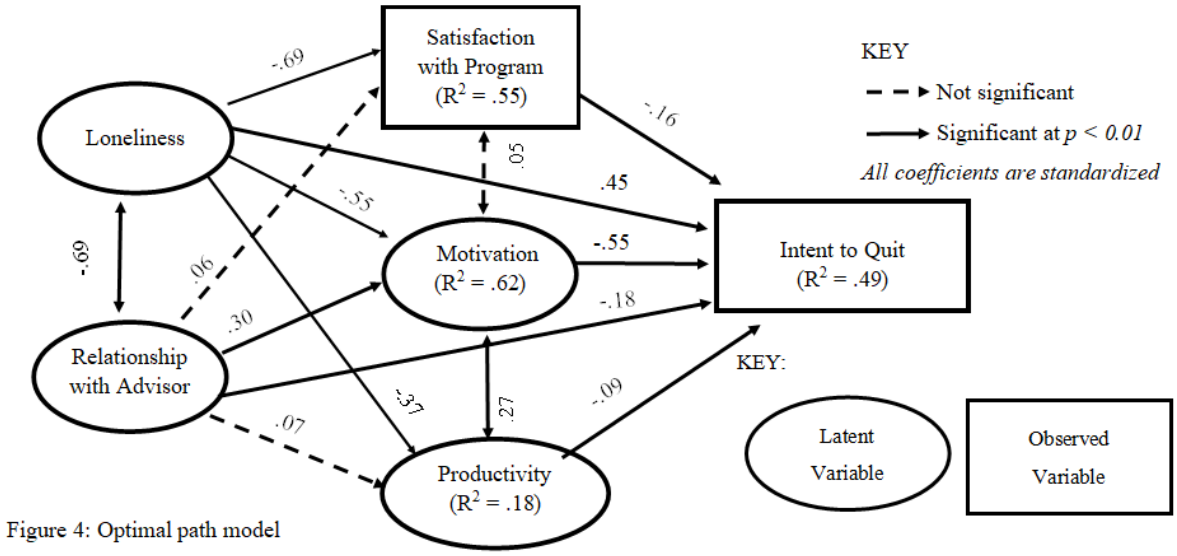

Figure 4: Optimal path model

specified in the model were statistically significant. Specifically, loneliness had a strong negative relationship with motivation (H1), relationship with advisor (H4a), productivity (H5a), and

program satisfaction (H6a), thus providing support for H1, H4a, and H6a, whereas relationship with advisor only predicted motivation, providing support for H4b. Hypothesis 5b, which stated that relationship with advisor would partially mediate the relationship between loneliness and productivity, was partially supported. Satisfaction, motivation, and productivity significantly predicted students' intentions to quit their graduate program (see Table 4 for full results).

Indirect Effects

Examination of the bias-corrected bootstrapped confidence intervals revealed that the total effect and specific indirect effects between loneliness and ITQ were statistically significant (Total β = 0.45 [0.39, 0.51]). This lends support for the optimal model; satisfaction, motivation, and productivity explained 49% of the variance between loneliness and intent to quit. The total effect and the specific indirect effects of motivation between relationship with advisor and ITQ were significant (Total β = -0.18 [-0.25, -0.12]). However, the indirect effect of productivity and satisfaction was not significant (see Table 4 for all analyses). These results indicate partial support for H5b (relationship with advisor would partially mediate the relationship between loneliness and productivity), direct: loneliness – relationship with advisor β = -.69, *SE* = .03; *p* = .00l; relationship with advisor – productivity β = .07, *SE* = .06, *p* = .2. The paths indicated full support for H6b (satisfaction with program will partially mediate the relationship between loneliness and intent to quit) direct: loneliness – satisfaction with program β = -.69, *SE* = .05, *p* = .00; satisfaction with program – intent to quit β = -.16, *SE* = .03, *p* = .00; indirect: intent to quit – satisfaction with program - loneliness β = .11, *SE* = .03, *p* = .00.

Table 4.

Direct and indirect effects results

Predictor Variable	Satisfaction β (S. E.)	Motivation β (S. E.)	Productivity β (S. E.)	ITQ β (S. E.)
Direct Effects				
Loneliness	-0.69 (0.05)**	-0.55 (0.04)**	-0.37 (0.05)**	
Relationship with Advisor	0.06 (0.05)	0.30 (0.05)**	0.06 (0.06)	
Satisfaction				-0.16 (0.03)**
Motivation				-0.55 (0.04)**
Productivity				-0.09 (0.03)**
Indirect Effects via Satisfaction				
Loneliness				0.11 (0.03)**
Relationship with Advisor				-0.01 (0.01)
Indirect effects via Motivation				
Loneliness				0.30 (0.03)**
Relationship with Advisor				-0.16 (0.03)**
Indirect effects via Productivity				
Loneliness				0.04 (0.03)*
Relationship with Advisor				-0.01 (0.01)
Total R^2	.55**	.62**	.18**	.49**

Note: ** $p < .001$, * $p < .01$

Testing for differences among STEM groups.

To test Hypothesis 3 (doctoral students in natural sciences will be less likely to experience loneliness than those in social sciences), I ran a multivariate analysis of covariance (MANCOVA) with natural vs social science as the grouping variable, the loneliness and isolation scales as the dependent variables, and lab interaction as the covariate. Using Roy's largest root as the multivariate test statistic (as Box's test of equality was significant and Roy's largest root is then the most robust), there was a significant effect of type of science (natural vs social) on loneliness controlling for lab interaction ($\Theta = .05$, $F(4, 1034) = 12.53$, $p < .001$, $\eta_p^2 = .05$). Separate univariate ANOVAs on the outcome variables revealed that professional isolation

and loneliness and belonging to program were not significant, although loneliness and belonging frequency, $F(2, 1037) = 6.40$, $p = .00$, $\eta_p^2 = .01$, and the UCLA loneliness scale were significant, $F(2, 1037) = 6.67$, $p = .00$, $\eta_p^2 = .01$). Post hoc analyses revealed that scores differed significantly between participants who were coded as other (e.g., did not enter a distinct category) and natural or social sciences, where those who were coded as other reported less professional isolation, but a stronger sense of belonging, less frequently lonely, and lower overall loneliness. This means that hypothesis 3 was partially supported, where there was a difference between groups, but not between social and natural science when controlling for lab interaction. Means and standard deviations can be found in Table 5.

I continued this line of questioning through an exploratory analysis to investigate whether loneliness would differ by field of study (i.e., science, technology, engineering, math, or other field of study) through a second MANOVA. Using Roy's largest root, there was a significant effect of STEM group on loneliness ($\Theta = .02$, $F(4, 1036) = 5.72$, $p < .001$). Separate univariate ANOVAs on the outcome variables revealed significant differences in terms of professional isolation, $F(4, 1036) = 3.60$, $p = .01$, $\eta_p^2 = .01$, loneliness and belonging to program frequency, $F(4, 1036) = 5.21$, $p < .001$, $\eta_p^2 = .02$, and UCLA loneliness scale, $F(4, 1036) = 4.78$, $p < .001$, $\eta_p^2 = .02$. Means, standard deviations, and relationships can be found in Table 6. Post hoc analyses revealed that scores differed significantly for the professional isolation scale, the loneliness and belonging frequency, and UCLA loneliness scale between science and math, engineering and math, wherein math reported the lowest amount of loneliness.

Table 5.

Type of Science Means

	Mean	*SD*	*N*
Professional Isolation Scale			
(Higher scores indicate more loneliness)			
Natural	2.51	0.83	594
Social	2.62^{O}	0.81	244
Other	2.45^{N}	0.71	203
Loneliness & Belonging Scale			
(Lower scores indicate more loneliness)			
Natural	3.44^{O}	1.16	594
Social	3.47	1.12	244
Other	3.64^{N}	1.08	203
Loneliness & Belonging Frequency			
(Higher scores indicate more loneliness)			
Natural	2.34^{O}	0.95	594
Social	2.31^{O}	0.87	244
Other	$2.10^{N\,S}$	0.81	203
UCLA			
(Higher scores indicate more loneliness)			
Natural	1.93^{O}	0.80	594
Social	1.90^{O}	0.75	244
Other	$1.73^{N\,S}$	0.62	203

Note: super scripts denote significant differences between groups. S = Social Science, N = Natural Science, O = Other, UCLA = UCLA Loneliness Scale.

Table 6.

STEM Group Means

	Mean	SD	N
Professional Isolation Scale			
(Higher scores indicate more loneliness)			
Science	2.55[M]	0.83	671
Technology	3.36	1.31	2
Engineering	2.72[OM]	0.86	82
Math	2.33[SE]	0.69	83
Other	2.45[E]	0.71	203
Loneliness & Belonging Scale			
(Lower scores indicate more loneliness)			
Science	3.44[M]	1.15	671
Technology	3.50	0.71	2
Engineering	3.47[OM]	1.18	82
Math	3.46[SE]	1.15	83
Other	3.64[E]	1.08	203
Loneliness & Belonging Frequency			
(Higher scores indicate more loneliness)			
Science	2.34[OM]	0.93	671
Technology	2.50	0.24	2
Engineering	2.49[OM]	0.96	82
Math	2.06[SE]	0.86	83
Other	2.10[SE]	0.81	203
UCLA			
(Higher scores indicate more loneliness)			
Science	1.93[OM]	0.79	671
Technology	1.63	0.32	2
Engineering	2.06[OM]	0.84	82
Math	1.73[SE]	0.67	83
Other	1.73[SE]	0.62	203

Note: Super scripts denote significant differences between groups. S = Science, T = Technology, E = Engineering, M = Math, O = Other, UCLA = UCLA Loneliness Scale..

Differences in gender, ethnicity and race.

To test Hypothesis 2 (underrepresented minority groups will report higher levels of loneliness and lower levels of motivation, satisfaction, and productivity, and higher intentions to

quit), I ran several MANOVAs. Using Pillai's Trace (as Box's test of equality was not significant and Pillai's trace is then the most robust), there was a significant effect of gender on loneliness, motivation, satisfaction, productivity, and intent to quit ($V = .11$, $F(27, 2238) = 3.24$, $p < .001$). Separate univariate ANOVAs on the outcome variables revealed that professional isolation, satisfaction, and subjective productivity were not significant, although intent to quit, $F(3, 752) = 4.21$, $p = .01$, $\eta_p^2 = .02$, loneliness and belonging, $F(3, 752) = 4.45$, $p = .00$, $\eta_p^2 = .02$, loneliness and belonging frequency, $F(3, 752) = 5.18$, $p = .00$, $\eta_p^2 = .02$, the UCLA loneliness, $F(3, 752) = 7.48$, $p = .00$, $\eta_p^2 = .03$, objective productivity, $F(3, 752) = 3.19$, $p = .02$, $\eta_p^2 = .01$, and motivation, $F(3, 752) = 8.75$, $p < .001$, $\eta_p^2 = .01$, were significant. Post hoc analyses revealed that scores differed significantly between participants who identified as non-binary compared to men or women, with those identifying as non-binary having more adverse scores. Means, standard deviations, and relationships can be found in Table 7.

Table 7.

Gender Means

	Mean	*SD*	*N*
Intent to Quit			
(Higher scores indicate greater intent to quit)			
Man	1.90 ^{WN}	0.80	257
Woman	2.06 ^{MN}	0.93	458
Non-binary	2.42 ^{MW}	1.09	34
Other/Prefer Not to Answer	1.81	0.81	7
Loneliness & Belonging Scale			
(Lower scores indicate more loneliness)			
Man	3.39 ^{N}	1.17	257
Woman	3.56 ^{N}	1.12	458
Non-binary	2.87 ^{MW}	1.22	34
Other/Prefer Not to Answer	3.62	1.41	7
Loneliness & Belonging Frequency			
(Higher scores indicate more loneliness)			
Man	2.30 ^{N}	0.98	257

Woman	2.22 [NO]	0.85	458
Non-binary	2.77 [MW]	0.90	34
Other/Prefer Not to Answer	2.90 [W]	0.71	7
UCLA			
(Higher scores indicate more loneliness)			
Man	1.93 [WN]	0.81	257
Woman	1.81 [MN]	0.71	458
Non-binary	2.39 [MW]	0.87	34
Other/Prefer Not to Answer	2.31	0.81	7
Objective Productivity			
(Higher scores indicate more productivity)			
Man	32.95 [W]	31.05	257
Woman	40.81 [M]	35.44	458
Non-binary	42.91	46.61	34
Other/Prefer Not to Answer	29.71	39.81	7
Motivation			
(Higher scores indicate higher motivation)			
Man	3.17 [WO]	0.24	257
Woman	3.26 [M]	0.25	458
Non-binary	3.21	0.25	34
Other/Prefer Not to Answer	3.38 [M]	0.36	7

Note: Super scripts denote significant differences between groups. M = Man, W = Woman, N = Non-binary, UCLA = UCLA Loneliness Scale.

Additionally, there was a significant effect of race on loneliness, satisfaction, motivation, productivity and intent to quit ($V = .13$, $F(45, 3730) = 2.12$, $p < .001$). Separate univariate ANOVAs on the outcome variables revealed that the professional isolation scale and loneliness and belonging scale were significant (PIS: $F(5, 750) = 2.67$, $p = .02$, $\eta_p^2 = .02$; LBS: $F(5, 750) = 4.32$, $p = .00$, $\eta_p^2 = .03$). Satisfaction, $F(5, 750) = 3.52$, $p = .00$, $\eta_p^2 = .02$, objective productivity, $F(5, 750) = 4.64$, $p = .00$, $\eta_p^2 = .03$, and motivation, $F(5, 750) = 2.23$, $p = .04$, $\eta_p^2 = .02$, were all significant. However, intent to quit, loneliness and belonging frequency, UCLA loneliness scale, and subjective productivity, were not significant. Post hoc analyses revealed that scores differed significantly, particularly for Asian participants. Asian participants reported lower professional

isolation, higher belonging, higher satisfaction with program, lower objective productivity, and lower motivation. Means and standard deviations of all significant measures can be found in Table 8.

Table 8.

Race Means

	Means	*SD*	*N*
Professional Isolation Scale			
(Higher scores indicate more loneliness)			
White	2.54[AO]	0.91	509
Hispanic	2.50[O]	1.03	65
Black/African American	2.61	0.95	21
Asian	2.31[WO]	0.84	100
Other	3.00[WHA]	0.85	14
Biracial/Multiracial	2.57	0.88	47
Loneliness & Belonging Scale			
(Lower scores indicate more loneliness)			
White	3.50[AO]	1.11	509
Hispanic	3.28[AO]	1.31	65
Black/African American	3.27	1.22	21
Asian	3.75[WHOM]	1.08	100
Other	2.50[WHAM]	1.08	14
Biracial/Multiracial	3.20[AM]	1.24	47
Satisfaction with Program			
(Higher scores indicate higher satisfaction)			
White	3.75[OM]	0.90	509
Hispanic	3.65[O]	1.04	65
Black/African American	3.50	0.82	21
Asian	3.86[OM]	0.87	100
Other	2.98[WHAM]	1.07	14
Biracial/Multiracial	3.44[WA]	0.94	47
Objective Productivity			
(Higher scores indicate more accomplishments)			
White	39.82[A]	34.78	509
Hispanic	46.17[A]	43.61	65
Black/African American	38.00	34.97	21
Asian	23.50[WHM]	21.85	100
Other	35.71	29.64	14
Biracial/Multiracial	40.55[A]	38.78	47

Motivation			
(Higher scores indicate higher motivation)			
White	3.22 [H]	0.25	509
Hispanic	3.30 [WA]	0.26	65
Black/African American	3.31 [A]	0.25	21
Asian	3.18 [WH]	0.24	100
Other	3.24	0.23	14
Biracial/Multiracial	3.22	0.23	47

Note: Super scripts denote significant differences between groups. W = White, H = Hispanic, A = Asian, O = Other, M = Biracial/Multiracial

DISCUSSION

As Green Day sang, (graduate students) walk a lonely road, often the only one they have ever known… while in graduate training (Green Day, 2004). Loneliness and isolation are common experiences for graduate students, likely due to limited social networks, high workload, and independent training (University of Michigan, n.d.a). This study identified the relationships between loneliness, graduate program satisfaction, motivation, productivity, and intent to quit program. Indeed, students who reported more loneliness perceived themselves to be less productive, have lower motivation, and lower satisfaction with program, leading to higher intent to quit. Additionally, students who felt more lonely reported lower relationships with their advisor and lower motivation. Previous research supports similar findings: advisor-advisee relationships can have implications on an individual's research productivity (Pinheiro et al., 2012), and decision to stay in a STEM program (Ruud et al., 2018). However, relationship with advisor is not enough; social interactions with peers and others outside of academia is warranted to increase graduate student well-being (Janta et al., 2014).

Although loneliness is prevalent among most graduate students, some groups are more affected than others. For example, students in math fields tended to report less loneliness than those in science and engineering. Although previous research suggests that graduate students in math may be more prone to loneliness (Herzig 2002; 2004), Herzig's work analyzed how interactions with mathematics faculty produce these feelings. Herzig (2002) identified that mathematics faculty often ignored first year doctoral students as an effective way to weed out students, and in a separate study that students reported low support or encouragement from faculty (2004). However, the relationship between Herzig's findings and the current study's

findings are largely explained by the work of Gardner (2010), who found that students in mathematics and engineering depended on faculty members for support compared to peers in non-STEM fields. Thus, the findings of the present study may contradict previous research because of the measured used. The current loneliness measures were aimed more strongly at assessing loneliness from peers than from faculty. However, participants in math fields still experienced the least amount of professional isolation, suggesting that the current sample is not congruent with previous research, and should be interpreted with caution.

Controlling for lab interaction revealed significant differences between social, natural science, and an undefined group in general loneliness and loneliness and belonging frequency, but not professional isolation or loneliness and belonging to the program, suggesting that individuals who did not fall into a distinct category (who may or may not have been in a science field) fared better in terms of general loneliness and belonging in graduate school, but professional opportunities and connections were still available for any group. Previous research has found differences in social interactions of natural sciences and social sciences because of the type of projects completed, wherein natural sciences require more social interaction due to the emphasis of teamwork in their projects (Chiang, 2003), and overall higher likeliness to complete a program than those in arts, humanities, and social sciences (64% compared to 51%; Wright & Cochrane, 2000). However, the current study did not replicate these differences. This could be because of COVID restrictions, and perhaps all labs were not meeting as often.

Further, loneliness in graduate school has different effects on different demographic groups. Professional isolation did not differ between genders, suggesting that professional connections and opportunities are not discriminated by gender, but general loneliness was higher, and sense of belonging was lower for non-binary individuals. Further, non-binary individuals

reported higher intent to quit, although no differences in satisfaction or motivation. This was only partially as expected; previous research has found women to experience less belonging and motivation in STEM fields (Smith et al., 2012). Although exploring differences in gender was not the intent of this study, this finding is nonetheless notable. Gender, especially for atypical genders, is not a variable that should be ignored when considering graduate student well-being. Emerging research notes that non-binary and gender non-conforming individuals experience more general loneliness than gender conforming individuals (Mereish et al., 2017), although much of the research on non-binary individuals often groups them with transgendered individuals.

Race was also related to loneliness, but not necessarily as expected. In fact, Asians reported the most positive outcomes, while other minorities and biracial/multiracial individuals reported the most negative outcomes, including higher loneliness, and lower satisfaction with program, although not lower productivity or motivation. This may be because other minorities (e.g., Native American, Pacific Islander) and biracial/multiracial individuals have complex identities (Elsheikh et al., 2020; King, 2008) and are not offered the same support and resources to support their racial identities (Meaux, 2020). Interestingly, Asian participants reported the most positive well-being outcomes, but lower objective productivity and motivation. Future research should investigate this unique interaction, perhaps through qualitative interviews to assess interactions of identity, social network, and program status.

Surprisingly, white participants did not necessarily rate themselves as the least lonely and isolated. Loneliness and isolation may be a universal phenomenon among graduate students, with majority groups at similar experiences as minority groups. White participants were less lonely than other minorities, but not significantly less lonely than Hispanics, or Blacks/African

Americans, and in fact were significantly more negatively impacted than Asian participants in professional isolation and belongingness. To the contrary, much of previous qualitative research have identified loneliness and isolation to pang underrepresented students (Alexander & Hermann, 2016; Figueroa, 2015; Le & Gardner, 2010).

Loneliness becomes problematic not only for an individual's wellbeing (Hawkley & Cacioppo, 2010), but also to the identified work outcomes of satisfaction, motivation, and productivity, leading to intent to quit. The current research finds support for the model of workplace loneliness, wherein loneliness is related to work outcomes, such as productivity. One predictor stood out above the others in predicting intent to quit: motivation. In this study, I defined motivation through the lens of self-determination theory as autonomy, competence, and relatedness; however, these constructs loaded onto different latent variables, suggesting that perhaps motivation (as defined this way) cannot be separated from productivity and loneliness. For example, competence loaded more strongly onto productivity, suggesting that perceived productivity is subject to an individual's perception of their own competence. In some ways, the relationship between competence and productivity also speaks to a need for more research on the relationship between competence, productivity, and imposter phenomenon. How might perceived competence drive imposter phenomenon and influence productivity? Additionally, relatedness loaded onto loneliness, leaving autonomy as the strongest predictor of motivation. Thus, it is either possible that the variable named motivation rather only addresses autonomy, or that autonomy is the strongest predictor of motivation within this model.

Surprisingly, year in program, first generation graduate student, positive and negative affect, and covid restrictions did not influence results. Contrary to Ali and Kohun (2006), there seemed to be no specific year in program where loneliness was significantly different. Although

Ali and Kohun (2006) suggested that isolation and loneliness is most found during socialization to the program and in dissertation years, the present research did not find there to be peak years of loneliness or performance. Past qualitative research has suggested that first years feel isolated as they are adjusting to workload and relocation (Grady et al., 2014; Ray et al., 2019), but perhaps assessing these constructs quantitatively at a larger scale suggests that loneliness and performance do not differ by year as much as previously expected. Indeed, even Ali and Kohun (2006) hinted that isolation and loneliness may occur at any stage from preadmission through matriculation. It is also possible that the measures used in this study did not assess loneliness in the same way that qualitative measures do. For example, the existing qualitative research seemingly addresses the underlying reasons for loneliness (Grady et al., 2014).

Similarly, I found no differences between first generation graduate students and non-first-generation graduate students, contrary to past research (Merolla & Serpe, 2013). However, Merolla and Serpe (2013) included first generation college students in their definition of first generation, whereas I did not. In a study of graduate school environment and imposter phenomenon, Cohen and McConnell (2019) also found no differences in perceptions of isolation when first generation was defined as first generation graduate students. It was also unexpected that COVID restrictions did not influence the model, although possible that the restrictions were not as stringent as they were at the beginning of the pandemic, and thus may not have as much of an impact on isolation and loneliness.

Intent to quit is multi-faceted. Although the optimal model addressed 49% of the variance in intentions to quit based on the variables included in this model, of the relationship between loneliness and intent to quit, that still leaves 51% unaccounted for. Future longitudinal research is needed to understand how intentions to quit predicts attrition. It is possible that although the

theory of planned behavior (Ajzen, 1991) expects that intentions and anticipated behavior will lead to actual behavior, students may experience fluctuations in quitting intentions due to external circumstances (e.g., family/spouse, health, finances) and internal attitudes, beliefs and events (e.g., attitudes about education or the profession, self-efficacy, social integration, academic integration, mental health) are associated with more between-student variance in trying to predict actual behavior based on intentions (Dewberry & Jackson, 2018).

Implications

The present research has identified several key areas wherein loneliness is associated with important graduate school outcomes. Further, this research has several important implications regarding connections to theory and practice.

Implications for Theory

The regulatory loop model postulated that loneliness can be circular, building on itself as an individual puts themselves in increasingly isolating situations (Cacioppo & Hawkley, 2009). In the current study, this can be seen with the relationship with isolation and intent to quit. All paths from loneliness to intent to quit were significant, and an exploratory reverse model showed the same significant relationship, although the relationships between intent to quit, satisfaction with program, motivation, and productivity were higher (See Appendix B for complete reverse model findings), likely because of fewer variables used to explain this reverse relationship. Longitudinal research could test directionality in the reverse model with stronger statistical meaning. However, this exploratory model suggests that there may be support for the regulatory loop model, as the regulatory loop model would show a bidirectional relationship between loneliness and intent to quit, and intent to quit would also predict satisfaction with program, motivation, and productivity.

Campbell's (1990) determinants of performance – declarative, procedural, and motivation – would suggest that motivation would predict performance. Although the model did not test the relationship between motivation and performance, the correlation matrix indicated that these variables are related. Thus, it is not completely surprising that competence loaded onto the productivity latent variable.

Some components of self-determination theory (Deci & Ryan, 1985) were exhibited differently than expected. In this model, the most salient factor of motivation was autonomy, as competence and relatedness fit with other latent constructs. Perhaps this suggests revisiting the basic needs and their relationship to motivation when individuals are also faced with loneliness and a performance requirement. It is also possible that other theories or measures of motivation (e.g., goal setting, job characteristics, work engagement) might exemplify motivation in a more cohesive way in graduate students.

Social comparison theory states that we often compare ourselves to others (Festinger, 1954). In this study, one manner in which students may compare themselves to others is with regard to performance or productivity in graduate school. This study included two measures of productivity: subjective productivity and objective productivity. Because the measure of subjective productivity asked participants to rate how others may perceive their productivity, the measure of subjective productivity was based upon the individual's perception of how others view them. Therefore, ratings on this measure are likely to be affected by social comparison, which may contribute to some degree of measurement error.

Implications for Practice

Perhaps the best way to address loneliness was posed in a question by the Beatles in *Eleanor Rigby,* "all the lonely people, where do they all belong?" (Beatles, 1996). Social

identification occurs when an individual classifies themselves with a group and induces a sense of belonging (Ashforth & Mael, 2016). Arguably, one of the best ways to address loneliness may be through identifying ways to create a sense of belonging (Lim et al., 2021), potentially through socialization tactics. Van Maanen & Schein (1979) conceptualized the experience of organizational socialization using six tactics: collective vs individual, formal vs informal, sequential vs random, fixed vs variable, and serial vs disjunctive, and investiture vs divestiture. Further, Jones (1986) sorted these tactics into general organizational approaches: institutionalized (collective, formal, sequential, fixed, serial, investiture), where the individual is set up to passively accept the preset role and maintain the status quo, and individualized (individual, informal, random, variable, disjunctive, divestiture), where the individual has more autonomy in questioning the status quo and developing their own approach to the job role. Ashforth and Saks (1996) identified outcomes of institutionalized versus individualized socialization tactics, noting slight differences in newcomer adjustment. Institutionalized approaches were negatively associated with outcomes such as stress symptoms and intent to quit, and positively related to job satisfaction. This may be because in an institutionalized approach, newcomers have a preset role to fill, are walked through a newcomer process, and are connected to others within the organization. Although newcomers who experience an institutionalized approach may have less autonomy, they are equipped with structured learning opportunities to increase competence and create a social network. On the other hand, Ashforth and Saks (1996) found that individualized approaches were associated with higher performance and intent to quit.

In practice, institutionalized socialization might take the form of establishing formal orientation processes, creating pathways to resources, and encouraging opportunities for graduate students to interact with each other on social and professional levels. Some examples of this

exist, such as admitting students as a cohort that take the same classes (Ali & Kohun, 2009), building mentoring programs (University of Michigan, n.d.b.), supporting on-campus organizations such as graduate student council or department graduate student associations, or encouraging students to volunteer with groups (University of Michigan, n.d. a).

Belonging and relatedness might also be gained through developing a science identity, or the process by which students recognize themselves as scientists. Decreasing imposter phenomenon and experiencing a sense of belonging and relatedness with others within STEM fields can build an individual's social identity as a STEM scientist, reduce loneliness, and reduce desire to leave the program (Merolla & Serpe, 2013). Science identities can be developed through STEM enrichment programs such as the NIH funded *Minority Access to Research Careers,* or through other methods of STEM exposure, along with a component of community building. Building a science identity is especially important for women and others who traditionally face bias in STEM fields (Merolla & Serpe, 2013). With a science identity, graduate students feel a sense of belonging to the field and can more easily form social relationships with others who identify in a similar way (Merolla & Serpe, 2013). In a way, having a science identity is a recognition of competence by the student and sense of relatedness to others like them, thus again fulfilling the basic needs of self-determination theory (Deci & Ryan, 1985).

Another vital point of intervention may be with the relationship with advisor. The present study indicated that relationship with advisor significantly predicted motivation, suggesting that the advisor influence basic need satisfaction, specifically autonomy, when working with students. Advisors should seek to create rapport, support professional development and networking, and be good role models of work, including organization, workload, communication, work ethic, and work-life balance. Creating opportunities for students to take on

their own challenges and make autonomous decisions while being supported, perhaps by scaffolding research or applied learning (Svinicki & Mckeachie, 2014), might be some ways to intervene at this point. For example, an advisor might work with a student to provide example R code but ask the student to complete the data analyses for a research project on their own, with the advisor being open to questions and for further support.

Limitations

Although the results are promising, some limitations restrict the conclusions. The model implies causality, but results were generated using cross-sectional data and thus it is not possible to claim causality nor directionality. Additionally, nearly all measures were significant, indicating high multicollinearity, which may have impacted the results, although theoretically the variables should be correlated. Along this vein, the study included multiple measures of loneliness, and based on a review of item content and psychometric results, a few scales that were anticipated to measure different constructs were combined in a single latent variable (e.g., work relationship was assumed to be measured under productivity, but was moved to loneliness). It is possible that the results may have differed or been interpreted differently had only one loneliness scale been used or if scales were loaded to latent variables solely based on the hypothesized model. However, arguably, constructs such as loneliness may be measured more thoroughly through the use of multiple scales.

There was possible selection bias from participants, wherein graduate students who did not participate may differ in unknown ways compared to those who did participate. Additionally, non-respondents may have different feelings or experiences than those who did. Although most loneliness scales were normally distributed, the UCLA loneliness scale was positively skewed, indicating a possible selection bias. However, transforming the scores on the UCLA loneliness

scale did not change any responses. It is possible that graduate students who want to share their experiences are not at the highest risk of loneliness or attrition, but those who did not participate feel disconnected and have a different graduate program experience.

There is some evidence of response fatigue from participants, as more missing data occurred toward the end of the survey. However, even after dropping participants who did not complete the loneliness scales, we still retained most participants, and scales were normally distributed. Recent research also suggests that of those who remained, data quality does not diminish over long questionnaires (Bowling et al., 2022), meaning that participants who completed all attention checks and the entire survey most likely shared responses of quality.

It is possible that STEM grouping may have grouped participants in categories they do not strongly fit with. For example, a student in computer science could be arguably put in science, technology, engineering, or math. I categorized computer science as math because of its origins, but in reality, the field is more nuanced than that. Asking for participants to self-report their field as science, technology, engineering, or math may result in more accurate groupings and thus more accurate comparisons of loneliness across groups.

Implications for Future Research

The current preliminary research establishes a solid basis for future research on isolation and loneliness among graduate students. There are several key points for furthering research in this area: First, a longitudinal design in which students report loneliness and program outcomes on multiple occasions will strengthen the opportunity to investigate reports of experience over multiple occasions will facilitate testing models that depict a process that unfolds over time (Ployhart & Vandenberg, 2010). Longitudinal research will also facilitate the opportunity to examine within-person change over time. Frequency of loneliness should also be further

explored. For example, in this study, loneliness frequency was measured based on their past week, allowing for only a snapshot of the graduate experience. Longitudinal research, or daily diaries for a period of time might capture more frequent fluctuations of within person change. Further, the present research only focused on intent to quit, but a longitudinal design may be able to examine actual attrition, whether through matriculation or drop out. Future research should examine fluctuations in intent to quit and its relationship with attrition in graduate school

Second, existing measures of loneliness address different aspects of the construct. One can lack a sense of belonging to their program, but not feel professional isolation, nor general loneliness. It is important to distinguish these constructs because they have potentially different future implications. A student who lacks a sense of belonging, but still has professional connections may be just as productive, or even more so, than one who has a sense of belonging. In this instance, isolation and loneliness become a concern of student wellbeing, but not necessarily future success. Further, future research should examine the role of social support, including support from family, peers, and faculty, in productivity, motivation, and intent to quit. Previous research has examined the role of social support in program satisfaction, with social support explaining 28% of the variance in program satisfaction (Tompkins et al., 2016), and familial support to be associated with doctoral persistence (Rockinson, 2019). Research could also investigate possible intervention strategies, such as creating avenues for positive emotional support (e.g., encouragement to continue), information support (e.g., sharing access to resources), or practical support (e.g., assisting with tasks or roles).

Third, future research should look into advisor – student dyads, and multidimensional productivity reporting. In this study, productivity was measured via self-report, but reports from

a supervisor, reports on file, and possibly qualitative data would provide richer insight into how loneliness influences subjective and objective productivity.

Fourth, the current research further denotes the need to distinguish gender and racial groups when observing loneliness in graduate students. One possible way to do this would be through testing a multiple-groups model, where the current optimal model could be tested separately for the different racial and ethnic groups to determine whether the model fits the data for each group and to compare associations among variables (i.e., path coefficients) based on different groups.

Conclusion

This research identified some important consequences of loneliness in graduate school and drives recommendations for adaptations to reduce feelings of loneliness. Understanding how loneliness is associated with productivity, motivation, and satisfaction can guide future research on the development of ongoing belongingness programs and processes for doctoral programs in STEM. After all, we "get by with a little help from our friends" (The Beatles, 2015).

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APPENDIX A: MEASURES

Items with * are reverse scored

Demographics

1. Are you still in grad school?
    a. When did you begin your current doctoral program?
    b. Did you complete your doctorate?
2. How do you identify? (gender)
    a. Man
    b. Woman
    c. Non-binary
    d. Other/Prefer not to answer
3. Which categories describe you? Check all that apply: (race/ethnicity)
    a. White
    b. Hispanic, Latino, or Spanish origin
    c. Black or African American
    d. Asian
    e. Native American or Alaskan Native
    f. Native Hawaiian or Other Pacific Islander
    g. Some other race, ethnicity, or origin
4. Are you a first generation graduate student?
5. Are you an international student?
6. What is your sexual orientation?
    a. Asexual
    b. Bisexual
    c. Gay
    d. Heterosexual or straight
    e. Lesbian
    f. Pansexual
    g. Queer
    h. None of the above/prefer not to answer
7. Do you consider yourself to be transgender?
8. What is your age?
9. What field of study are you in?
10. How did you hear about this study? Please select all that apply
    a. Social Media
    b. Direct email
    c. Through a club

    d. Through my department
    e. Through a professor
    f. Other
11. Please select all that apply in your area regarding COVID precautions and restrictions at this time:
    a. There is a mask mandate
    b. Limited capacity indoors
    c. Limited capacity outdoors
    d. Classes are mostly online or hybrid
    e. Vaccine requirement
    f. No precautions or restrictions in place
    g. I'm not sure/I don't know
    h. Other
12. The following questions are about meeting with your lab group:
    a. How often do you interact with others in your lab?
    b. How did you primarily meet as lab this semester?
    c. What is the primary reason for your lab meetings?
13. Since enrolling in your current graduate program, have you participated in any type of mentoring program or student success initiative at your college/university?
    a. Are you currently enrolled in any type of mentoring program or student success initiative at your college/university?

Satisfaction with Program

1. (1= Extremely dissatisfied 5 = Extremely satisfied)
2. Overall, how satisfied are you with:
    a. Your academic experience at your university.
    b. Your student life experience at your university.
    c. Your overall experience at your university.

Intention to Quit

1. (1= Strongly disagree, 5 = Strongly agree)
    a. I often think about dropping out of my current graduate program.
    b. I am sure that my current graduate program is the right one for me. *
    c. It is unlikely that I will complete my current graduate program.

Isolation and Loneliness Scales

1. Loneliness & Belonging Scale
    a. (1= Strongly disagree, 5 = Strongly agree)
        i. I see myself as a part of my graduate programs' community.
        ii. I feel that I am a member of my graduate programs' community.

iii. I feel a sense of belonging to my graduate program.

2. Loneliness & Belonging Frequency
    a. (1= Never, 5 = Always)
        i. How often do you feel that you lack companionship?
        ii. How often do you feel left out?
        iii. How often do you feel isolated from others?
3. Professional Isolation Scale (Golden, Veiga & Dino, 2008)
    a. (1= Rarely, 5 = Most of the time)
        i. I feel left out on activities that could enhance my career.
        ii. I miss out on opportunities to be mentored.
        iii. I feel out of the loop.
        iv. I miss face-to-face contact with coworkers.
        v. I feel isolated.
        vi. I miss the emotional support of coworkers.
        vii. I miss the informal interaction with others.
4. UCLA Loneliness scale (Russell et al., 1978)
    a. (1= Never, 5 = Always)
        i. I am unhappy doing so many things alone.
        ii. I have nobody to talk to.
        iii. I cannot tolerate being so alone.
        iv. I lack companionship.
        v. I feel as if nobody really understands me.
        vi. I find myself waiting for people to call or write.
        vii. There is no one I can turn to.
        viii. I am no longer close to anyone.
        ix. My interests and ideas are not shared by those around me.
        x. I feel left out.
        xi. I feel completely alone.
        xii. I am unable to reach out and communicate with those around me.
        xiii. My social relationships are superficial.
        xiv. I feel starved for company.
        xv. No one really knows me well.
        xvi. I feel isolated from others.
        xvii. I am unhappy being so withdrawn.
        xviii. It is difficult for me to make friends.
        xix. I feel shut out and excluded by others.
        xx. People are around me but not with me.

Subjective Productivity

1. Health and Work Questionnaire
    a. This next group of questions asks about how satisfied you are with your life, relationships with friends and family, and your work. This week, how satisfied were you overall with...
    b. (1= Extremely dissatisfied 5 = Extremely satisfied)
        i. Your graduate program?
        ii. Your relationships with your fellow students?
        iii. Your relationships with your professors?
    c. The next set of questions asks you about how you felt about your work this week. Rate each question on a scale from 1 to 10, where 10 reflects the highest level you think you could possibly achieve and 1 reflects the lowest level you have ever experienced at work
        i. How would you and the following people describe your efficiency this week?
            1. Self
            2. Supervisor
            3. Coworkers
        ii. How would you and the following people describe the overall quality of your work this week?
            1. Self
            2. Supervisor
            3. Coworkers
        iii. How would you and the following people describe the overall amount of work you did this week
            1. Self
            2. Supervisor
            3. Coworkers
    d. Think of your worst level of efficiency ever and your best possible efficiency, then rate how efficient you felt you were this week as compared to your worst ever and best possible. Example: Let's say that you feel that you were so efficient this week that it is close to being your best possible performance. In this case, your answer would fall somewhere between 8-9. (1-10 scale)
        i. Rate your highest level of efficiency this week
        ii. Rate your lowest level of efficiency this week
    e. This week, how frequently did you:
    f. (1= Never, 5 = Always)
        i. Have difficulty concentrating at work?
        ii. Fail to finish assigned tasks?
        iii. Feel too exhausted to do your work?
2. Health-Related Quality of Work and Productivity Questionnaire

a. In the last week, how much of the time:
b. (1= Never, 5 = Always)
    i. Was your speed of work or productivity higher than expected? *
    ii. Was your speed of work or productivity lower than expected?
    iii. Did you do no work at times when you were supposed to be working?
    iv. Did you find yourself not working as carefully as you should?
    v. Was the quality of your work lower than expected?
    vi. Did you find yourself daydreaming and not concentrating on your work?
    vii. Did you have trouble controlling your emotions when you were around people at work?
    viii. Did you get along well with others at work?

Motivation (BPNSF)

a. Below, we ask you about the kind of experiences you actually have in your life. Please read each of the following items carefully and indicate the degree to which the statement is true for you.
b. (1 = Strongly disagree, 5 = Strongly agree)
    i. I feel a sense of choice and freedom in the things I undertake.
    ii. Most of the things I do feel like "I have to".
    iii. I feel that the people I care about also care about me.
    iv. I feel excluded from the group I want to belong to.
    v. I feel confident that I can do things well.
    vi. I have serious doubts about whether I can do things well.
    vii. I feel that my decisions reflect what I really want.
    viii. I feel forced to do many things I wouldn't choose to do.
    ix. I feel connected with people who care for me, and for whom I care.
    x. I feel that people who are important to me are cold and distant towards me.
    xi. I feel capable at what I do.
    xii. I feel disappointed with many of my performances.
    xiii. I feel my choices express who I really am.
    xiv. I feel pressured to do too many things.
    xv. I feel close and connected with other people who are important to me.
    xvi. I have the impression that people I spend time with dislike me.
    xvii. I feel competent to achieve my goals.
    xviii. I feel insecure about my abilities.
    xix. I feel I have been doing what really interests me.
    xx. My daily activities feel like a chain of obligations.
    xxi. I experience a warm feeling with the people I spend time with.
    xxii. I feel the relationships I have are just superficial.

xxiii. I feel I can successfully complete difficult tasks.
xxiv. I feel like a failure because of the mistakes I make.

Advisor Relationship (AWAI)

*Reverse coded

(1 = Strongly disagree, 5 = Strongly agree)

1. Rapport
    a. I get the feeling that my advisor does not like me very much*
    b. I do not think that my advisor believes in me.*
    c. My advisor does not encourage my input into our discussions. *
    d. My advisor is not kind when commenting about my work.*
    e. I do not feel respected by my advisor in our work together.*
    f. My advisor offers me encouragement for my accomplishments.
    g. My advisor welcomes my input into our discussions.
    h. My advisor takes my ideas seriously.
    i. I do not think that my advisor has my best interests in mind.*
    j. I feel uncomfortable working with my advisor.*
    k. I am often intellectually "lost" during meetings with my advisor.*
2. Apprenticeship
    a. My advisor introduces me to professional activities (e.g., conferences, submitting articles for journal publication).
    b. My advisor helps me conduct my work within a plan.
    c. My advisor has invited me to be a responsible collaborator in his/her own work.
    d. My advisor helps me establish a timetable for the tasks of my graduate training.
    e. Meetings with my advisor are unproductive. *
    f. My advisor helps me recognize areas where I can improve.
    g. My advisor facilitates my professional development through networking.
    h. I consistently implement suggestions made by my advisor.
    i. I learn from my advisor by watching him/her.
    j. I am an apprentice of my advisor.
    k. My advisor does not help me stay on track in our meetings. *
    l. My advisor strives to make program requirements as rewarding as possible.
    m. My advisor does not educate me about the process of graduate school.*
    n. My advisor is available when I need her/him
3. Identification-Individuation
    a. I do not want to be like my advisor. *
    b. I tend to see things differently from my advisor. *
    c. I do not want to feel similar to my advisor in the process of conducting work. *
    d. My advisor and I have different interests. *

e. I feel like my advisor expects too much from me*

PANAS

1. To what extent do you feel this way right now?
2. (1 = Very slightly or not at all, 5 = Extremely)
    a. Interested
    b. Distressed
    c. Excited
    d. Upset
    e. Strong
    f. Guilty
    g. Scared
    h. Hostile
    i. Enthusiastic
    j. Proud
    k. Irritable
    l. Alert
    m. Ashamed
    n. Inspired
    o. Nervous
    p. Attentive
    q. Jittery
    r. Active
    s. Afraid

Objective Productivity

1. Please list the number of each that are in progress or that you have completed during your time in graduate school
    a. Research Attendance
        i. On-campus conference
        ii. Regional Meeting
        iii. National Meeting
        iv. International Meeting
        v. Other
    b. Coauthor/author publications before and after enrollment
        i. Conference Presentations
        ii. Refereed articles
        iii. Book chapters
        iv. Book reviews
        v. Abstracts

vi. Popular press
vii. Electronic Data Information Source
viii. Other

c. Participated in formal or informal instruction, practice, or development training
    i. Writing proposals for funding
    ii. Oral communication and presentation skills
    iii. Preparing articles for publication
    iv. Conducting independent research/scholarship
    v. teaching/pedagogy
    vi. Working in collaborative groups
    vii. research/professional ethics
    viii. Preparation for job interviews
    ix. Speaking to non-academic audiences
    x. Project management
    xi. Supervision and evaluation
    xii. Jobs held that are unaffiliated with the program
    xiii. Other
d. Teaching experiences
    i. Mentor a high school students
    ii. Mentor/tutor an undergrad
    iii. mentor/tutor a grad student
    iv. Grade papers for UG class
    v. Lead discussion sections
    vi. Lead lab sections
    vii. Guest lecture
    viii. Teach a course based on set curriculum
    ix. Teach a course based on curriculum you developed
    x. Other

APPENDIX B: ALTERNATIVE MODEL

A common practice when running a path model is to test alternative models. I tested a reverse model (shown in Figure 5 below). Model fit statistics were $\chi^2(170) = 1314.96$, $p < .001$; RMSEA = .08; CFI = .92; TLI = .90; SRMR = .08. Results indicated significant relationships between most variables, with several notable differences. First, path coeffiennts from intent to quit to outcome variables were higher in the reversed model. However, the direct effects from satisfaction with program, motivation, and productivity to loneliness showed lower coefficients, but higher coefficients to relationship with advisor. See Figure 5 for all coefficients.

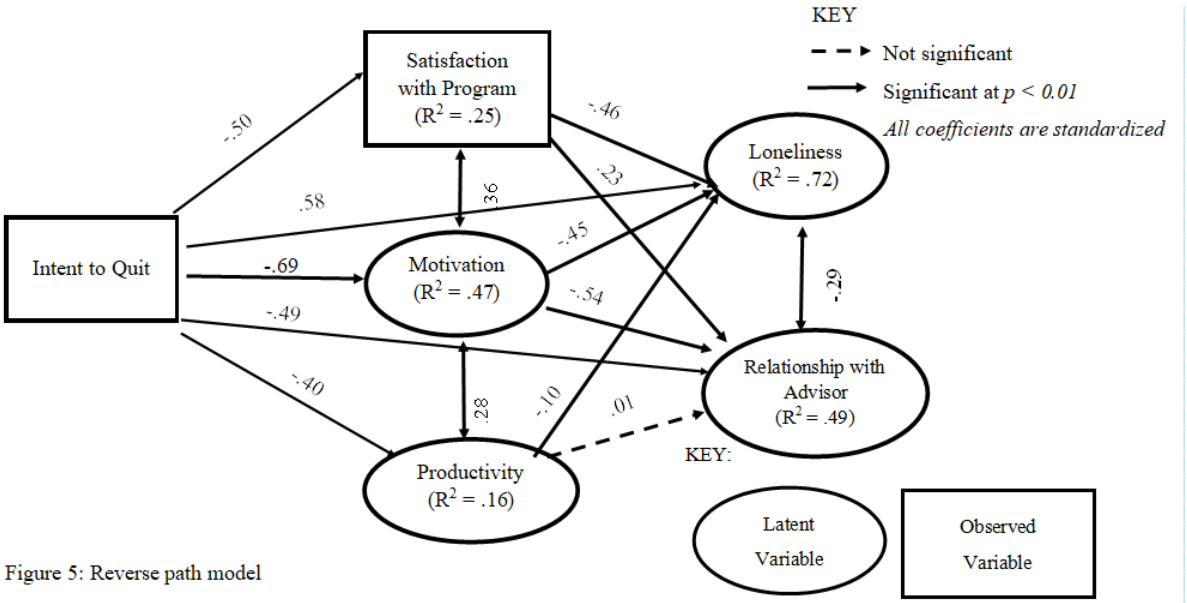

Figure 5: Reverse path model