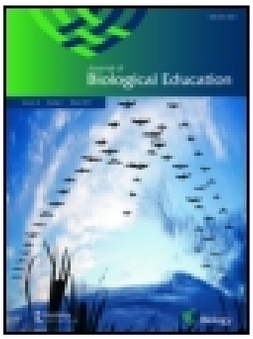

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Grit matters to biology doctoral students' perception of barriers to degree completion

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ABSTRACT

Biology doctoral students face a myriad of barriers that may extend or impede their degree completion. These barriers result in a less diverse workforce, considering that institutionalised prejudices have created more barriers to academic success for some groups than others. Here, we aimed to understand the role that non-cognitive and demographic factors play in predicting doctoral students' perceived barriers, and identify which factors best predict personal/psychological, situational, and institutional barriers to degree completion. We surveyed 289 current biology doctoral students in the U.S. We measured grit, sense of belonging, and science identity as well as participants' perceived barriers. We tested the efficacy of non-cognitive factors alone in predicting the three barrier types versus models including demographic factors. We found that both non-cognitive and demographic factors were important in explaining perceived barriers. Higher scores of grit were associated with lower perceived personal/psychological barriers. However, we assert that grittiness is shaped by unique experiences and is highly situational. We do not imply that grit should be used as a main predictor of 'success' in doctoral programs. We suggest future research on what mechanisms facilitate growth of inherently gritty characteristics in biology doctoral students which lead to fewer perceived barriers to degree completion.

PLAIN LANGUAGE SUMMARY

During graduate school, biology doctoral students may face barriers that extend or stand in the way of their degree completion. Historically, academia has excluded some groups of people more than others and this has created more barriers to the success of those groups in academia. The result of these barriers can have great effects on the diversity of our workforce where only some groups of people graduate with their degree and go on to work in the field. In this study we aimed to understand the role that personality-type traits (non-cognitive factors) and demographic factors, such as age and race, play in predicting the degree to which doctoral students perceive barriers. Additionally, we aimed to identify which factors best predict personal/psychological, situational, and institutional barriers to degree completion. We surveyed 289 current biology doctoral students in the U.S. and measured participants' perceived barriers, as well as three non-cognitive factors: grit, sense of belonging, and science identity. We tested whether non-cognitive factors alone predict the three barrier types best or if models including demographic factors better predict these barriers. We found that both non-cognitive and demographic factors were important in

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explaining how biology doctoral students perceive barriers to their success. Further, students with higher grit scores did not see personal/psychological barriers as large barriers to their degree completion. However, grittiness is shaped by unique experiences and can be formed through very specific situations. We do not mean to say that grit should be used as a main predictor of "success" in doctoral programs. We suggest future research on how to best promote growth of naturally gritty characteristics in biology doctoral students which lead to fewer perceived barriers to degree completion.

Introduction

Biology graduate students constitute an important population of future educators, researchers, government, and industry leaders. However, only 63% of life science doctoral students in the U.S. complete their degree within ten years (Sowell et al. 2008). While some of these students opt to leave programs that no longer fit their career goals (Gardner 2009), it is unclear why other doctoral students do not complete their degrees. Previous research suggests that different barriers prevent degree completion, including personal/psychological barriers, situational barriers, institutional barriers, or barriers that are discriminatory (Kittell-Limerick 2005; Clark et al. 2012; King and Williams 2014; Hwang et al. 2015). A better description of biology doctoral students' barriers to degree completion may mitigate attrition and help uncover inequities.

Doctoral attrition may be affected by personal or psychological factors, including motivation, time management, self-regulation, and self-efficacy (Geraniou 2010; West et al. 2011; Kelley and Salisbury-Glennon 2016). Doctoral students in particular are subject to great pressure to succeed, increasing their risk of mental health challenges (Gewin 2012; Garcia-Williams, Moffitt, and Kaslow 2014). In fact, Evans and colleagues (2018) found that graduate students are six times more likely to be affected by depression and anxiety than the general public. Nagy and colleagues (Nagy et al. 2019) then connected psychological problems, and burnout specifically, to doctoral students' consideration of leaving their programs. Collectively, institutional, situational, and psychological factors can serve as barriers to graduate student success.

Doctoral students' individual situations, i.e. their situational barriers, may influence their capacity to succeed. Sheridan and Pyke (1994) found that domestic citizenship and greater financial support contributed to quicker graduate degree completion. External obligations (e.g. employment, family) can induce anxiety and lead to attrition of doctoral students (Gardner 2009; Lott, Gardner, and Powers 2009; Shepherd and Nelson 2012; Rockinson-Szapkiw 2019; Chen Musgrove and Schussler 2022), while supportive family and friend relationships positively influence persistence (Estrada et al. 2019).

Institutional barriers include factors that are directly tied to a student's relationship with their institution and its internal structure (Tinto 1987) including skill-building opportunities. Golde (2005) attributes doctoral attrition to student isolation from, or lack of integration within, their department or discipline. Socialisation into the norms, policies, and practices within these structures can represent academic capital (Mendoza 2007; Gopaul 2016) but can also be a hindrance to graduate students unable to navigate them. Most of the research on institution barriers to doctoral success are related to the value of positive student-advisor and mentor relationships (Rose, Rukstalis, and Schuckit 2005; Zhao, Golde, and McCormick 2007; Gardner 2009; Overall et al. 2011; Hund et al. 2018). Additionally, evidence shows that the relationships of doctoral students with other graduate students and postdocs are crucial for student success and degree completion (Kemp et al. 2014; Jeong, Blaney, and Feldon 2019; Feldon et al. 2019). Far less frequently do students note that insufficient resources (e.g. training, time) or personal competence (e.g. writing skills, ability to conduct independent research), also considered institutional factors (Kittell-

Limerick 2005), are barriers. However, these factors do contribute to the multifaceted issue of attrition (Castelló et al. 2017).

Unfortunately, each of these three types of barriers likely impact students of different backgrounds unequally. Doctoral students who are women (Ferreira 2003; Lott, Gardner, and Powers 2009), international students (Laufer and Gorup 2019), first-generation college students (Gardner 2013), and students of colour (Okahana et al. 2018) often have higher attrition rates than their counterparts. Moreover, intersectionality of identities can further limit opportunities and success of graduate students (Holley and Gardner 2012; Espino 2014). While abundant literature describes how barriers to degree completion vary by demographic characteristics, previous research does not concurrently explore non-cognitive factors (i.e. personality, social, and emotional traits) (Cunha, Heckman, and Schennach 2010) and how they may predict doctoral barriers to success. Specifically, grit (Cross and Cross TM 2014; Blanchard 2018), sense of belonging (Hausmann, Schofield, and Woods 2007; Estrada et al. 2011), and science identity (Carlone and Johnson 2007; Chang et al. 2011) have been well described as predictors of success for undergraduate students in STEM (Science, Technology, Engineering, and Mathematics) and individually for graduate students in some STEM programs. However, no previous study has focused on biology doctoral students and investigated these three factors as predictors of how barriers to program success are perceived. Understanding the relative importance of these non-cognitive factors (i.e. grit, sense of belonging, and science identity) to doctoral students' perceptions of their barriers to completion of their programs may help their mentors and program staff better support these students' success.

Grit

Grit includes one's passion (i.e. consistency of interest) and perseverance of effort in pursuit of long-term goals (Duckworth et al. 2007). While grit has been studied in educational settings for children and undergraduates (Lai Lam and Zhou 2019), research on the role of grit in graduate student populations is lacking. Duckworth et al. (2007) describe a trend suggesting grit increases with education; when controlling for age, students with a graduate degree are grittier than those with a bachelor's degree, who are grittier than those with only some college – a finding that has been replicated in other studies of grit in higher education (Kannangara et al. 2018).

Current research about grit in graduate school settings has been completed in contextual settings, such as online or professional doctoral programs, and is often related to academic outcomes such as GPA. Cross and Cross TM (2014) identified that grittier students in online doctoral programs spent more time studying and had higher GPAs, supporting Duckworth and colleagues' (Duckworth et al. 2011) idea that grit increases intentional practice and that it also applies to graduate students. Similarly, Fillmore and Helfenbein (2015) found that grit and course grade positively correlate in medical students. However, these findings are not consistent with other research which suggests that grit is not more effective than other personality traits at predicting academic success in online doctoral programs (Walsh 2020), or may not consistently predict positive academic outcomes in pharmacy students (Gruenberg, Brock, and Macdougall 2019). In a unique case, measures of grit were used as a complement to the notoriously biased GRE (Miller and Stassun 2014) for graduate admissions (Powell 2013). Grit has generally been found to be a good predictor of success; however, it is definitionally a student-deficit framing where students are solely responsible for their success. Over-reliance on grit to predict persistence erases institutional accountability to examine barriers that hinder equity (Ris 2015); hence the importance of exploring grit together with other structural barriers.

We posit that grit may provide a new perspective to doctoral students' perceptions of the challenges they encounter throughout their degree programs. As a doctoral program in the basic sciences often involves juggling three or more years of research, scientific writing, and publication pressure (Waaijer et al. 2016), in addition to coursework and possible teaching responsibilities, it is likely that both consistency of interest and perseverance of effort are critical for doctoral students to

succeed in their programs. While not overtly represented in the grit scale, metacognitive resilience may characterise grit in response to such challenges (Hazy 2019) by forming a view that barriers are manageable (Almeida 2016), proceeding without consistent positive feedback (Duckworth et al. 2007), and approaching challenges with a growth mindset (Hudson et al. 2020). Indeed, Blanchard (2018) found that doctoral graduates report the importance of grit in completing their degree programs. Qualitative work also implicates grit in physics Ph.D. students' approaches to problem-solving, which doctoral studies necessitate (Leak et al. 2017). However, the literature so far is lacking with regard to how grit varies among students enrolled in research-intensive doctoral programs, such as biology doctoral programs, and whether grit may contribute to student perception of barriers.

Sense of belonging

Sense of belonging is the extent to which an individual believes they are accepted into a group or community and that their presence and contributions are valued within that community (Pascale 2018; Strayhorn 2019). In STEM education, most research on sense of belonging focuses on undergraduate students. Trends in research about sense of belonging indicate that undergraduate students with a high sense of belonging stay in STEM (Rainey et al. 2018) and matriculate into graduate programs (O'brien, Bart, and Garcia 2020). In contrast, a low sense of belonging among undergraduate students has been correlated with low academic achievement and self-efficacy (Zumbrunn et al. 2014) and is a significant predictor of student intentions to persist in a program (Hausmann, Schofield, and Woods 2007; Good, Rattan, and Dweck 2012). Findings from these studies also indicate that students in minoritized demographic groups, such as military service members (Barry, Jackson, and Fullerton 2021) and students' gender and racial identities (Rainey et al. 2018; Rodriguez and Blaney 2021) may experience disproportionately lower sense of belonging in STEM at four-year institutions but not necessarily two-year institutions (Gopalan and Brady 2020).

While one may extrapolate that undergraduates who matriculate into STEM graduate programs may have a higher sense of belonging than students who did not continue in a STEM post-baccalaureate education pathway, there may be variance in how graduate students experience a sense of belonging within STEM fields and on campuses. Graduate students experience unique challenges to their sense of belonging compared to undergraduate populations; while undergraduate belongingness includes on-campus living and social elements as built-in components to the college experience, graduate students often have additional life demands outside of graduate school that impact their experience of belonging within it (Pascale 2018). Ostrove, Stewart, and Curtin (2011) found evidence of social class negatively affecting graduate students' sense of belonging in their programs. Additionally, identity by gender and underrepresented groups significantly affects the sense of belonging of graduate students and postdoctoral scholars (Herzig 2010; Stachl and Baranger 2020). Studies suggest that sense of belonging may be impacted by both discipline and year within their graduate program (White and Nonnamaker 2008; Stachl and Baranger 2020). In addition to being linked to other demographic factors, graduate students' feelings of belonging reflect their perceived productivity (Stachl and Baranger 2020), and evolve throughout their academic program and may ultimately alter their career trajectories (Stachl and Baranger 2020). From the few studies on graduate students' sense of belonging, it is unclear how this factor or its intersectionality with demographic characteristics contributes to doctoral student success and degree completion.

Science identity

Science identity is the ability of an individual to see themselves as fitting into the world of science (Hazari, Sadler, and Sonnert 2013; Stets et al. 2017). Science identity develops

through one's feeling of belonging within the specific domain of science (Lu 2015). However, science identity also incorporates self-assessment of one's capability to participate within the scientific domain. For example, Carlone and Johnson (2007) investigated the development of science identity in undergraduate and graduate women of colour and found that there are three overlapping facets that describe these identities: performance, recognition, and competence. Thus, an individual who has a strong science identity would rate themselves as having strong abilities to perform scientific methodologies, believes their peers see them as scientists, and see themselves as capable of understanding scientific concepts (Carlone and Johnson 2007; Lu 2015). Unfortunately, science is historically exclusionary and science identity is influenced by demographic factors including gender, race, ethnicity, and socioeconomic status (Carlone and Johnson 2007; Hazari, Sadler, and Sonnert 2013).

As a predictor of academic success, development of a science identity has been linked to increased academic retention in undergraduates (Auchincloss et al. 2014) and matriculation into graduate programs (Estrada et al. 2011; Merolla and Serpe 2013) because individuals with a science identity feel as though they belong in science and persevere in the field. Nevertheless, most research on this subject uses undergraduate student populations; thus, research is needed to explore science identity as a factor in graduate student perceptions of barriers to their own success.

Purpose and research questions

Understanding whether non-cognitive factors (i.e. grit, science identity, and sense of belonging) predict barriers to degree completion for biology doctoral students may inform strategies to increase the retention of these students in their degree programs. In this study we aimed to characterise the factors that matriculating biology doctoral students perceive as barriers to completing their degree. Here, we measure perceived barriers as we aimed to investigate the experience of students actively entrenched in the graduate school experience. Previous work has focused on barriers experienced by people who successfully completed their doctoral degrees (e.g. Shepherd and Nelson 2012; Hwang et al. 2015), which may neglect the experience of those that do not reach the successful completion of their program. Insights provided by matriculating students provides a better view of the barriers that may hinder all doctoral students from achieving success (e.g. graduation). We anticipate that perceived barriers likely reflect the potential for success, and are subsequently appropriate measures. This study offers an opportunity to inform graduate faculty, mentors/advisors, and organisations of the issues that a nationwide sample of doctoral students may perceive so that they may transfer these findings to their own student populations to better support their persistence. We utilised a national survey and conditional random forest modelling to characterise the factors that matriculating biology doctoral students perceive as barriers to completing their degree. We have two research questions that guided this work:

RQ1: Do non-cognitive factors (i.e. grit, science identity, and sense of belonging) alone, or these factors combined with demographics, better explain how biology doctoral students perceive barriers to their degree completion?

RQ2: Which factors best predict biology doctoral students' perception of barriers to degree completion?

Methods

Participants and sampling procedure

The procedures for this study were approved by the Institutional Review Board of the University of Northern Colorado (IRB# 1568219–1). We secured written, informed consent from all participants prior to data collection. No personal identifying information was collected or associated with any of our data.

We recruited doctoral students from biology-related PhD programs at institutions within the United States or outlying territories. Participants were recruited in March 2020 by email through personal contacts, professional listservs, and on social media. Participation was voluntary, anonymous, and no compensation was provided. Participants were removed from the final sample if they did not complete the survey or if they reported not being a PhD student. We had 289 participants who completed some portion of the survey, but after accounting for our exclusion criteria, the final sample size was $N = 200$. In our final sample, 21.5% of our participants were first-generation students, 18.5% identified as belonging to an ethnic or racially minoritized group, 60.5% were aged 27–35 years, and 23% identified as male and 73.5% identified as female (S1 Table). In our sample, 38.5% reported having a disability, and mental health was the most frequently reported disability (S1 Table). We suspected that our participants' educational backgrounds and their parents' educational and occupational backgrounds may affect their perception of barriers; we noted variability in these factors among our participants (S1 Table).

Our participant sample was similar in racial and/or ethnic demographics to USA national statistics of biology-related PhD recipients in a 2019 National Science Foundation (NSF) survey (National Science Foundation NC for S and ES 2020. However, our population has more first-generation students than the reported national average from all areas of study. Gender was not compared due to disparities in data collection (i.e. the NSF 2019 survey reported by sex, we collected gender identity). A separate NSF (2019) survey reported that 7.2% of STEM doctoral recipients in biology reported having a disability which is much lower than the 38.5% of our sample, who reported having at least one disability. Importantly, the above comparative statistics represent data from recipients of doctoral degrees, not currently enrolled doctoral students which was our population of interest.

Research design

In this non-experimental research design, we sought to rank the best predictors of doctoral students' perceptions of barriers to their degree completion. The response variables include subscales of perceived barriers (Kittell-Limerick 2005): Personal/psychological, situational, and institutional barriers. These subscales were designed by Kittell-Limerick (2005) after first compiling and condensing barriers identified by academic advisors of doctoral students and surveying additional advisors on the relative importance of barriers to degree completion using Likert-type data. The predictor variables were the subscales of grit, subscales and single item measurement of science identity, sense of belonging, and participant demographic characteristics (S1 Table). Throughout this paper, we indicate subscales with italics for emphasis and contrast to its scale name. The grit subscales, *passion* (i.e. consistency of interest) and *perseverance* (i.e. persistence of effort; Duckworth and Quinn 2009), are used as individual predictors. The sense of belonging scale (Estrada et al. 2011) was used as a single predictor. We also use the three science identity subscales: *competence*, *interest*, and *recognition*, and a single item measurement of *identity* (Hazari et al. 2010; Hazari, Sadler, and Sonnert 2013; Estrada et al. 2011; Godwin et al. 2016) as predictors in our models.

Measures

Demographic variables

We used 16 demographic variables (S1 Table) in each model. The categorical demographic variables include disability identity, race/ethnicity, previous research experience, type of financial support throughout their program, highest education of each parent, age category, gender, and institution type (S1 Table). The binary demographic variables include completion of comprehensive exams, parents in STEMM (Science, Technology, Engineering, Mathematics, and Medicine), international student, English as a first language, bachelor's degree earned in the US, and financial independence as a minor. Finally, the only numerical variable was the number of disabilities participants identified with, which was the only researcher-bagged variable (i.e. we created this metric from data provided by the participants rather than using direct participant responses). Number of disabilities was calculated by summing the selected 'check all that apply' responses of participants when asked which disabilities or impairments they identified with, from a list of five options (S1 Table). All other variables were analysed using unique participant responses and are operationally defined in S1 Table.

Science identity (SI)

The SI scale (13 items) used in this study contained three subscales that were adapted from a previously published instrument (*competence*, *recognition*, *interest*) as well as a single measure of student's overall identity in science (*identity)* (Hazari et al. 2010; Godwin et al. 2016)

Item wording was modified (i.e. to replace the word 'physics' with 'science') for our intended population of doctoral students. Items in each subscale were scored on a 5-point Likert scale, and all SI subscales were scored individually as the average of item ratings within that subscale. The items on each subscale ranged from acceptably to highly reliable, and comparable to other work using the original instruments (Table 1). The exception to this is the *identity* measure for which a Cronbach's alpha could not be calculated due to single item measurement.

Sense of belonging

The sense of belonging scale (four items) was originally developed by Chemers et al. (2011) and later modified by Estrada et al. (2011). Estrada et al. measured 'Scientific Identity', though the theoretical framework used in the development of this metric characterised science identity differently than the framework used to develop the science identity metric noted above from Hazari, Sadler, and Sonnert (2013). While the SI scale we use presents items asking for agreement to statements about competence, interest, and recognition in science, the items included in the Estrada et al. (2011) subscale presented attitudes about social dimensions of

Table 1. Reliability and descriptive statistics for all subscales/scales. N/A listed for scales that include only one item or when reliability had not been reported previously (e.g. barriers scales; (Kittell-Limerick 2005).

Scale or Sub-Scales		Cronbach's alpha from current study	Cronbach's alpha from previous literature	Current study mean (SD)
Science Identity	*Competence*	.776	.940 (Godwin et al. 2016)	4.4 (0.709)
	Recognition	.717	.886 (Godwin et al. 2016)	4.31 (0.551)
	Interest	.895	.883 (Godwin et al. 2016)	4.63 (0.504)
	Identity	N/A	N/A	4.28 (0.443)
Sense of Belonging		.812	.86 (Estrada et al. 2011)	3.961 (0.733)
Grit	Consistency of interest (*passion*)	.641	Range from .60 to .78 (Angela Lee Duckworth and Quinn 2009)	3.16 (0.721)
	Persistence of Effort (*perseverance*)	.669	Range from .73 to .79 (Angela Lee Duckworth and Quinn 2009)	3.65 (0.612)
Perceived Barriers	Personal/Psychological Barriers	.905	N/A	2.25 (0.835)
	Situational Barriers	.802	N/A	1.88 (0.745)
	Institutional Barriers	.829	N/A	1.85 (0.726)

participating in science communities. In this way, the scale items overlap with (Strayhorn 2019) conceptualisation of sense of belonging as connectedness within a community. Because the items (e.g. 'I have a strong sense of belonging to the community of scientists') are similar to measures of sense of belonging in STEM (see also, Trujillo and Tanner (2014), we differentiate the construct measured by scale as 'sense of belonging' instead of science identity. We did not modify the scale's items, but one of the original items was omitted due to its similarity with items on the *interest* subscale from the SI instrument. The item omitted read, 'The daily work of the scientist is appealing to me'. Items were scored on a 5-point Likert scale and averaged into a final score for each participant. This scale had high internal consistency, and reliability estimates comparable to Estrada et al. (2011; Table 2).

Grit

The short grit scale (Grit-S) used in this study is an 8-item scale adapted from the original 12-item grit scale (Duckworth and Quinn 2009), and is composed of two subscales: consistency of interest (i.e. *passion*; four items) and persistence of effort (i.e. *perseverance*; four items). Items were collected on a 5-point Likert scale, and the four items for the *passion* scale were reverse coded. Scores for *passion* and *perseverance* were the average of four items. The internal consistency of each subscale was deemed acceptable and was close to reliability estimates from other work using original instruments (Table 1).

Perceived barriers

The perceived barriers scales used in this study were adapted from a study by (Kittell-Limerick 2005), who developed the scales to examine graduate advisors' perceptions of doctoral students' barriers to degree completion. The Perceived Barriers scales were generated by Kittell-Limerick (2005)through a Delphi study (also called Delphi panel). A Delphi study qualitatively analyzes experts' opinions, which are collected through an iterative series of confidential and anonymous questionnaires (Helmer-Hirschberg 1967; Helmar and Helmer-Hirschberg 1983). Each new round of questionnaires contains recurrent themes reported by experts in previous questionnaires, ultimately leading to a consensus of opinions. In the 2005) Delphi study, each questionnaire asked experts (i.e. graduate advisors) to report on their perceptions and descriptions of critical barriers to doctoral completion. Through the iterative Delphi process, opinions reported by graduate advisors ultimately converged on the set of barriers compiled into the *Perceived Barriers* scales.

As the scales were originally created for faculty use, numerous items in all subscales were adapted to better fit our sample composed of doctoral students (S2 Table). The three scales capture the perceived barriers related to personal/psychological factors (*personal/psychological barriers*), situational factors (*situational barriers*), and institutional factors (*institutional barriers*). Items were scored on 5-point Likert scales, and scores as the average of items within each scale. A score of 1 indicated that a specified barrier was perceived as trivial to degree completion, and five indicated that a barrier was perceived as being a crucial barrier to the participant's degree completion. The items on each subscale were shown to be highly reliable; however, reliability data from previous work were not available for comparison (Table 1).

Table 2. Confirmatory factor analysis of scales. Bold values are above the accepted values noted by Klein (2016): CFI: >0.9, RMSEA: <0.06, SRMR<0.09, Model X2 $p > .05$.

	CFI	RMSEA (CI)	SRMR	Chi-square (df)	p-value
Science Identity	**0.951**	**0.057** (0.040, 0.07)	0.049	57.93 (19)	<0.0001
Grit	0.891	0.097 (0.069, 0.127)	0.070	316.24 (113)	<0.0001
Perceived Barriers	0.800	0.075 (0.068, 0.082)	0.087	943.33 (347)	<0.0001

Validity of scales

Assessing the validity of any measure is critical for evaluation of its quality (American Educational Research Association, American Psychological Association, National Council on Measurement in Education 2014), and some of the measures we selected were not validated as a part of their development. Neither the grit nor the perceived barriers scales have been applied previously to a doctoral student population. Items of the perceived barriers scale were altered to fit our specific population and to be self-assessed (from the student perspective) rather than assessed by a second party (from the advisor/mentor perspective) as done in the original study. Finally, the perceived barriers scale was not validated in the original study. We ran Pearson correlations between all scales and subscales to provide convergent and divergent validity evidence.

We used confirmatory factor analyses to provide validity evidence for each construct within the three multi-item instruments included in our survey. Confirmatory factor analysis in science education research models the relationship between items and the proposed non-cognitive and cognitive constructs they measure (Taasoobshirazi and Wang 2016). The overall fit of the model is evaluated using several fit statistics, most commonly, Chi-square model fit, the comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardised residual fit model (SRMR; (Hu and Bentler 1999; Kline 2015). All tests modelling our data were run using the lavaan package in R Studio 3.5.2 (Rosseel 2012; Team RC, R Development Core Team 2018. Model fit was acceptable for science identity across all fit indices except Chi-square (Table 2) and the indicators all showed significant positive factor loadings (Tabri and Elliott 2012). However, while neither the grit nor barriers scales satisfied the Chi-square, CFI, or RMSEA fit statistics, both met the SRMR fit criteria. The SRMR is an absolute fit index, and meeting criteria indicates that our data fits the proposed model of the relationship between these variables and the underlying constructs. The RMSEA did not meet criteria for good fit, though this measure can be sensitive to small degrees of freedom and smaller sample sizes (Taasoobshirazi and Wang 2016). The CFI, in contrast with the SRMR, is a relative fit index that tests the data against a model in which none of the variables are correlated. Not meeting the criteria for an acceptable CFI indicates that there may not be a high degree of correlation between the items, though in our CFA analyses, each item still correctly regresses to the underlying construct in each subscale. Taken together, the evidence from the fit indices indicate that the items assess underlying latent variables, but the overall model structure poorly fit our data. These results may be because the degrees of freedom available in the grit scale was low compared to the sample size (Taasoobshirazi and Wang 2016).

Data analysis

Our central goal was to rank variables on their predictive capacity in explaining factors contributing to perceptions of barriers to degree completion. We used conditional random forest (cRF) models to answer both research questions within the 'party' package of R (Hothorn et al. 2006; Strobl et al. 2007, 2008). This **modelling** approach has been used in other education research (e.g.Golino and Gomes 2016; Fahd et al. 2022) to rank predictive factors (Tan, Main, and Darolia 2021). We selected cRF modelling due to its ability to accommodate a large number of independent variables, avoid selection bias against categorical variables with fewer levels (Strobl et al. 2007), and built-in interactions between independent variables. Statistical analyses were conducted in R Studio 3.5.2. We opted to not bag responses for demographic variables such as gender or race/ethnicity to better represent our study population, as removing certain groups might exclude or invalidate the experience of those participants (Cameron and Stinson 2019). Additionally, the overwhelming majority of respondents fell into male or female (96.5%) and Caucasian/Caucasian and another race/ethnicity (88.5%; S1 Table) and bagging these responses had minimal effect on our conclusions. Finally, we also found no difference in our final conclusions when we bagged participants based on disability into only two bins: those reporting no disabilities and those reporting one or

more disabilities. Therefore, we retained categories as we collected them to better understand our population.

Specifically, cRF models were used to identify the efficacy of non-cognitive factors (i.e. grit, sense of belonging, and science identity subscales) and demographic variables to predict doctoral students' perceived barriers to degree completion. Two models were tested for each barrier type: a final model with non-cognitive factors and demographic variables combined and a subset model with only non-cognitive factors. We compared these models to 1) identify the model that explained the most variation and 2) identify the best performing predictors of barriers to degree completion. We grew 5,000 regression trees based on a bootstrap sample of participants and predictors. We used an adjusted R^2 value to evaluate the predictive performance of each model, adjusting for the number of predictors in the model. Permutation importance plots were generated to visualise each response variables' contribution to model performance. Single-variable and bivariate partial dependence plots were also generated for the explanatory variables that contributed the most to model accuracy using the 'pdp' package in R (Greenwell 2017).

Results

Descriptive statistics

Participants reported perceiving, on average, 'slightly significant' to 'significant' barriers to degree completion (Table 1). Overall, participants perceived that *personal/psychological barriers* contributed the most to their perception of barriers in completing their doctoral degree (Table 1). Average perceived *situational barriers* and *institutional barriers* scores ranged from 'not significant (trivial)' to 'slightly significant'. These two barrier scores were strongly positively correlated (Figure 1). Our participants had high average scores for all science identity subscales (Table 1). The *identity* measure had strong positive correlations with the *recognition* subscale and sense of belonging scale, and we found that the grit subscales, *passion* and *perseverance*, were strongly positively

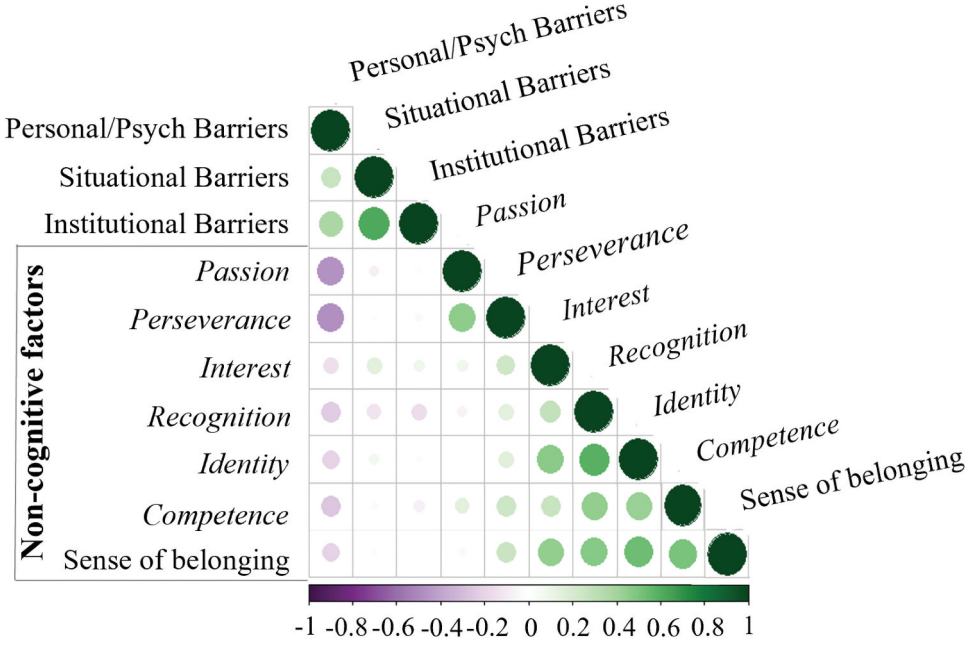

Figure 1. Correlation matrix of response variables (*personal barriers*, *situational barriers*, *institutional barriers*) and the predictors (non-cognitive factor subscales). Symbol size depicts the relative strength of Pearson correlation coefficients. The color ramp denotes the type of correlation: green = positive, purple = negative.

correlated with each other. Non-cognitive factors were weakly and negatively correlated with barrier scales, with the exception of the grit subscales having strong negative correlations with perceived *personal/psychological barriers*.

cRF models

We tested two conditional random forest models (cRF) for each barrier scale: one full model with the seven subscales of non-cognitive factors and 16 demographic factors, and a subset model including only the non-cognitive factors. We found the models that explained the most variance for each perceived barrier included both demographic variables and non-cognitive factors. We then identified the best predictors from each full model. Below we highlight the influential variables of each model as determined by the permutation importance measures. Relationships of variables to the barriers are described by partial dependence plots.

Personal/Psychological barriers

The best cRF model predicting perceived *personal/psychological barriers* included all predictors (adjusted $R^2 = 0.27$). This full model explained 0.43% more variance than the non-cognitive factors alone, signifying that although demographic variables helped explain variance in *personal/psychological barriers*, they contributed little to model performance. *Perseverance* and *passion* were the two best performing predictors of perceived *personal/psychological barriers* (Figure 2A). Participants who scored lower on the *perseverance* and *passion* grit subscales perceived more *personal/psychological barriers* than students with higher *perseverance* and *passion* scores, and these subscales were interactive (Figure 2B). Specifically, students who scored in the high range for one grit subscale but scored low on the other subscale perceived moderate barriers (Figure 2B). The next best predictors, the *competence* subscale and the number of disabilities participants identified for themselves,

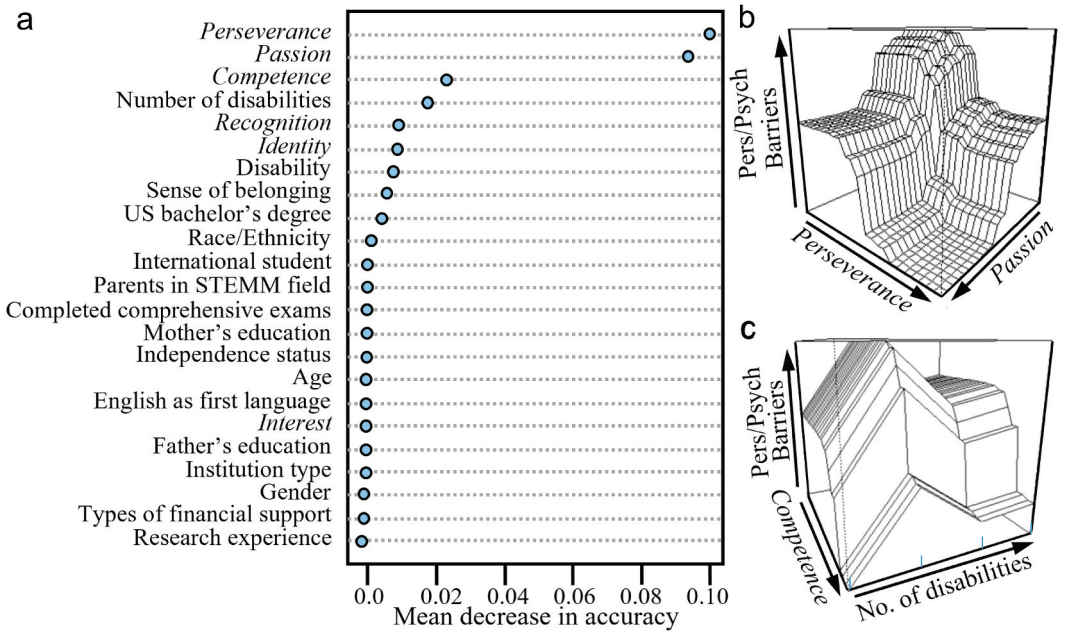

Figure 2. Full cRF model for *personal/psychological barriers* (Pers/Psych). (A) Permutation importance plot for the model including all variables. (B) Bivariate partial dependence plot of the grit subscales, *perseverance* and *passion*, in predicting Pers-B. (C) Bivariate partial dependence plot of the number of disabilities with which participants identified and the science identity subscale, *competence*, in predicting *personal/psychological barriers*.

performed only marginally better than all other predictors in the low range of the mean decrease in accuracy of this model. Biology doctoral students who scored lower on the *competence* subscale perceived more barriers than students who scored themselves as more competent (Figure 2C). Additionally, this pattern of *competence* predicting *personal/psychological barriers* interacted with the number of disabilities students identified with, where students identifying with one disability reported more barriers than students with two or more, or no disabilities (Figure 2C). This pattern should be considered with caution due to the small sample size for individuals with two or three disabilities ($n = 9$ and 4, respectively) and the low mean decrease in accuracy from permutating each of these variables.

Situational barriers

The best cRF model predicting *situational barriers* also included all predictors (adjusted $R^2 = 0.074$). The subset model of non-cognitive factors alone did not predict perceived *situational barriers* (adjusted $R^2 = -0.02817$), indicating the important role of demographic variables in explaining how doctoral students perceived *situational barriers*. The number of disabilities participants identified with, and their age were the best performing predictors in this model (Figure 3A). Biology doctoral students who identified as having one disability perceived more *situational barriers*. than students who did not identify with a disability (Figure 3B). Economic concerns were the primary driver of this pattern (S3 Table), as 39% of all students reporting one disability viewed economic conditions as a moderate (4) to extremely (5) significant barrier to degree completion compared to 21% of students reporting no disabilities. Family obligations, employment, and health concerns also contributed to students identifying with one disability perceiving more *situational barriers*. Participants who reported three disabilities also perceived high situational barriers, which was driven mostly by health concerns (S3 Table). The number of disabilities predicting *situational barriers* interacted with age, where older students perceived more *situational barriers* than younger students with the same number of disabilities (Figure 3B).

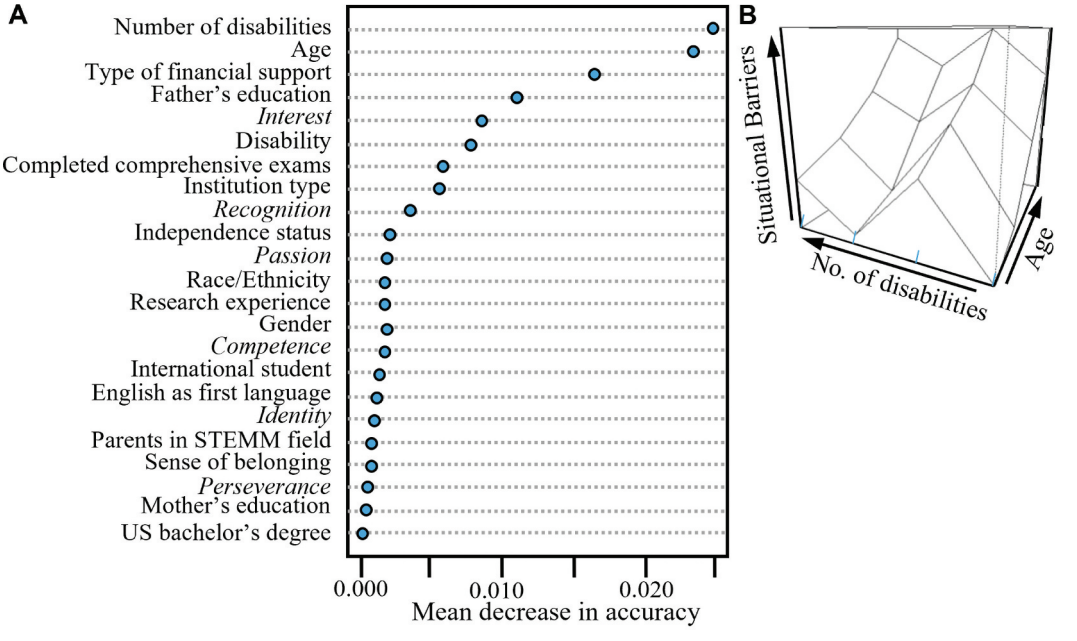

Figure 3. Full cRF model for *situational barriers*. (A) Permutation importance plot for the model including seven non-cognitive factors and 16 demographics. (B) Bivariate dependence plots for number of disabilities with which participants identified and the age of participants from the cRF model predicting *situational barriers*.

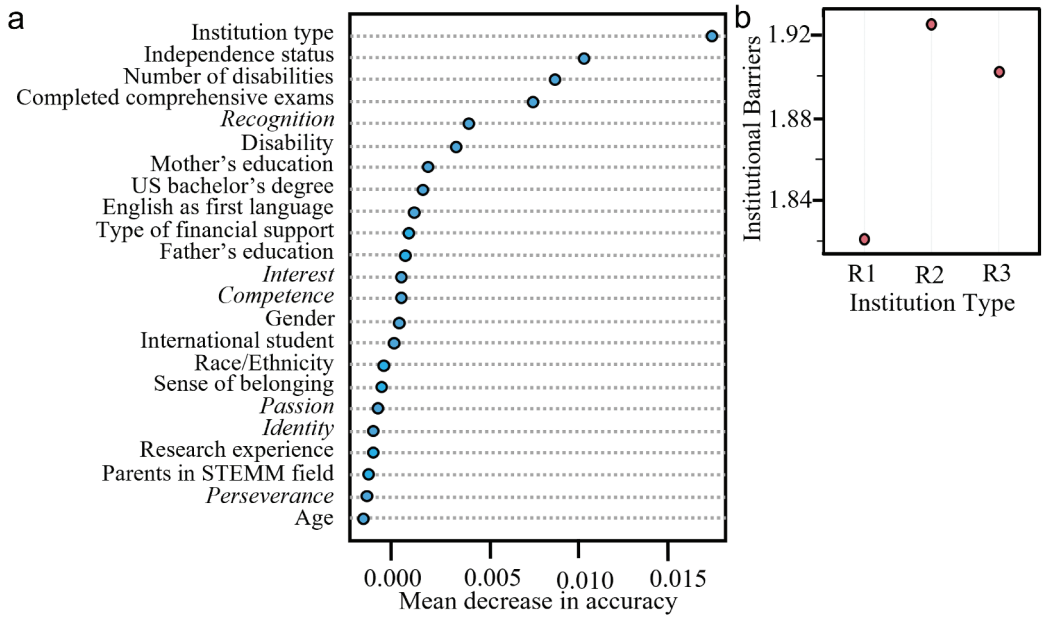

Figure 4. Full cRF model for *institutional barriers*. (A) Permutation importance plot for the model including seven non-cognitive factors and 16 demographics. (B) Partial dependence plot of institution type predicting *institutional barriers*.

Institutional barriers

The full cRF model predicting *institutional barriers* performed poorly (adjusted R^2 value = 0.023). The subset model excluding demographic variables did not predict *institutional barriers* (adjusted R^2 value = −0.0672). Institution type was the best predictor of *institutional barriers* (Figure 4A). Students who attend R1 institutions perceive less *institutional barriers* than students who attend R2 or R3 institutions (Figure 4B). We did not conduct any additional analyses for this model because of the low predictive power and because lower ranking variables did not meaningfully contribute to model performance.

Discussion

We found that biology doctoral students reported experiencing more personal/psychological barriers on average than situational or institutional barriers. Generally, barriers students perceived were low or 'slightly significant' (Table 1). Our primary goal was to understand what factors explained the various types of barriers that graduate students experience by describing how both non-cognitive and demographic factors may influence perceived barriers to degree completion.

RQ1: Non-cognitive factors combined with demographics represented our best models

We found that the combination of non-cognitive factors and demographics best explain doctoral students' perceived barriers to degree completion. In some cases, the models with non-cognitive factors alone were not significant, as depicted by negative variance explained (Acharjee et al. 2011). Within the full models including all factors, grit best explained perceived personal/psychological barriers, but demographic factors are stronger predictors of situational and institutional barriers.

We hypothesised that both non-cognitive and demographic factors would be important determinants in doctoral students' perceptions of barriers to their degree completion. Specifically, we suspected gender and race/ethnicity would be strong predictors of perceived barriers to degree

completion given that STEM fields have historically excluded groups based on gender, race, and ethnicity (Carter, Razo Dueñas, and Mendoza 2019). These demographic factors have notably been associated with attrition rates (Berg and Ferber 1983; Ferreira 2003), publishing productivity (Hopkins et al. 2013; Roksa, Feldon, and Maher 2018), hours spent on research (Feldon et al. 2017), and representation as faculty within the STEM academy (Li and Koedel 2017). However, gender and race/ethnicity did not rank highly in any of our models. Interestingly, age and disability status were ranked higher than gender and race/ethnicity in some of our models.

Second, we selected three non-cognitive factors, grit, sense of belonging, and science identity that we anticipated may influence doctoral students' perception of barriers to their degree completion. Overall, we found that personal/psychological barriers were the only barriers to be meaningfully explained by any of the non-cognitive factors tested. The grit subscales (*passion* and *perseverance*) ranked highly as predictors in this model and were found to have a strong negative effect on perceived barriers to success in that individuals who scored higher on the grit scale perceived fewer of these barriers (Figure 2B). Other non-cognitive factors we investigated (i.e. sense of belonging and science identity) were not important predictors of the perceived barriers we measured. This pattern may indicate the structural selection bias of doctoral programs. Zumbrunn et al. (2014) found that a low sense of belonging negatively impacts academic achievement in undergraduates, which may inhibit students with a low sense of belonging from entering doctoral programs. However, little work has been conducted on the sense of belonging of doctoral students as it relates to perceptions of success. In this study, participants on average had similar sense of belonging scores to other studies (Chemers et al. 2011; Estrada et al. 2011), yet this level of belonging did not predict the degree to which they perceived barriers to their degree completion. It is possible, therefore, that biology doctoral student populations have sufficient science identity to reduce perceived barriers to degree completion, whereas in other populations, science identity has been associated with graduate school matriculation (Merolla and Serpe 2013; Piatt et al. 2019), where students with higher science identity are more likely to enrol in STEM graduate programs. In our study, participants on average scored within the upper range on all science identity subscales (Table 1), which may be indicative of a ceiling effect for science identity in the population of students entering doctoral programs.

RQ2: Which factors overall best predict biology doctoral students' perception of barriers to degree completion?

Overall, our models and the variables we examined only explained a small amount of variance in how biology doctoral students perceive barriers to their degree completion. However, our study contributes evidence about the mindset and perceptions of biology graduate students that can inform stakeholders in graduate biology education.

Perceived personal/psychological barriers

The final perceived *personal/psychological barriers* cRF model explained the most variation (adjusted $R^2 = 0.27$) of all three final models, and the grit subscales, *passion* and *perseverance*, were the best predictors of perceived *personal/psychological barriers*. Although our sample of biology doctoral students with higher grit subscale scores perceived less of these barriers than students with lower scores, grit is not a consistent predictor of doctoral student 'success' in the literature. Previous studies have not found significant relationships between grit and performance metrics such as GPA for law or pharmacy graduate students (Zimmerman and Brogan 2014; Gruenberg, Brock, and Macdougall 2019), which conflicts with patterns for online doctoral students (Cross and Cross TM 2014; Walsh 2020). Still, grit has been a significant predictor of social/personal stressors that lead to attrition and burnout in professional medical contexts (Burkhart et al. 2014; Shakir et al. 2020), and these patterns may look similar to the influence of grit on our measure of perceived barriers to success. Neurosurgery residents with fewer social/personal stressors were

significantly associated with high grit scores and increased retention (Shakir et al. 2020), and general surgery residents with below average grit scores were significantly more likely to consider dropping out of their programs (Burkhart et al. 2014). Additionally, higher grit scores were weakly but significantly associated with decreased burnout for post-graduate medical doctors (Halliday et al. 2017). It is therefore unsurprising that 'grittier' biology doctoral students perceived fewer barriers to degree completion.

We did not directly measure factors that may represent barriers to degree completion, nor did we survey doctoral students that had successfully completed their programs. Instead, we identified the degree to which matriculated students perceive barriers to completing their degrees and what factors relate to those perceptions. The doctoral student experience is often marked with 'highs' and 'lows' that occur throughout the graduate journey, which can influence their perception of barriers (Weise, Aguayo–González, and Castelló 2020). Support from academic advisors, mentors, and peers can improve the graduate experience and potentially reduce barriers to degree completion (Burkhart et al. 2014; Blanchard 2018; Weise, Aguayo–González, and Castelló 2020). Mentorship and active skill building related to grit, such as goal-setting, increasing focus, and ensuring follow-through, could reduce the impact of stressors on doctoral students that affect perceived barriers to degree completion and increase personal reinforcement and validation (Blanchard 2018; Weise, Aguayo–González, and Castelló 2020).

Our finding that grit subscales are the best predictors of perceived *personal/psychological barriers* is expected due to the overlap in constructs. The *passion* subscale (i.e. consistency of interest) captures how individuals remain committed to goals/projects over time, and it describes one's ability to maintain long-term 'focus', 'interest', or 'goals' (Duckworth and Quinn 2009). Meanwhile, the personal/psychological barriers scale infers how 'motivation', 'commitment', 'confidence', and 'sense of responsibility' can hinder a student's ability to complete their degree (Kittell-Limerick 2005). Therefore, the *passion* subscale, the *personal/psychological barriers* scale, and the constructs they aim to represent are interrelated (Figure 1). Similar alignment is also evident for the *perseverance* subscale (i.e. consistency of effort). While our finding that gritty biology doctoral students perceive less personal/psychological barriers may be partially explained by the degree of construct overlap, this correlation does not undermine the predictive capacity we find through this study because of the multidimensional nature of grit (Guo, Tang, and Xu 2019).

The science identity subscale, *competence*, and the number of disabilities that students reported were the next best predictors of *personal/psychological barriers* after the grit subscales. However, these predictors only performed marginally better than the lowest ranked predictors. Questioning one's own competence and feelings of inadequacy, however, are common among educated professionals in other fields (Brooks et al. 2018). Weise, Aguayo–González, and Castelló (2020) documented that doctoral students often demonstrated anxiety in response to experiences that required them to re-evaluate their competencies. In other contexts, the intention to complete an engineering graduate degree program was significantly correlated with competence (Choe and Borrego 2019), and Castelló et al. (2017) found 10.9% of doctoral students considered dropping out of their program because they felt incompetent in research skills. This self-critique of competence similarly reflects the ubiquity of imposter phenomenon demonstrated in graduate populations (Tigranyan et al. 2021). Again, supportive mentoring (Paglis, Green, and Bauer 2006; Hish et al. 2019) and valuing self-care (Dewa et al. 2020) can promote self-efficacy to contradict self-talk that questions one's own competency. *Competence* was only marginally better than the lowest ranked predictors, including the other SI subscales. Perhaps at the doctoral level, science identity plays less of a role in self-efficacy and success than at the undergraduate level (Trujillo and Tanner 2017).

Interestingly, we also found that students who reported one disability perceived more *personal/psychological barriers* than students reporting no disabilities or those identifying with two or more disabilities (Figure 2C). Although the number of disabilities that students reported contributed relatively little to model accuracy, it was the fourth strongest predictor in this model (Figure 2A). The most frequently reported disability in this study, and specifically for those with one listed

Table 3. Frequency of disability type, by the number of disabilities reported. Frequencies are standardised by the number of participants with the same number of disabilities (i.e. 1, 2, or 3 different disabilities).

	Type of Disability				
Number of Disabilities	Mental Health	Sensory	Learning	Mobility	Not Listed
1	71.88%	6.25%	10.94%	3.13%	7.81%
2	44.44%	5.56%	22.22%	0.00%	27.78%
3	33.33%	25.00%	25.00%	0.00%	16.67%

disability, was a mental health disorder, which includes depression and anxiety disorders (Table 3) (Battle 2013). Existing literature suggests that graduate students suffer mental illness disproportionately more frequently than comparison groups (Casey et al. 2016; Levecque et al. 2017), and that graduate student mental health is at crisis levels (Evans et al. 2018). While mental health disorders may be a 'concealable stigmatised identity' (Cooper, Gin, and Brownell 2020), the high incidence in our sample population and its rank as the fourth top predictor of perceived *personal/psychological barriers* further underscores the need for interventions to support graduate mental health (Evans et al. 2018).

Perceived situational barriers

The final cRF model for perceived *situational barriers* had a low to moderate amount of variation explained (adjusted $R^2 = 0.074$); however, the demographic variables included in the final model did explain variation meaningfully compared to the subset model containing only non-cognitive factors (adjusted $R^2 = -0.02817$). Although low, other studies have reported similar variance explained for cRF models in medical research contexts (Taxiarchi et al. 2020) or do not report R^2 values at all (Garnaik et al. 2022). The number of disabilities reported by participants was the best predictor of *situational barriers*. Accordingly, Paul (2000) summarised how undergraduate students with disabilities face additional challenges in their education not experienced by their peers, and this pattern also emerged in doctoral students (Shinohara, McQuaid, and Jacobo 2020). In our study, mental health was the most frequently reported disability impacting 71.88%, 44.44%, and 33.33% of participating students with one, two, and three disabilities, respectively. Biology doctoral students with one disability perceived more situational barriers than students who did not identify with a disability or those who identified with two disabilities. Casey et al. (2016) found that graduate students experienced moderate to extremely high stress and anxiety, and risk increased in older students (i.e. $\geq$30 years of age). The *Situational Barriers* Scale assesses perceptions of health and social support influencing degree completion (Kittell-Limerick 2005); while our sample of graduate students overall suggested that these were only slight barriers for their degree completion (Table 1), some variation in perception of situational barriers was predicted by the number of disabilities to which participants identified. Hefner and Eisenberg (2009) described how graduate and undergraduate students with poor social support were six times more likely to experience depression symptoms than students with high quality support, and social support was also strongly associated with a lower likelihood of anxiety, suicidality, and eating disorders. Doctoral students in other studies described overcoming significant barriers to obtain degrees, and that social support, specifically from individuals within graduate programs, significantly improved doctoral experiences and degree completion (Blanchard 2018).

Participant age was the second-best predictor of *situational barriers*. Participant perception of *situational barriers* as a barrier to their own degree completion increased with age, and biology doctoral students older than 40 years perceived the greatest level of *situational barriers* (Figure 3B). Older graduate students are more likely than their younger peers to have more responsibilities and obligations, including children, financial obligations, and employment outside of their degree program (Hostetler 2005; Benshoff, Cashwell, and Rowell 2015), all of which may lead to greater

perception of barriers. Many of these situational factors may be related and are difficult for individual programs or advisors to address; yet, their association with delayed degree completion elsewhere (Maher, Ford, and Thompson 2004) suggests these barriers should be evaluated in future work to better support older, non-traditional doctoral students.

Perceived institutional barriers

The variance explained by the final model for perceived institutional barriers was low (adjusted R^2 value = 0.0227). We found the best predictor of perceived *institutional barriers* was institution type (e.g. R1, R2; Carnegie Foundation 2013). These classifications reflect differences in research expenditures, the number of personnel conducting research, and number of degrees awarded (Kosar and Scott 2018). These differences may manifest as different pressures, expectations, or available support to graduate students at these institutions. Nevertheless, the low performance of this model indicates that although institution type explains some variance in perceived barriers to degree completion, we likely did not capture factors that meaningfully predict perceived institutional barriers to biology doctoral student degree completion. Additional research is needed to more extensively explore predictors of institutional factors that biology doctoral students view as barriers to their degree completion.

Limitations

Although we report on some interesting and novel findings, they reflect only the summarised experiences of the 200 doctoral students sampled. Our sample was majority White, majority identified as a woman, and majority without reported disabilities. Thus, our results disproportionately represent the perceived barriers (or lack thereof) of White, female students with no reported disabilities. Further, doctoral students often describe themselves as on an 'emotional rollercoaster' (Weise, Aguayo–González, and Castelló 2020), and perceptions of barriers or progress in their doctoral program captured at one time point during our survey may not reflect their entire experience. It is worth noting that data collection occurred in March 2020, as awareness of the COVID-19 pandemic and oncoming quarantine was increasing in the US, and our data may reflect heightened barriers, especially from those concerned about their own physical and mental health. Finally, while our models yielded significant results, they were moderate to low performing models. The low adjusted R^2 values of each model indicate there may be other predictive variables which were not measured in our study.

Conclusions

Identifying the barriers that doctoral students perceive to degree completion will raise awareness to prompt advocacy for support structures that affect graduate student success, and can help address workforce gaps for positions requiring advanced degrees by increasing retention rates (Mason et al. 2016; Dunn and Bourne 2017). Our study provides insight into how biology doctoral students perceive different barriers to their degree completion and how both non-cognitive factors (grit, sense of belonging, and science identity) and demographics may contribute to these barriers or not. The strongest relationship we detected was that higher grit scores predicted lower perceived personal/psychological barriers. Ris (2015) warns that leaning too heavily on grit as an explanation of disparities in performance, often noted in K-12 students of colour, may remove some of the critical pressure needed for institutions to take responsibility for their students and their diverse backgrounds. While our work with a different population indicates that our participating students with more grit perceived fewer personal/psychological barriers, we do not imply that doctoral students need to be grittier nor that grit should be used as a main predictor of success in doctoral programs. Grit is a personality trait that is cultivated through life experience and can be situational (Cheng, 2017). Individuals' experiences shape their outlook on challenges and obstacles they must overcome. We posit that there are mediators of grit that help to explain perceptions of barriers. Addressing these mediators (e.g.

supportive mentorship, culture to encourage growth mindset and skills associated with grit) may reduce barriers that biology doctoral students perceive. We maintain there is both an institutional and personal responsibility to nurture skills associated with graduate programs, and we expect that implementation of these supports can help reduce perception of barriers related to degree completion.

It is also important to note that although the grit subscales contributed the most to the *personal/psychological barriers* model, non-cognitive factors contributed little to *situational barriers* and *institutional barriers* models such that including demographic factors changed the outcomes from insignificant to significant. On average, our participants reported they perceived the situational and institutional barriers as less than 'slightly significant' (Table 1); thus, these types of barriers were likely less meaningful to our participants and most of their concern was focused on personal/psychological barriers. From interviewing a panel of experts, Kittell-Limerick (2005) also found that situational and institutional barriers had minimal effects on degree completion. The perception, by our sample of biology doctoral students, that these latter types of barriers minimally impacted their success, likely limited our ability to discern strong predictors and resulted in low R^2 values and relatively weak performance for situational and institutional barriers models. It is interesting, however, to consider why biology doctoral students may perceive these barriers as less significant than personal/psychological barriers (Table 1). Much of the current academic system has unequally benefited some groups more than others (Eaton et al. 2020), and we suspect students enrolled in doctoral programs have discovered and refined methods to overcome barriers related to situational and institutional support irrespective of their grittiness. Additionally, doctoral programs in biology and health sciences provide more financial support to graduate students than most other fields (Ostriker et al. 2010; Aihara 2020), which may be reflected in their low perception of institutional and situational barriers for this population.

Future directions

While our participants did not signal significant perceived barriers barricading their successful completion of their programs, the variability they noted helped us explore the factors leading to these barriers. Given previous literature, we were surprised to find that gender and race/ethnicity were not strong predictors of these barriers. Although members of some of these groups have been historically excluded from science fields, our data suggests that these identities did not intersect in meaningful ways to increase barriers to perceived degree completion. Rather, the few individual demographics that were predictors of the barriers we measured included number of disabilities and age. The importance of these factors underscores broadening the scope of support provided by programs and staff members to support women graduate students or graduate students of colour, but also graduate students with disabilities and of non-traditional age. Biology doctoral programs may be neglecting extra support that is needed by these latter groups, as evidenced by our work.

We also explored three non-cognitive factors to understand their role in predicting barriers to biology doctoral student perceived completion. We felt these may be skill sets that programs could actively support or influence through active intervention. However, grit was the only factor that arose as a notable predictor of the perceived barriers indicated by our participants. Further research is needed to better understand why personal and institutional barriers are perceived less than psychological barriers within biology doctoral programs and if this differs from other doctoral programs. Our study prompts the need for more research into what factors relate to grittiness at the graduate level, how an individual's grit changes throughout the doctoral program process, what support factors enhance traits associated with higher grit, and if higher grit leads to higher degree completion in doctoral students. Additionally, our work prompts the need for research on why science identity and sense of belonging were not strong predictors of barriers for our population. While the literature suggests these are important factors, little research has included them in investigations with graduate populations and our research does not unpack why they were weak predictors.

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