Disparities in Perceived Disciplinary Knowledge Among New Doctoral Students

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Abstract

Purpose –The purpose of this study is to examine whether there are differences in beginning doctoral students' perceptions of the disciplinary knowledge needed to be successful in doctoral education and identify pre-doctoral characteristics and experiences that explain these differences.
Design/methodology/approach – This study relied on survey data of first-year PhD students enrolled at a large, research-intensive university. Survey responses were matched to institutional information, missing data were imputed, and responses were weighted to account for groups' differential probabilities of being included in the analytical sample. The authors used regression analysis to examine the relationship between students' background characteristics, anticipatory socialization experiences, academic performance, and perceived levels of disciplinary knowledge.
Findings – Study findings indicated significant differences in doctoral students' perceived levels of disciplinary knowledge. Students who identify as female or URM had significantly lower levels of perceived disciplinary knowledge than students who identify as male or non-URM. Additionally, several anticipatory socialization experiences were significantly and positively related to perceived disciplinary knowledge.
Originality/value – While there is evidence that doctoral students start graduate school with varying identities and experiences, little is known about how students perceive their abilities and knowledge. This study found that students differ in their self-assessment of disciplinary knowledge as they embark on doctoral work, with implications for academic identity development and student success.
Keywords PhD Students, Disciplinary Knowledge
Paper type Research paper

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Introduction

A central purpose of doctoral education is to develop scholars who create and disseminate knowledge. Across the disciplines, PhD programs share the common expectation that doctoral students will become stewards of their discipline, develop an academic identity in which they recognize themselves and are recognized by others as experts in their chosen field, and know the norms and behaviors that underlie disciplinary expertise (Golde & Walker, 2006; Golde, 2010).

Despite the importance of knowledge acquisition to scholarly development and success in academia, we know little about the factors that influence doctoral students' disciplinary knowledge as they begin their programs. This paper adds to our understanding of doctoral student development by answering the following research question: *Are there differences in entering students' perceptions of possessing disciplinary knowledge and, if so, what are the factors that predict these differences?* Informed by socialization and sociocognitive learning perspectives, we examine students' educational experiences prior to enrollment, social identities, and academic preparation as potential factors affecting how knowledgeable they feel as they begin doctoral study. Students' self-perceptions in this area are critical to examine because lacking knowledge about disciplinary content, norms, and practices is a key correlate of early doctoral attrition (Golde, 1998, 2005).

We begin with a brief discussion of the integral role of disciplinary knowledge in scholarly development and consider how students acquire this knowledge and develop perceptions of possessing it. Then, we introduce our conceptual framework and examine the relationships between these constructs and disciplinary knowledge.

Literature Review and Conceptual Framework

Knowledge and Identity

As aspiring knowledge producers, graduate students engage in a long training process before they are considered experts in their discipline's intellectual territory. Not surprisingly, knowledge acquisition is a central component of socialization theory, which is the most prominent perspective used to describe scholarly development (Gardner & Mendoza, 2010). This perspective views doctoral study as a process by which individuals learn how to think, feel, and act like full-fledged scholars (Weidman, Twale, & Stein, 2001). The primary outcome of socialization is the development of an academic identity, or an internalization of the scholar role (Weidman, Twale & Stein, 2001). Traditionally, the process of developing an academic identity begins as an undergraduate in the *anticipatory* period. During this phase of socialization, potential doctoral students begin to learn the cultural norms of academia and form expectations about the scholar role (Austin, 2002; Gardner, 2007). As students' progress into PhD programs and socialization continues, they acquire the knowledge they need for successful identity development.

Dimensions of knowledge. Three types of knowledge are particularly integral to students' successful completion of a doctoral program and acceptance as a disciplinary expert: content, normative, and strategic. *Content knowledge* is the documented intellectual product and practice of a discipline—its theories, methods, and axioms that must be mastered for a scholar to be considered competent (Antony, 2002). Incoming doctoral students are most likely to acquire this type of knowledge through undergraduate activities such as coursework and reading (Delamont & Atkinson, 2001; Golde, 1998). Although content knowledge is critical to master, it

alone is not enough to certify one as a genuine member of an academic community (Becher & Trowler, 2001; Delamont & Atkinson, 2001). Doctoral students must also learn to adhere to the fundamental cultural rules of the discipline and department. This is *normative knowledge*, or an awareness of the tacit expectations and standards for appropriate behavior and practice in the discipline. Largely uncodified, it is appropriated through experience and by observing core members in the disciplinary community (Delamont & Atkinson, 2001; Tierney & Rhoads, 1993). Finally, *strategic knowledge* includes knowing how to develop realistic goals, aligning oneself with appropriate faculty, and understanding how to network (Adler & Adler, 2005; Delamont & Atkinson, 2001).

Self-perceptions of knowledge. Although socialization theory is a useful framework for understanding the general process of doctoral student development, it is less helpful for understanding the situated ways in which knowledge acquisition occurs (Baker & Lattuca, 2010). Learning is an active process shaped not only by prior knowledge and cognitive structures, but also by social contexts and self-reflection (Bandura, 2001; Schunk, 1989). Sociocognitive perspectives suggest that students develop notions of their academic capabilities by assessing their previous performance and comparing themselves to peers (Bong & Skaalvik, 2003; Mantai, 2018). Educational psychologists are particularly interested in *domain-specific academic self-concepts* - the perceptions that learners hold about their abilities in a specific content area. These perceptions matter because "individuals who are otherwise similar feel differently about themselves and choose different courses of action, depending on how they construe themselves" (Bong & Skaalvik, 2003, p.1). In sum, socialization and sociocognitive perspectives suggest that the subjectivity of academic self-construals, their propensity to vary across students, and their connection to the important process of academic identity development makes understanding self-perceived disciplinary knowledge critical to student success.

Factors Shaping Students' Knowledge Perceptions

Understanding the processes of knowledge acquisition and identity development among doctoral students requires the consideration of multiple interrelated factors. Students bring a variety of prior academic and professional experiences to their programs. Whereas some students may pursue doctoral training immediately after obtaining a bachelor's degree, others are likely to have work experience or other training prior to entry. Additionally, doctoral students' social identities may be more or less compatible with their field's conception of an "ideal" disciplinary expert and thus we might expect beginning students' assessment of their disciplinary knowledge to vary based on their social identities, prior disciplinary experiences, and academic achievements.

Social identities. Stewart and Dottolo (2005) note that "everyone who enters the academy for socialization—that is, attends graduate school—comes with a history and social identities" (p. 168). Students' sense of belonging in their discipline and normative congruence with academia will depend, in part, on the gendered, raced, and classed nature of these identities. Socializing agents often positively reinforce ways of knowing, acting, and thinking associated with majority groups. This implicit ideal results in an environment that enables some students to feel "at home" in academic programs that seem alienating and unfamiliar to others (Gardner, 2008; Stewart & Dottolo, 2005).

There are myriad ways members of minoritized groups encounter subtle and overt forms of oppression in academia.[1] In departments and disciplines, it might be implied that minoritized students are inexperienced, less competent, or admitted only by affirmative action (Archer, 2008; Solórzano & Villalpando, 1998), or their academic interests might be framed as too 'niche' (Margolis & Romero, 1998). These students may also be directed toward opportunities and resources associated with lower status in the academy (Archer, 2008). The cumulative effect of experiences like these lead many women, working-class, and racially minoritized students to feel isolated and frustrated by the socialization process, and, as a result, some feel less secure in their academic worth and abilities (Archer, 2008; Austin, 2002; McCoy, 2018). Studies on undergraduates have found that women perceive themselves as having lower academic skills than men, despite scoring equally on related skill assessments and tests (MacPhee, Farro & Canetto, 2013), and both White women and people of color of all genders have lower levels of academic self-confidence than White men (Antonio, 2004). Similar trends exist for women in science and engineering programs and women of color in a variety of graduate programs (Cross, 2001; Hurtado, 1994).

Anticipatory socialization. Although most academic socialization research focuses on identity development during graduate school or the early career phase, individuals often begin forming perceptions of the graduate student role, their disciplines, and their competencies before entering doctoral programs (Austin, 2002; Gardner, 2008). The main introduction students have to their disciplines and academic careers occurs while taking undergraduate coursework, which often differs substantially from what they will experience in graduate school.

To foster graduate school enrollment and success, higher education institutions and government-sponsored programs (e.g., McNair, NSF) encourage undergraduates to learn and practice research skills. Undergraduate research participation has been associated with enhanced intellectual curiosity, oral communication, and academic skills (Kardash, 2000; Russell, Hancock, & McCullough, 2007; Seymour et al., 2004). Other early socialization experiences that help students prepare for doctoral study include attending conferences, presenting research, and publishing (Gittens, 2014). These experiences provide undergraduates with a front-row view of the realities of doctoral education and the knowledge needed to succeed in academia.

However, minoritized students often have unequal access to such experiences. In an analysis of undergraduate research participation, Kim and Sax (2009) found that Black, first-generation college students, and students from lower socioeconomic backgrounds were significantly less likely to participate in undergraduate research with faculty. Black, Latinx, and Asian American/Pacific Islander students also participated in culminating experiences (e.g, senior projects, practicums) at significantly lower levels than their White counterparts (National Survey of Student Engagement, 2007). Furthermore, undergraduate access to highly selective, research-intensive institutions is similarly stratified by social class, race, and gender (Bielby, Posselt, Jaquette, & Bastedo, 2014). These disparities in pre-socialization experiences influence whether students pursue postbaccalaureate degrees (Ishiyama & Hopkins, 2003), suggesting they may also lead to differences in students' levels of disciplinary knowledge upon entry into graduate school.

Lastly, receiving encouragement from others is an important part of the anticipatory socialization process (Weidman et al., 2001). Students who are recognized by members of the

[1] We use the term *minoritized* to foreground racialization as a social process and to recognize groups that are systematically and socially marginalized in the US. This term signifies that persons are not born into a minority status, but are subordinated into minority positions by social institutions (See Harper, 2012).

discipline as possessing the skills and traits needed for future success are more likely to develop an identity as a competent scholar (Bess, 1978; Carlone & Johnson, 2007). This is likely a result of positive reflected appraisals—or individuals' perceptions of how others view them—in developing academic self-beliefs (Bong & Skaalvik, 2003).

Academic credentials. Undergraduate grades, college selectivity, and GRE scores are the strongest predictors of admission to graduate programs (Attiyeh & Attiyeh, 1997). Research suggests that admissions committees place considerable emphasis on quantitative measures like the GRE to manage the application review process and often use institutional selectivity as a signal of applicants' potential (Posselt, 2018). Despite their continued use in the admissions process, many scholars question whether these academic indicators accurately predict students' graduate school performance (Kuncel & Hezlett, 2007; Lovitts, 2005; Miller & Stassun, 2014; Miller, Zwickl, Posselt, et al., 2019; Moneta-Koehler, Brown, Petrie, et al., 2017). Most likely, undergraduate GPA and GRE scores are relatively poor measures of graduate students' actual levels of disciplinary knowledge and skills. Both lack disciplinary knowledge specificity and may reflect underlying biases against non-majority groups (Posselt, 2016; Solórzano & Villalpando, 1998). Institutional selectivity does not measure the actual learning that occurs at a college, as it is largely a measure of reputation.

Nevertheless, these academic credentials may inform students' *self-perceptions* of their knowledge. Research on academic self-concept, for example, has taught us that students' self-perceptions of their abilities is reciprocally related to academic achievement; thus, individuals' perceptions of their abilities is based on prior achievement and visa-versa (e.g., Marsh & Craven, 2006). Therefore, academic achievement, in the form of strong test scores or grades, serve as a form of feedback for students to construct their academic self-concepts. Given this research, it may also be the case that students who do well on these metrics perceive themselves as having higher levels of disciplinary knowledge. That is, better performance on the GRE, higher undergraduate GPAs, and attendance at selective colleges and universities may increase students' self-perceptions of their academic capabilities.

Current Study and Conceptual Framework

Although many initiatives seek to prepare students for graduate education, we know little about students' baseline knowledge as they embark on doctoral studies. What we do know is that there are disparities in pre-socialization experiences and academic credentials across social identity groups, and that some social identities are affirmed and supported more than others within educational contexts (Kim & Sax, 2009; Posselt, 2016). Taken together, evidence suggests that a variety of factors influence students' perceived disciplinary knowledge upon entry into doctoral study. Our hypothesized model, as displayed in Figure 1, suggests that students' background characteristics, anticipatory socialization experiences, and academic performance prior to doctoral study influence levels of perceived knowledge at the outset of PhD study. Our analysis explores how these factors are related to self-perceived disciplinary knowledge.

[Figure 1 here]

Methods

Data

We use base year data from the Michigan Doctoral Experience Study, an ongoing longitudinal study of PhD students at the University of Michigan developed to answer questions about doctoral student socialization and development. The base year survey was administered at the beginning of the students' first term of PhD study, thus allowing us to collect baseline

measures of students' beliefs and perceptions before intervening doctoral experiences could change them. Over 790 students responded to the base year survey. We used institutional data to augment student records with information about demographics and academic records.

Measures

Dependent variable. The dependent variable in this study is doctoral students' subjective ratings of their disciplinary knowledge. Throughout this paper, when we refer to students' levels of disciplinary knowledge, we are implicitly referring to their self-perceptions. Although the survey included separate items that asked about students' content, normative, and strategic knowledge, exploratory factor analysis indicated the items coalesced into a single construct of disciplinary knowledge (Cronbach's alpha=0.85). Thus, we generated a single factor using principal components analysis with varimax rotation. Table 1 presents the six items that comprise the knowledge factor and their means.

[Table 1 here]

Demographics and discipline. Our analysis includes several groups of variables posited to influence students' perceived disciplinary knowledge. The first group, demographic characteristics, include social identities that are differentially affirmed in educational contexts (Margolis & Romero, 1998; Stewart & Dottolo, 2005). Using institutional data, we generate a set of dichotomous variables for sex, citizenship (Domestic or International), under-represented minority status (URM are those who identify as Black, Latinx/Chicanx/Hispanix, and/or Native American), and low-SES background (a combination of parental educational levels and self-reported family income). Additionally, we account for potential disciplinary differences in knowledge using the National Science Foundation's program classification scheme to group programs into broad disciplinary categories.

Anticipatory socialization. We account for students' anticipatory socialization experiences with variables derived from institutional and survey data. We include indicators for the following experiences: previous master's degrees in a related field, assisting faculty with research, working professionally in their field, presenting at an academic conference, publishing, and joining a disciplinary organization. To account for the importance of others in the development of academic self-construals (Carlone & Johnson, 2007; Mantai, 2018), we also include a measure of students' perceptions of having received recognition and encouragement during their past degree program.

Academic credentials. We include measures of students' undergraduate GPA and their verbal and math GRE percentiles obtained from institutional data. To account for the prestige of students' undergraduate institutions, we use the Times Higher Education (THE) World University Rankings to classify their colleges into three categories (top 50, 51-200, etc.).

Analytical Strategy

The goal of this study is to understand the factors that predict new doctoral students' levels of disciplinary knowledge. As a first step, we calculate descriptive statistics to understand sample distributions and examine correlations with disciplinary knowledge. We disaggregate these statistics across sex, race, and class to explore inequitable educational conditions at the graduate level. Then we employ ordinary-least-squares regression to examine associations between the previously discussed explanatory and outcome variables. We use linearized robust variance estimation in these analyses. As a final step, we calculate predictive margins of perceived disciplinary knowledge.

Missing data. Despite a high survey response rate (77%), there are disparities in the likelihood of students' response by sex and citizenship status. We address this by applying

survey weights throughout the analyses. Because 16% of survey respondents are missing data on at least one variable used in the analysis, we employ multiple imputations to retain observations and more accurately calculate standard errors.

Limitations. It is important to note that the data we use in this study comes from one selective research-intensive institution. This limits the external validity of the findings to students who attend similar institutions. Relatedly, the selectivity of doctoral programs at this university resulted in highly right skewed distributions of the continuous academic credentials. As a result, it is possible that our analysis does not adequately reflect the true overall relationship between these factors and disciplinary knowledge due to sparse data at lower levels of academic achievement. Although this study serves as a first step in better understanding the disciplinary knowledge students possess as they begin doctoral study, additional work will be needed at institutions that enroll students with a more expansive range of academic credentials. See Appendix B for additional details about the weighting, imputation procedure, and collinearity checks conducted to mitigate and identify other potential issues.

Results

Table 2 presents descriptive statistics of the variables used in the analysis. The first column presents the means/proportions and standard errors for the full sample, while the following three columns show statistics across social identities. These statistics are bolded if they differ from the mean/proportion for their comparison groups at the 90% confidence level or greater.[2] Overall, the results in Table 2 indicate that female or URM students have lower levels of perceived disciplinary knowledge than students who identify as male or non-URM. Low-SES students, however, have higher knowledge scores than their peers. There are several differences in students' anticipatory socialization and academic credentials across sex, race, and SES status. Females are more likely than males to have had previous professional experience or have joined a disciplinary organization, but were less likely to score highly on the math GRE test. URM students were less likely than non-URM students to have earned a previous master's degree or publish, but were more likely to have presented research.

[Table 2 here]

Table 3 furthers the descriptive analysis with an OLS regression. The results suggest that the differences in knowledge across sex and URM status remain after controlling for other factors. On average, females' knowledge scores are 0.23 sd lower than males' scores and URM students' scores are 0.19 sd lower than non-URM students' scores, but we find no significant difference in knowledge scores across SES status. Further, several anticipatory socialization variables are significantly associated with knowledge scores. Students who have a master's degree, research experience, and those with more recognition from faculty during previous degree programs all tend to report higher levels of disciplinary knowledge.

[Table 3 here]

Contrary to our expectation, there is little relationship between students' academic credentials and their knowledge scores, with one unexpected exception. The results in Table 3 indicate that students in the right half of the GRE verbal score distribution have *lower* knowledge scores than students in the left. Although math GRE scores do not generally appear to be significant predictors of knowledge when the first quartile is used as the reference group, an additional regression (not shown) indicates that students in the second GRE math quartile have significantly *higher* knowledge factor scores than students in the fourth quartile. Undergraduate institutional selectivity and GPA are not related to knowledge scores.

[2] We use a 0.10 significance threshold due to the small number of low-SES and URM students in the sample.

Figure 2 presents predicted knowledge scores across sex, URM status, and selected GRE verbal quartiles while other values are held at their sample means. When sex, race, and verbal reasoning skills are considered jointly, the results suggest that high-achieving females from underrepresented racial/ethnic groups begin doctoral study with lower self-perceived levels of disciplinary knowledge than students from other groups.

[Figure 2 here]

Discussion

The transition into doctoral study is a critical juncture in academic socialization, yet we know little about students as they undertake this intensive period in their academic identity development. The results from this study suggest that well-qualified doctoral students at a research-intensive institution differ in their perceived baseline disciplinary knowledge, and that these differences vary across social identities, anticipatory socialization experiences, and academic credentials.

It is highly problematic that sex and URM status are both associated with perceived knowledge even though we controlled for the major metrics and experiences used to select students into doctoral programs. We suspect that disparities in knowledge scores result from differences in self-construals of competence. In other words, there is a confidence gap between males and females and URM and non-URM students when it comes to their disciplinary knowledge. We base this assumption on a wealth of research that finds minoritized individuals underestimate their academic skills and traits to a much greater extent than White males do (Correll, 2001; MacPhee, et al., 2013). This occurs because learners internalize societal messages about competence related to gender and race/ethnicity that bias their self-perceptions (Clance & Imes, 1978; Correll, 2001). Thus, even when objectively performing well, members of disadvantaged groups can feel like "imposters" in academe because they doubt their own intellectual competence (Clance & Imes, 1978).

That academic confidence gaps exist before the intensive process of doctoral training commences has implications for educational stratification. Research suggests that faculty may make decisions about how to invest their limited time by choosing to work most intensively with "promising" students, which in turn could influence student growth and later research self-efficacy (Feldon et al., 2016; Green & Bauer, 1995; Paglis, Green & Bauer, 2006). Even if minoritized students are as knowledgeable as their non-minoritized peers, they could receive fewer resources and opportunities if they lack confidence in their knowledge. A final result we wish to highlight is the lack of a relationship between almost all pre-doctoral academic credentials and self-reported knowledge scores. This may be because undergraduate selectivity and GPA lack relevance to disciplinary knowledge. It may also be that the competitive graduate admissions process at this university reduces variation in students' GPA and institutional selectivity to such an extent that we are unable to measure an association. However, lack of variation in credentials does not explain why verbal GRE scores (which are strongly right-skewed in our sample) *are* associated with perceptions of knowledge. Contrary to our proposed framework, knowledge scores actually decrease as GRE quartiles increase, suggesting that students with higher academic performance perceive themselves to be less knowledgeable.

We offer two possible explanations for the negative relationship between GRE scores and disciplinary knowledge. First, this may be evidence of the Dunning-Kruger effect, which is the tendency of people who are more knowledgeable in a domain to perceive the limits of their competence more readily than people who are less knowledgeable (Dunning, 2011). The second explanation is that the association is spurious. Very few students in the first quartile of GRE

scores are admitted to the university and those admitted likely have unique experiences and credentials valued by their discipline that we are not able to observe in this study. However, this a less plausible explanation than the Dunning-Kruger effect, given that students who score in the third quartile of GRE scores (51st-75th percentiles) rate their knowledge more highly than students in the fourth quartile of GRE scores (76th-99th percentiles). We plan to continue exploring this relationship as more data becomes available.

Implications

The results from this study highlight the potential interactive role of sociocognitive factors in shaping identity development in doctoral students and suggest both a practical set of implications and next steps for future research. Specifically, after accounting for previous academic performance, our research finds disparities in students' perceptions of their disciplinary knowledge at the start of graduate school according to gender and race. If the self-perceptions students hold at the start of their programs are related to the self-perceptions they hold later in their programs—as previous research suggests (Paglis, Green, & Bauer, 2006)—then graduate schools might consider offering programming that includes sociocognitive components to address these early gaps in self-construals of knowledge. There is growing awareness that self-concept misperceptions such as imposter syndrome pose a serious challenge to academia's diversity, equity, and inclusion efforts (Chrousos & Mentis, 2020). Self-concept interventions have been employed with undergraduate populations (Gibbons & Shoffner, 2004), thus establishing a set of interventions that could be extended to graduate students.

The strong association between anticipatory socialization experiences and perceptions of knowledge is problematic when we consider that certain types of undergraduates are more likely than others to engage in high-impact practices, such as helping faculty with research (Kim & Sax, 2009). If educational leaders are serious about improving the diversity of the nation's scientists and scholars, then they should expand programs that facilitate access to research opportunities and disciplinary mentoring for minoritized undergraduates and increase financial support to minority-serving institutions. These colleges excel at teaching Asian/Pacific Islander, Black, Latinx, and Native students in culturally sensitive and supportive environments but may lack funds for research infrastructures (Gasman, Baez, & Turner, 2008). To the degree that students' perceived knowledge at the start of doctoral study facilitates future academic identity development, our study's results suggest that expanding undergraduate research programs and investing in MSI infrastructures could help lessen the racial/ethnic gaps in PhD completion and the professoriate that currently exist.

Finally, future research should validate and extend these findings across multiple institutions. The survey used in this study is currently administered at only one institution—a public, selective, research-intensive institution, and the results from this study are likely most valid for students at similar types of institutions. Thus, while the doctoral population at the University of Michigan includes a wide array of disciplines and a diverse body of students across various demographic dimensions, it is possible that institutional characteristics might affect the strength and tenor of our findings. Although we suspect institutional effects on perceptions of knowledge are minimal this early in students' doctoral careers, a cross-institutional sample might help illuminate differences in how students self-select into institution types. Larger sample sizes might also allow for more targeted analytical approaches that thoroughly examine intersectional differences across a host of demographics.

Conclusion

This study provides some of the first evidence about how students differ in their self-assessment of disciplinary knowledge as they embark on doctoral work. Our findings highlight important differences in how students see themselves across sex and race categories despite equivalence across a host of independent academic markers. These self-perceptions have important implications for identity development, and by extension impact students' capacity to advance as scholars in their chosen discipline. These disparities should be closely monitored, and as appropriate, institutions should deploy a full host of strategic interventions to mitigate the potential negative effects these disparities may have on the experience of doctoral students.

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Appendix A

Figure 1. Conceptual model

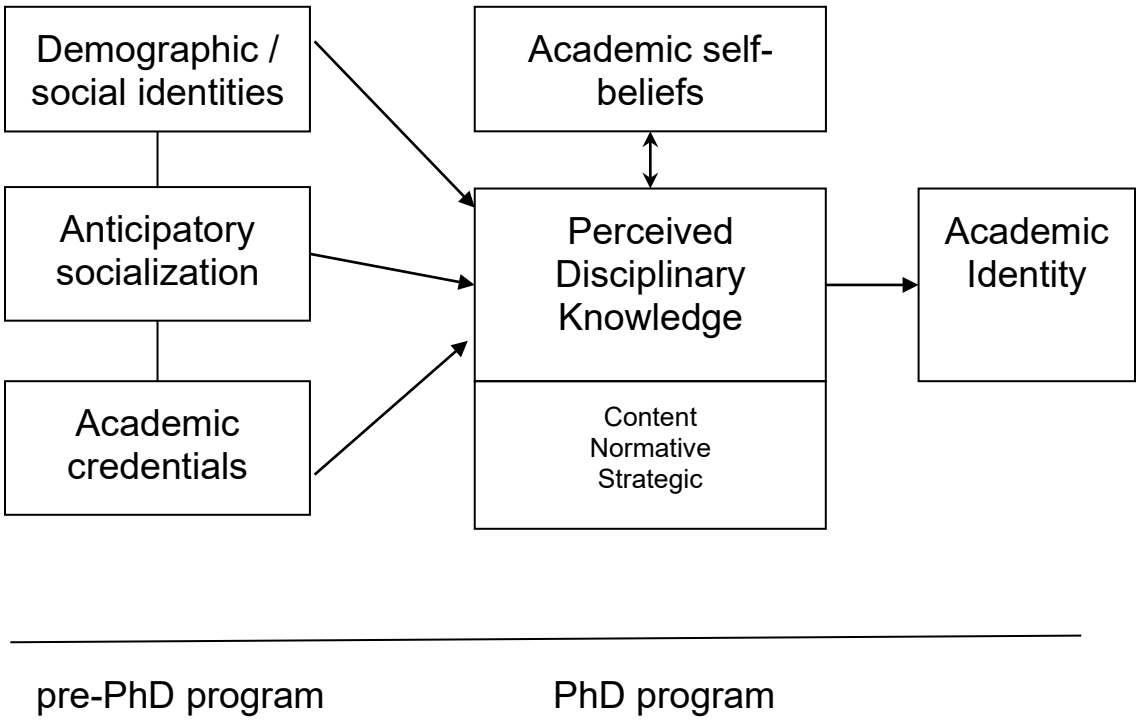


Table 1. Disciplinary knowledge items and their sample means

Question: Please indicate how true the following statements are at this stage in your program: (1=Not at all true; 2=Slightly true; 3=Moderately true; 4=Very true; 5=Extremely true)	Sample Mean
Content Knowledge Items	
I have extensively read the foundational literature in my discipline	2.88
I have a deep understanding of the theories used in my discipline	2.84
Normative Knowledge Items	
I know the standards in my discipline for good work	3.40
I have a good understanding of how to frame research so that it is appealing to scholars in my discipline	3.02
Strategic Knowledge Items	

I know the steps I need to take to achieve my academic goals	3.51
I can navigate departmental politics easily	2.73

Table 2. Means/proportions and standard errors of variables used in the analysis, by female, URM, and low SES status.

Variable	Full Sample *(N=793)*	SE	Female *(N=467)*	SE	URM *(N=158)*	SE	Low SES *(N=116)*	SE
Knowledge factor	0.01	0.04	**-0.10**	0.05	**-0.15**	0.10	**0.05**	0.09
Demographics and discipline								
US citizen or perm. resident	0.64	0.02	**0.70**	0.02	**0.99**	0.01	0.64	0.05
Discipline								
Bio & health sciences	0.22	0.01	**0.28**	0.02	0.25	0.04	0.19	0.04
Physical sciences	0.50	0.02	**0.33**	0.02	**0.39**	0.04	0.46	0.05
Social sciences	0.11	0.01	**0.14**	0.02	**0.19**	0.03	0.12	0.03
Humanities	0.10	0.01	**0.13**	0.02	0.09	0.03	**0.14**	0.03
Professional fields	0.07	0.01	**0.11**	0.02	0.09	0.02	0.09	0.03
Anticipatory socialization								
MA degree	0.42	0.02	0.45	0.03	**0.33**	0.04	0.49	0.05
Research experience	0.86	0.01	0.83	0.02	0.86	0.03	**0.78**	0.04
Professional practice	0.47	0.02	**0.51**	0.03	**0.40**	0.05	0.43	0.05
Presentation experience	0.50	0.02	**0.53**	0.03	**0.63**	0.04	0.57	0.05
Published	0.46	0.02	0.44	0.03	**0.36**	0.04	0.39	0.05
Disciplinary org. membership	0.48	0.02	**0.55**	0.03	**0.58**	0.04	0.54	0.05
Recognition	-0.01	0.04	**0.07**	0.05	0.01	0.10	-0.12	0.09
Academic credentials								
Undergraduate GPA	3.67	0.01	3.66	0.02	**3.58**	0.03	3.63	0.03
GRE Verbal %tile	74.67	0.80	75.94	1.09	**70.44**	2.00	**67.78**	2.18
GRE Math %tile	76.91	0.78	**69.54**	1.23	**59.22**	2.27	**69.45**	2.29
Undergrad institution ranking								
Not in top 200	0.57	0.02	0.60	0.03	0.62	0.04	**0.66**	0.04
Top 200-51	0.18	0.01	0.16	0.02	0.16	0.03	**0.12**	0.03
Top 50	0.26	0.02	0.24	0.02	0.22	0.04	0.21	0.04

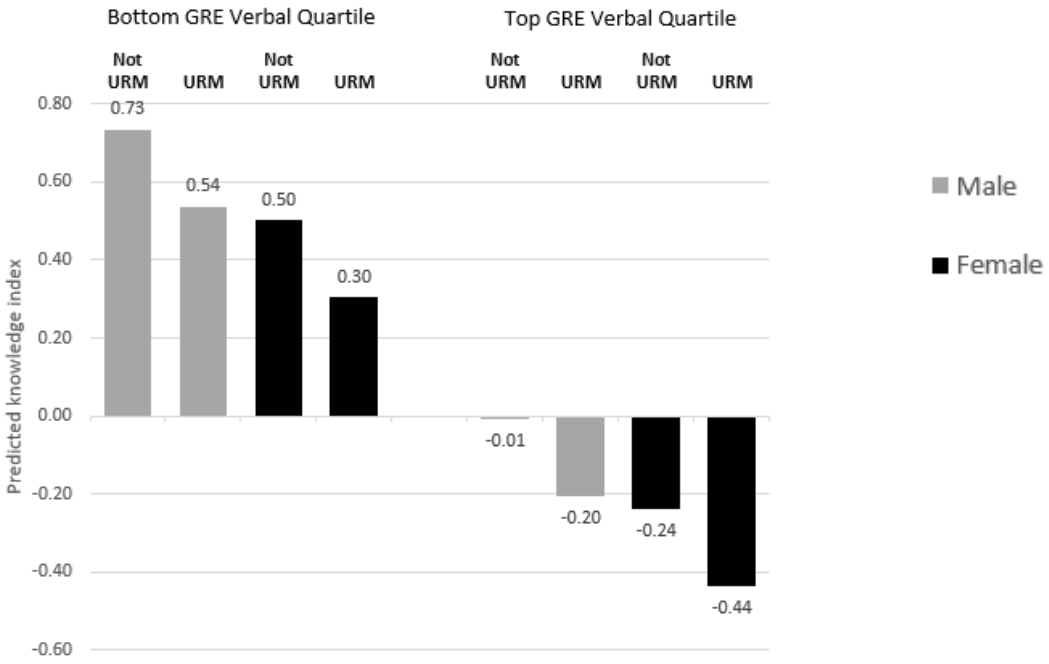
Notes. Data source is Michigan Doctoral Experience Study. Missing data are imputed and statistics are weighted to reflect the target population. Bolded means/proportions are significantly different from the reference group at the 90% confidence level or higher.

Table 3. Blocked regressions of doctoral students' disciplinary knowledge on covariates (n=793)

Covariate	Coef		SE
Demographics			
Female	-0.23	**	0.07
URM	-0.20	†	0.11
Low SES	-0.02		0.09
US Citizen or perm. resident	-0.18	*	0.09
Discipline type			
Bio & health sci (vs prof fields)	0.63	***	0.15
Phys sci & eng. (vs prof fields)	0.60	***	0.14
Social sci (vs prof fields)	0.63	***	0.15
Humanities (vs prof fields)	0.62	***	0.17
Anticipatory socialization			
MA degree	0.22	*	0.07
Research experience	0.28	**	0.10
Professional practice	0.11		0.07
Presentation experience	0.04		0.07
Published	0.02		0.07
Disciplinary org. membership	0.11		0.07
Recognition	0.24	***	0.03
Academic credentials			
Undergraduate GPA	-0.06		0.12
GRE verbal quartile			
2nd (vs 1st / lowest)	-0.33		0.21
3rd (vs 1st / lowest)	-0.46	**	0.19
4th (vs 1st / lowest)	-0.74	***	0.20
GRE math quartile			
2nd (vs 1st / lowest)	0.35	†	0.21
3rd (vs 1st / lowest)	0.27		0.19
4th (vs 1st / lowest)	0.03		0.19
Undergrad institution ranking			
Top 200-51 (vs not in top 200)	0.06		0.09
Top 50 (vs not in top 200)	0.08		0.08
Constant	-0.10		0.52
Adjusted R2	0.20		

Notes. Disciplinary knowledge factor scores (the outcome variable) are standardized. Data source is Michigan Doctoral Experience Study. Missing data are imputed and statistics are weighted to reflect the target population.
† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure 2. Predictive margins of knowledge factor scores across sex, URM status, and GRE verbal quartile



Notes: Covariates set at sample means.

Appendix B
Methodological Details

Weights. All first year PhD students at the University of Michigan were invited to take the MDES survey in 2017. However, only 77% accepted the invitation. Analysis indicates that students' propensity to respond to the survey is correlated with several demographic variables. Females, citizens and permanent residents, social scientists, and White and Asian students are more likely to respond than males, international students, physical scientists and engineers, and URM students, respectively. In an effort to reduce selection bias and make our results representative of the population of interest (first year PhD students at the university), the survey employs probability weights. Probability weights were calculated using the following model:

[Eq. 1] $1/pr(r)=\alpha+\beta_1 female+ \beta_2 USPR+ \beta_3 discipline+ \beta_4 URM+ \beta_5 age$

where *1/pr(r)* is the inverse of the predicted probability of responding to the survey, *female*, *USPR* (US citizen or permanent resident) and *URM* are dichotomous indicators, *discipline* is a multinomial variable with four values (biological and health sciences, physical science and engineering, social sciences, and the arts and humanities), and *age* is a continuous measure of the students' age at the time of the survey. We used these covariates because they were available for all in the population and correlated with students' likelihood of response.

Imputation procedure. Our approach to dealing with missing data among survey respondents is to assume that the data is missing at random (MAR) and use multiple imputation (MI) to infer the missing values. We used using Royston's ICE program to generate 30 imputed datasets with predictive mean matching applied to continuous covariates. The imputation model includes all independent and dependent variables used in the analyses, as well as additional contextual variables such as age, marital status, and intrinsic motivation levels that may help explain missingness. Doing so supports the assumption of MAR and improves the precision of estimates during the analysis stage (Schaefer & Olsen, 1998; White, Royston, & Wood, 2011).

Collinearity. To explore the possibility of highly correlated predictor variables, we conducted a multicollinearity test using Klein's mivif module in Stata. This module accounts for Rubin's rules by pooling the VIF statistics across all imputed datasets. The test indicated that our analysis does not suffer from multicollinearity, as all of the independent variables in our regression model have a VIF of well below 10 (results available upon request). The mean VIF across all variables is 1.68.