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# STEM doctoral students' skill development: does funding mechanism matter?

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## Abstract

**Background:** A substantial monetary investment supports STEM doctoral students in the United States (U.S.) through a variety of funding mechanisms (e.g., fellowships, research, and teaching assistantships). However, we have limited knowledge of how students' funding influences their development of career-relevant skills during graduate school. Using survey data from STEM doctoral students ( $n = 719$ ) across 35 highly ranked U.S. institutions, we use exploratory factor analysis and nested multivariate regression modeling to understand how students' primary funding influences development of: (a) research skills; (b) teamwork and project management skills; (c) peer training and mentoring skills, and (d) communication skills.

**Results:** We find significant differences in students' self-reported development for all four career-related skills based on their primary funding type. Students with research assistantships reported higher research and teamwork and project management skills than those with teaching assistantships. Yet, students with teaching assistantships reported significantly higher development of peer training and mentoring than students funded via all other types. Students funded via external fellowships reported lower skill development than students funded primarily by research assistantships across all four career-relevant skills.

**Conclusions:** Doctoral students' development of career-relevant skills are not uniform across primary funding types. Particularly, the perceived benefits of external fellowship funding (i.e., prestige, autonomy, increased pay) may come at the cost of fewer opportunities to develop skills important for career success. STEM graduate education scholars, practitioners, and policymakers should consider and ameliorate the varied impacts that funding mechanisms can have on graduate students' development of career-relevant skills.

**Keywords:** Graduate education, Funding, Doctoral, Survey, Skill development, Assistantship, Fellowship, Research

## Introduction

The manners and extent to which countries around the world fund graduate students pursuing doctoral degrees in STEM vary considerably (e.g., Corcelles et al., 2019; Nori et al., 2020; van Rooij et al., 2019). Across international contexts, however, funding seems to play a prominent role in doctoral students' experiences and outcomes (e.g., Horta et al., 2018; Horta et al., 2019). In the United States (U.S.), the country of focus in this

study, a substantial monetary investment supports the vast majority of STEM graduate students in their pursuit of doctoral degrees through a variety of funding mechanisms, including fellowships, research assistantships, teaching assistantships, and other institutional, industry, and grant sources (Knight et al., 2018; Nettles & Millett, 2006; Sowell et al., 2015). Funding packages are competitive and are often used strategically in the recruitment of doctoral students (Wall Bortz et al., 2020), with the majority of STEM doctoral students receiving offers for funding at admission (Bortz et al., 2019; Nettles & Millett, 2006). Although students receiving funding are more likely to finish doctoral degrees compared to self-funded

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students (Ehrenberg & Mavros, 1992; Sowell et al., 2015), the type of funding students receive can differentially influence their graduate school experiences (Ethington & Pisani, 1993), graduation and career outcomes (Ehrenberg & Mavros, 1992; Nettles & Millett, 2006), agency (Borrego et al., 2019), and career productivity (Buchmueller et al., 1999; Nettles & Millett, 2006).

Prior research has focused primarily on the three major sources of funding for STEM doctoral students—research assistantships, teaching assistantships, and fellowships—and highlights the tradeoffs afforded to each funding type. Research assistantships have been linked with expediting students’ dissertation and degree progress, providing students with experiences that enhance their research skills, and strengthening their advisor, faculty, and peer interactions through participation in research groups (e.g., Crede & Borrego, 2012; Nettles & Millett, 2006). Fellowship funding, which is not tied to a specific research project or topic, offers students the flexibility to participate across multiple research projects, autonomy to engage in research that is of interest to them in alignment with their dissertation, and prestige associated with receiving these funding awards (Choe et al., 2018). Teaching assistantships have been linked with the acquisition of teaching and communication skills (Mitchell et al., 2003), organization and time management skills (Curtis & Jacobe, 2006), and improved research skills (Feldon et al., 2011).

Given the varied impacts, funding can have on graduate students’ experiences and development, ideally, students would make strategic and intentional decisions about their funding that align with their career goals. Unfortunately, STEM doctoral students, in general, may lack sophistication in their understanding of how doctoral training prepares them for post-doctoral careers, particularly those outside of academia (e.g., industry, government, start-ups) (Austin, 2010; Borrego et al., 2019; Gibbs et al., 2014). Borrego et al. (2019) investigated the funding experiences of 39 STEM doctoral students and found that, across funding types, students recognized the importance of research and teaching experiences to

be competitive for faculty positions but were unable to identify other career-relevant skills (e.g., communication) important to career success after graduation. The extent to which the skills students develop align with their intended career pathways will impact their career pursuits, yet considerably little attention has been paid to how funding type impacts how students think about and develop career-relevant skills.

This paper examines STEM doctoral students’ experiences with funding and its impact on developing career-related skills. Specifically, we investigate the following research question: To what extent does STEM doctoral student funding type work to develop students’ (a) research skills; (b) teamwork and project management skills; (c) peer training and mentoring skills, and (d) communication skills development? Table 1 details how we define each career-relevant skill as aligned with primary funding (note: refer to the ‘Methods’ section for a fuller description).

**Literature review**

Although most U.S. STEM doctoral students are fully funded (Knight et al., 2018), there are variations in the mechanisms used across the fields of engineering, life sciences, and the physical sciences. Examining five years of data from the Survey of Earned Doctorates (SED), Knight et al. (2018) found that, among the STEM disciplines, fellowships are more predominant in the life sciences, teaching assistantships in physical sciences, and research assistantships in engineering. More specifically, grants and fellowships seem to be more commonly available in the life sciences than in the physical sciences or engineering, and private institutions were more likely to use fellowship and grant funding than research institutions and public institutions. Research assistantships were more prevalent in the physical sciences and engineering than in life sciences, whereas teaching assistantships fund physical science graduate students at a higher rate than engineering and life science students (Knight et al., 2018).

In the following sections, we reviewed the literature on the three most common types of U.S. STEM doctoral

**Table 1** Definitions of career-relevant skills

Career-relevant skill	Definition
Research skills	My current primary funding source helped me learn how to conduct research, make progress for my dissertation, and critically evaluate a journal article
Communication skills	My current primary funding source helped me learn how to communicate my ideas verbally, in writing, and to facilitate a difficult conversation
Peer training and mentoring skills	My current primary funding source helped me learn how to train and mentor peers
Teamwork and project management skills	My current primary funding source helped me learn how to work collaboratively in a team and to manage projects

student funding (research assistantships, fellowships, and teaching assistantships) and their influence on students' skill development. We focused on skills related to communication, peer mentoring, teamwork, project management, and research. First, to contextualize our findings within an international context, we summarize literature that addresses funding doctoral programs internationally and then describe literature based on funding doctoral students within the United States.

### **The international context of funding STEM doctoral students**

How doctoral students are funded varies considerably around the world. In many European countries, for example, "a sizeable group of PhD students have a formal employment agreement with a university and have full-time working schedules and a full scholarship... which means they do not have to balance research with paid work in other areas" (Levecque et al., 2017, p. 869). For example, Van Rooij et al. (2019) asserts that financial concerns are hardly an issue as almost all students are on fully funded contracts within the Netherlands. In contrast, funded full-time positions in Nordic countries, such as Finland, are limited to only some students, which has created a fiercely competitive environment for funding (Nori et al., 2020).

The influence of funding on doctoral student outcomes, such as time-to-degree completion and research productivity, has been investigated across a number of international contexts. In Portugal, for example, Horta et al. (2018) found that PhD grants—monies awarded by national funding agencies through public competitive research funds—positively affected research performance during and after doctoral studies when compared with research project grants, which are given to research assistants through a university or research institute to assist with research. In a different study, Horta et al. (2018) investigated the relationship between funding and time-to-degree completion. Unfunded students who were highly productive in research during their PhD as well as funded students who did not publish during their PhD took longer to complete compared with funded students with high levels of research productivity. Other studies have shown that students who encounter issues with funding progress more slowly or stop out entirely of doctoral pursuits (e.g., Nori et al., 2020). Thus, these studies across national contexts demonstrate that exploring the relationship between funding and doctoral students' outcomes is warranted.

### **Research assistantships**

In the United States, research assistantships (RAs) are designed to provide graduate students with practical research training skills (Rossouw & Niemczyk, 2013) and have been linked with increased research productivity, agency, and prestige (Ampaw & Jaeger, 2012; Borrego et al., 2019; Ethington & Pisani, 1993). RAs are considered by many to be more desirable than teaching assistantships because they often lead to increased opportunities to publish articles, present at conferences, and identify dissertation topics (Heiss, 1970; Nettles & Millett, 2006; Niemczyk, 2015). Additionally, RAs often provide membership in research groups where students can collaborate with faculty and peers on research from one or more projects, develop research skills and experience, and take advantage of the prestige associated with participation in well-funded research groups (Ampaw & Jaeger, 2012; Ethington & Pisani, 1993; Szelényi, 2013). Access to research labs plays a critical role in exposure to the research process and the development of research-related skills (Ampaw & Jaeger, 2012; Niemczyk, 2015). Research labs have also been linked with doctoral students' skill development in areas such as communication and peer interaction. Most graduate students in science and engineering disciplines participated in a research group similar to a community of practice that was mentored by an advisor and organized by the advisor's research interests (Crede & Borrego, 2012). Crede and Borrego (2012) interviewed 20 engineering graduate students and observed research groups from one large public research university and analyzed 820 survey responses from engineering graduate students at four research universities. They found that research group size influenced the mechanisms of student learning. In particular, peer interaction, mentoring, communication, learning, and development of professional skills were more prevalent in large research groups than medium and small-sized research groups.

However, not all RA positions have opportunities to engage in high-level research design or make connections between research tasks and the larger research project, especially for students who are new to research or a research lab (Feldon et al., 2011; Rossouw & Niemczk, 2013). This could, in part, be a result of most RA contracts lacking formal written position descriptions with job duties, which may threaten the research assistant's skill development (Rossouw & Niemczk, 2013). Szelényi (2013) also found concerns among faculty for students working on industry-funded research in that they

would be focused on small pieces of a project and miss the larger picture, thus impeding their scientific development. Niemczyk (2015) interviewed 13 doctoral students in non-STEM disciplines about their experiences with RAs and found many students perceived their research supervisors as too busy to formalize training and development of research skills, preferring instead to hire research assistant candidates with pre-existing research skills.

### Fellowships

Fellowships are coveted because they cover students' financial needs without additional work requirements (Bowen & Rudenstine, 1992; Lovitts, 2001; Mendoza et al., 2014). Szélényi (2013) found that "the value of fellowships reached beyond the market, holding considerable symbolic meaning as a conveyor of freedom and prestige" (p. 283). Fellowships also provide greater autonomy and more time available for research, thereby reducing time-to-degree (Graddy-Reed et al., 2021; Herzig, 2004) and increasing students' potential access to multiple research projects. They have a positive relationship with retention because they are typically awarded based on merit and students' potential to complete their PhD studies (Mendoza et al., 2014), and have also been linked with increased publications, citations, and co-author network size (Graddy-Reed et al., 2021). Internal—university or department-based—fellowships are typically offered to students as a competitive recruiting tool and have also been used to recruit students from underrepresented groups (Lovitts, 2001). However, in STEM fields, fellowships do not provide access to research groups in the same ways as RAs, which can delay students' degree progress, limit their access to faculty and peer mentors, and negatively impact attrition (Lovitts, 2001; Mendoza et al., 2014). Considering these disadvantages, "some argue that research assistantships can be more useful than fellowships" in the sciences (Bowen & Rudenstine, 1992, p. 185). We have not seen prior literature that has examined the relationship between fellowship funding and career-relevant skills, as benchmarked against other forms of funding.

### Teaching assistantships

Teaching assistantships (TAs) contribute to socialization with faculty and peers and, in turn, support graduate student retention (Mendoza et al., 2014). This funding mechanism also provides teaching opportunities that may help graduates attain faculty appointments (Curtis &

Jacobe, 2006; Prieto & Meyers, 2001; Wan et al., 2020). In addition to teaching and communication experiences, TAs also provide opportunities for other career-related skill development. In a national assessment of the U.S. National Science Foundation (NSF)-funded Graduate Teaching Fellows in K-12 (GK-12) Education outreach program, participating fellows showed improvements in their communication and teaching skills, as judged by the fellowship recipients themselves, faculty advisors, project directors, and K-12 teachers with whom they worked (Mitchell et al., 2003). Specific gains included "gauging their audience and articulating difficult concepts clearly" (Mitchell et al., 2003, p. 5). In an evaluation of Cornell University's GK-12 program, Trautmann and Krasny (2006) found faculty advisors attributed improvements in their advisees' teaching, curriculum development skills, organization and time management skills, self-confidence, and professionalism to the program. TAs may be a compelling supplemental funding source for doctoral students seeking faculty careers—Borrego et al. (2019) found that students with a steady fellowship or RA funding, exceptionally strong agency and a supportive advisor viewed a one-semester TA as an opportunity to develop skills needed for a faculty position.

TA positions, in some cases, also offer research skill development opportunities, including those related to high-level research design, decision-making, and self-explanations of research processes and decisions (Feldon et al., 2011). For example, in a small, qualitative study, French and Russell (2002) found that TAs for a mixed-major, inquiry-based biology laboratory self-reported improvements in their research skills, such as problem identification, research design, hypothesis formation, and oral and written communication. Feldon et al. (2011) used a performance rubric to compare the methods sections of research proposals written by STEM graduate students with research duties to students who had both research and teaching duties. After controlling for pre-existing differences, they found that the group with research and teaching duties had greater gains in "their abilities to generate testable hypotheses and design valid experiments" (Feldon et al., 2011, p. 1037). Trautmann and Krasny (2006) found that 33% of faculty advisors identified positive impacts on GK-12 participants' research abilities and improved presentation skills in year-end interviews, and some teaching fellows published their GK-12 work in journal articles or a book.

Despite providing students with opportunities to develop teaching and communication skills relevant for

faculty careers, Borrego et al. (2019) found that for most STEM doctoral students, TAs were the least desirable funding type because they distracted from research and degree progress. For example, teaching assistantships have been linked with delayed time-to-degree, a result of having less time available to make progress on a dissertation (Borrego et al., 2019; Nerad & Cerny, 1991; Nettles & Millett, 2006).

Collectively, these studies have investigated skill development for doctoral students funded through RAs, TAs, and to a lesser extent fellowships. Looking across these studies, RAs have been linked with increased access to research experiences and development of research skills, whereas TAs provide opportunities for students to communicate and articulate complex concepts with peers, and when paired with RAs, opportunities to develop research skills. Prior research linking fellowships with skill development is absent, focusing instead on the advantages like prestige and autonomy provide to students funded via fellowships. Our study extends this prior research by systematically comparing skill development across funding types across STEM fields, distinguishes internal and external fellowships, and considers how the development of career-relevant skills aligns with students' career goals.

## Methods

Data for this study were collected as part of a larger project funded by the National Science Foundation aimed at investigating STEM doctoral students' funding mechanisms from the perspectives of doctoral programs as well as doctoral students. To be included in the sampling frame for that larger project, institutions had to have doctoral students enrolled in at least three of the eight target STEM disciplines (i.e., biological sciences, chemical engineering, chemistry, civil engineering, electrical engineering, math/statistics, mechanical engineering, and physics) and either: (1) be among the 25 institutions in the United States that graduate the highest number of Ph.D. earners in one of those disciplines annually, or (2) be ranked in the top 25 graduate programs by *US News and World Report* in one those disciplines. A total of 35 institutions met these criteria—this sampling plan focused the project on the largest programs nationally that were well-regarded within each discipline. Multiple programs within a single institution often met these criteria (e.g., large and highly ranked mechanical engineering programs and civil engineering programs tended to be clustered within the same institution), which was important for the larger project's data collection strategies.

## Data collection

This specific study completed analyses on one form of data collected within that larger project: an IRB-approved survey designed for STEM doctoral students who had completed at least one year of doctoral studies in a STEM discipline. We sent survey distribution requests to university administrators from colleges of engineering and colleges of science (or arts and science in some circumstances), typically an associate dean for graduate studies within each college, and asked those individuals to send the survey request to doctoral students enrolled in STEM programs. If we did not receive a response from the college representative, we reached out to departmental leaders in STEM disciplines. Administrators from 25 of the 35 institutions in the larger project's sampling frame sent survey invitations to doctoral students in STEM disciplines (refer to Appendix 1 for a list of institutions with survey responses). The sample comprised institutions with very high research activity and includes both public and private institutions that are geographically dispersed across the United States. The survey was administered during the Fall 2019 semester, was available to students for one month, and was implemented in one wave.

The survey was designed to explore the relationship between graduate student funding type and students' experiences, competencies, and skill development associated with their funding. Survey questions addressed several areas that mapped on the larger NSF project's goals, including students' demographic characteristics; prior college degrees and experiences; funding sources; experiences and skills associated with primary funding type; academic productivity; employment goals; experiences with one's dissertation advisor, faculty, staff, and peers; familial responsibilities' impact on graduate school experiences, and information about competing admissions and funding offers. We consulted a broad range of previously administered surveys or interview protocols of graduate students and incorporated such items when appropriate. Instruments that informed the development of this paper's items of focus include the Graduate Student Experience in the Research University Survey (Jones-White et al., 2018), institutional surveys of engineering graduate students (Choe et al., 2018), and surveys of administrators as well as interviews of program leaders and students previously conducted by the larger project team. This set of items built upon our own prior data collection focused on program administrators within the same sampling frame, interviews with graduate students at a limited number of institutions, and also built in ideas based upon similar survey work from other researchers (e.g., Jones-White et al., 2018). We received a total of

**Table 2** Exploratory factor analysis results of dependent and focal independent variables

Question stem	Factor	Item	Loading	Alpha	
Describe the following aspects of your skill development associated with your current primary funding source. My current primary funding source helped me learn how to	Communication skills	Communicate my ideas verbally	0.79	0.84	
		Communicate my ideas in writing	0.74		
		Facilitate a difficult conversation	0.60		
	Peer training and mentoring skill	Train peers	0.92		0.95
		Mentor peers	0.93		
	Teamwork and project management skills	Work collaboratively in a team	0.55		0.80
		Manage projects	0.56		
	Research skills	Critically evaluate a journal article	0.36		0.89
		Make progress for my dissertation	0.91		
Conduct research		0.95			
How would you describe the following aspects of your experience associated with your primary funding type for your doctoral studies on average? My primary funding type	Alignment between funding and career goals (career alignment)	Offers skill development opportunities	0.43	0.79	
		Is relevant to my career goals	0.85		
		Positively influences my job prospects	0.84		
		Prepare for a career	0.46		
Describe the following aspects of your skill development associated with your current primary funding source. My current primary funding source helped me learn how to					

1162 survey responses, of which 719 were included in the final analytical sample based on full responses to the variables utilized in this study.

### Variables

**Dependent variables** The dependent variables were created by conducting an exploratory factor analysis with oblique, promax rotation on skill development variables from a subsection of the survey. The goal of rotation is to generate a simple (i.e., more interpretable) factor structure. Promax is a type of oblique rotation that is used when the factors are assumed to be correlated. These variables were measured on a Likert scale of 1 "strongly disagree" to 5 "strongly agree". The listing of the items, question stem, factor loadings, and Cronbach's alpha are shown in Table 2. We re-coded each of these variables to be "low agreement" for responses less than 4 and "high agreement" for values greater than or equal to 4, thereby creating a dichotomous outcome variable of 0 = low agreement and 1 = high agreement.

**Independent variables** Primary funding type was the key independent variable. Students responded to the question: "Which funding source do you consider your current primary funding source?" In this study, we examine fellowships and assistantships. We created a categorical variable with research assistantships as the reference group; other categories included external fellowships, internal fellowships, and teaching assistantships.

Additionally, we derived a variable to capture students' perceptions of how their primary funding source influenced their career-relevant experiences during doctoral studies. We created this variable from a set of items asking respondents to describe how "My primary funding type (e.g., positively influences my job prospects)". Using exploratory factor analysis with oblique, promax rotation, a composite variable was created that included four items (refer to Table 2) that grouped around career-relevant skill development. These items were measured on a Likert scale ranging from 1 "strongly disagree" to 5 "strongly agree." We named this variable Alignment Between Funding and Career Goals (hereafter referred to as career alignment).

We re-coded this variable dichotomously with responses less than 4 labeled "low career alignment" and responses greater than or equal to 4 labeled "high career alignment". Table 2 shows the question stem, items, factor loading, and Cronbach's alpha for this scale.

**Control variables** We used several control variables in our models based on students' demographic information, year in the doctoral program, academic field, research group participation, institutional type and having multiple funding sources; all variables were gathered from students' survey responses. Gender was coded as 0 for man and 1 for woman. All other possible response categories (i.e., transgender man, transgender woman, genderqueer/gender non-conforming, decline to state and prefer to self-describe) were not selected by the respondents in the final dataset for the analysis. Two questions captured

students' racial/ethnic background: (1) Are you Hispanic or Latinx? and (2) What is your racial background? Race/ethnicity was dummy coded for each category present in the dataset: White (reference category), Black, Asian, and Hispanic. Some students marked more than one racial category, American Indian/Native Hawaiian, and Native Hawaiian/Pacific Islander. However, these students also marked Hispanic and therefore were categorized as Hispanic or Latinx. Students answered "What is your citizenship status?": U.S. Citizen (since birth), U.S. Citizen (naturalized), Non-U.S. Citizen (with a permanent U.S. Resident Visa "Green Card"), Non-U.S. Citizen (with a temporary U.S. Visa), and Other or prefer not to answer. We created a dichotomous variable to capture citizenship (0 = U.S. citizen and 1 = Non-U.S. Citizen).

The number of years the student was in the doctoral program was also categorical, ranging from 1 to 7 or more years. The reference group was first-year doctoral students. Students' academic field was a categorical variable with engineering (including computer science) as the reference group and additional categories for biosciences, math, and physical sciences (including physics and chemistry). Research group participation was assessed by asking the participants: "A research group is a collection of students working under the guidance of a faculty advisor (or a team of faculty advisors) that share similar research interests, equipment or collaborate on research projects. Are you currently a member of a research group?" The response categories were categorical yes, no, and unsure and we preserved these categories in the coding of the variable (0 = yes, 1 = no, 2 = unsure). Institution type was a dichotomous variable (0 = public and 1 = private). We created a variable called "split funding" (0 = no, 1 = yes) to indicate students who received funding beyond their primary funding source (defined as providing 75% or more of funding). Table 3 shows the descriptive statistics of the dependent, independent, and control variables. Demographic information by funding type is provided in Appendix 2.

### Data analysis

To understand the impact of funding type on doctoral students' skill development, we conducted a series of logistic regression analyses using Stata/MP 16.0. A three-step model was conducted for each outcome (communication skills, peer training and mentoring skills, teamwork and project management skills, and research skills). In the first step, only control variables were included, in the second step the primary funding types

**Table 3** Descriptive summary of the dependent, independent, and control variables (n = 719)

Dependent variables	Proportion
Research skills	0.59
Teamwork and project management skills	0.55
Peer training and mentoring skills	0.49
Communication skills	0.46
Independent variables	
<i>Primary funding type</i>	Proportion
Research assistantship (reference group)	0.42
External fellowship	0.16
Internal fellowship	0.20
Teaching assistantship	0.21
<i>Low career alignment</i>	0.50
<i>High career alignment</i>	0.50
Control variables	Proportion
<i>Student demographics</i>	
Man (reference group)	0.55
Woman	0.45
White (reference group)	0.57
Asian	0.31
Black	0.03
Hispanic	0.09
US citizen (reference group)	0.67
Non-US citizen	0.33
<i>Discipline</i>	
Engineering (reference group)	0.61
Biological sciences	0.12
Math	0.08
Physical sciences	0.19
<i>Research group participation</i>	
Yes	0.90
No	0.08
Unsure	0.02
<i>Institution type</i>	
Public (reference group)	0.86
Private	0.14
<i>Split funding</i>	
No (reference group)	0.85
Yes	0.15
<i>Year in doctoral program</i>	
Year 1 (reference group)	0.20
Year 2	0.22
Year 3	0.24
Year 4	0.18
Year 5	0.12
Year 6	0.03
Year 7 or more	0.02

were added to the model, and in the third step the career alignment variable was also added to the model. In total, we conducted 12 regression models.

### Limitations

There are a few limitations to note. Although this sample of students is from a variety of institutions, we do not make claims that this sample is statistically representative of the STEM doctoral population in the United States. In comparison to the proportions provided by the National Science Foundation in *Survey of Graduate Students and Postdoctorates in Science and Engineering: Fall 2019* (National Science Foundation, 2020), our sample has a higher proportion of students funded by fellowships (external and internal combined) and research assistantships, which is likely a function of our institutional sample. We sought to account for this bias by accounting for institutional control (i.e., public or private), which prior research has shown relates to funding portfolios, particularly with respect to funding via fellowships (Knight et al., 2018). We elected against including institution as a fixed effect because that prior research also showed that academic field, which we do account for in the model, is a stronger influence on graduate education processes than the institution (e.g., engineering at Institution X is more like engineering at Institution Y than physical sciences at Institution X). Future research with a larger sample size could seek to account for fixed effects of specific academic programs (e.g., mechanical engineering at institution X).

Additionally, because of the nature of the study design, which relied on programs forwarding invitations for participation, it is difficult to calculate the survey response rate. Therefore, we cannot determine what (if any) biases contributed to some students completing the survey and not others. Further related to the respondents, we were unable to conduct a finer analysis based on demographics at the intersection of race, gender and citizenship. Creating exhaustive demographic categories (e.g., black and male and non-U.S. citizen) led to certain groups being inestimable. Therefore, we kept demographics as independent, dichotomously coded variables.

There are also limitations to consider related to the skills selected for this study and how to interpret findings of self-report data. First, we recognize that there are numerous types of skills that we did not ask about in our survey (e.g., teaching skills). Although we relied on empirical tools (i.e., exploratory factor analysis) to

identify skill constructs from the skill-related survey items, there are likely other skills that are not captured in our survey that should be addressed in future research. We do not assert that these are the only skills important to consider as related to graduate education and funding mechanisms. We also recognize that doctoral students may not desire or intentionally work toward developing each of these skills in this study, nor consider them important as a learning outcome of their degree. We also recognize that students may not be able to choose the funding type that best aligns with their career goals. Relatedly, we recognize as a limitation our decision to exclude some variables in our analysis such as “academic productivity” and “experiences with one’s doctoral advisor” that have previously been linked with students’ experiences and outcomes in PhD programs (e.g., Dericks et al., 2019; Zhang et al., 2019). We have done so intentionally as we are focused on STEM broadly, and there is widespread variation in publication and advising norms across STEM disciplines. Finally, any interpretation of these findings should consider limitations around self-reported data and the Dunning–Kruger effect (Dunning, 2011). Future longitudinal studies that include job placement or hiring organizations’ evaluations of graduates would complement and test the validity of this research.

### Results

On average, 46–59% of students in the sample report “high agreement” for each of the dependent variables examined in this study (Table 3). The highest frequency of students in the sample reported having research assistantships as their primary funding type ( $n=302$  or 42%), followed by teaching assistantships ( $n=154$  or 21%), internal fellowships ( $n=147$  or 20%) and lastly external fellowships ( $n=116$  or 16%). We highlight these particular descriptive statistics as they provide the lens for the results of the regression analysis.

To address the research question, we conducted a series of logistic regression analyses examining how primary funding mechanisms related to different learning outcomes of STEM graduate students. Tables 4, 5, 6 and 7 show each of the 3-step models for each dependent variable: research skills (Models 1–3), teamwork/project management skills (Models 4–6), peer training and mentoring skills (Models 7–9) and communication skills (Models 10–12). The first step for each set of models shows the control variables or baseline model. In the remaining models, primary funding type and career alignment are added as the focal independent variables, with the full model for each skill type being Models 3, 6, 9 and 12. The regression coefficients are reported in odds ratios where



**Table 4** Logistic regression of research skills

n = 719	Model 1	Model 2	Model 3
<i>Gender (ref. = man)</i>			
Woman	0.88 (0.15)	0.86 (0.16)	0.84 (0.16)
<i>Race (ref. = White)</i>			
Asian	1.56 (0.36)	1.65* (0.41)	1.57 (0.42)
Black	0.68 (0.33)	0.71 (0.36)	0.74 (0.41)
Hispanic	0.94 (0.27)	0.96 (0.30)	0.83 (0.27)
<i>Citizenship (ref. = U.S. citizen)</i>			
Non-U.S. citizen	0.93 (0.21)	1.02 (0.25)	1.20 (0.33)
<i>Ph.D. field (ref. = engineering)</i>			
Biological sciences	1.02 (0.28)	1.16 (0.35)	1.23 (0.40)
Math	0.26*** (0.09)	0.50 (0.20)	0.53 (0.23)
Physical science	0.56** (0.11)	0.77 (0.18)	0.90 (0.23)
<i>Institution (ref. = public)</i>			
Private	0.80 (0.20)	0.73 (0.20)	0.86 (0.25)
<i>Year in doctoral program (ref. = year 1)</i>			
Year 2	1.37 (0.33)	1.30 (0.34)	0.92 (0.27)
Year 3	1.45 (0.35)	1.40 (0.36)	1.23 (0.34)
Year 4	1.88* (0.50)	2.00* (0.57)	1.91* (0.59)
Year 5	1.13 (0.33)	1.20 (0.38)	1.41 (0.49)
Year 6	1.41 (0.75)	1.18 (0.67)	1.37 (0.85)
Year 7 or more	1.79 (1.13)	1.31 (0.85)	0.92 (0.66)
<i>Research group (ref. = yes)</i>			
No	0.28*** (0.10)	0.33** (0.13)	0.27** (0.11)
Unsure	0.64 (0.35)	0.67 (0.39)	0.71 (0.45)
<i>Two or more funding sources</i>			
	0.80 (0.18)	0.95 (0.23)	1.01 (0.27)
<i>Primary funding (ref. = research assistantship)</i>			
External fellowship		0.58* (0.15)	0.41** (0.12)
Internal fellowship		0.57* (0.14)	0.54* (0.14)
Teaching assistantship		0.11*** (0.03)	0.11*** (0.03)
<i>Career alignment</i>			
			6.75*** (1.35)
Constant (intercept)	1.52 (0.34)	2.50*** (0.65)	1.16 (0.33)
Pseudo-R <sup>2</sup>	7.0%	16.4%	27.1%

**Table 4** (continued)

In models with engineering doctoral students only, internal fellowship is no longer significant. All other results are comparable. When interacting primary funding with career alignment, there is a significant finding only for the interaction between external fellowship and career alignment (Appendix 4;  $b = 0.31$ ;  $p < 0.029$ )  
 $*p \leq 0.05$ ,  $**p \leq 0.01$ ,  $***p \leq 0.001$

a value less than 1 indicates a lower likelihood of the outcome. A correlation table of the dependent and independent variables can be found in Appendix 3.

**Research skills**

As shown in Table 4 (Model 1), the baseline model accounted for 7% of the variance in research skills as reported by the pseudo-R<sup>2</sup>. The significant control variables were math Ph.D. field, physical science Ph.D. field, year four in program, and no participation in a research group. With the addition of primary funding type (Table 4, Model 2), the proportion of variance explained in the research skills outcome increased to 16.4%. Examining the coefficients, we observed three changes in the control variables from baseline. First, Asian students are more likely to report higher research skills as a function of their primary funding type in comparison to white students. Furthermore, math Ph.D and physical sciences Ph.D. are no longer significant. In regard to primary funding, we found those funded by external fellowships ( $b = 0.58$ ;  $p < 0.05$ ), internal fellowships ( $b = 0.57$ ;  $p < 0.05$ ) and teaching assistantships ( $b = 0.11$ ;  $p < 0.001$ ) were less likely (as seen by an odds ratio of less than 1) to have high research skills because of their funding compared to those primarily funded by research assistantships. In the full model (Table 4, Model 3), the variance explained is 27.1% with the addition of the career alignment variable. The coefficient shows that those with reporting high career alignment (i.e., a rating of 4 or higher) of their primary funding type and career goals are nearly seven times more likely to report high research skills because of their funding ( $b = 6.75$ ;  $p < 0.001$ ). Even with the addition of this variable to the model, external fellowship ( $b = 0.41$ ;  $p < 0.01$ ), internal fellowship ( $b = 0.54$ ;  $p < 0.05$ ) and teaching assistantship ( $b = 0.11$ ;  $p < 0.001$ ) coefficients remain significant ( $p < 0.05$ ). Appendix 4 displays full models with the career alignment variable interacted with the primary funding variable. Interaction effects were largely non-significant across models (this one and subsequent models), indicating that relationships between students' perceptions of their primary funding's influence on their career-related experiences (i.e., the career alignment variable) and the skill development dependent variables held true across funding types.

**Table 5** Logistic regression of teamwork and project management skills

n = 719	Model 4	Model 5	Model 6
<i>Gender (ref. = man)</i>			
Woman	0.85 (0.14)	0.90 (0.15)	0.89 (0.16)
<i>Race (ref. = White)</i>			
Asian	1.96** (0.44)	2.00** (0.46)	1.96** (0.48)
Black	0.60 (0.29)	0.69 (0.34)	0.70 (0.37)
Hispanic	1.50 (0.43)	1.71 (0.50)	1.60 (0.49)
<i>Citizenship (ref. = U.S. citizen)</i>			
Non-U.S. citizen	1.22 (0.27)	1.08 (0.25)	1.22 (0.30)
<i>Ph.D. field (ref. = engineering)</i>			
Biological sciences	0.69 (0.19)	0.69 (0.20)	0.67 (0.20)
Math	0.26*** (0.10)	0.34** (0.13)	0.34** (0.14)
Physical science	0.70 (0.15)	0.75 (0.16)	0.85 (0.20)
<i>Institution (ref. = public)</i>			
Private	0.74 (0.18)	0.83 (0.21)	0.94 (0.26)
<i>Year in doctoral program (ref. = year 1)</i>			
Year 2	1.31 (0.32)	1.26 (0.32)	0.99 (0.27)
Year 3	1.13 (0.27)	1.15 (0.28)	1.02 (0.27)
Year 4	1.44 (0.37)	1.49 (0.40)	1.35 (0.38)
Year 5	1.47 (0.44)	1.46 (0.45)	1.65 (0.53)
Year 6	1.56 (0.85)	1.42 (0.79)	1.65 (0.96)
Year 7 or more	1.23 (0.76)	0.97 (0.59)	0.73 (0.48)
<i>Research group (ref. = yes)</i>			
No	0.28*** (0.10)	0.30*** (0.11)	0.24*** (0.10)
Unsure	0.58 (0.32)	0.60 (0.34)	0.62 (0.37)
<i>Two or more funding sources</i>			
	1.30 (0.30)	1.42 (0.34)	1.55 (0.38)
<i>Primary funding (ref. = research assistantship)</i>			
External fellowship		0.37*** (0.09)	0.27*** (0.07)
Internal fellowship		0.56* (0.13)	0.54* (0.13)
Teaching assistantship		0.31*** (0.07)	0.37*** (0.09)
<i>Career alignment</i>			
			4.20*** (0.78)
Constant (intercept)	1.11 (0.25)	1.78* (0.44)	0.93 (0.25)
Pseudo-R <sup>2</sup>	8.2%	11.7%	18.4%

**Table 5** (continued)

In models with engineering doctoral students only, all results are comparable. When interacting primary funding with career alignment there were no significant findings (see Appendix 4)

\*p ≤ 0.05, \*\*p ≤ 0.01, \*\*\*p ≤ 0.001

**Teamwork/project management skills**

As shown in Table 5 (Model 4), the control variables accounted for approximately 8% of the variance in teamwork/project management skills. With the addition of primary funding type (Table 5, Model 5), there was an increase in the R<sup>2</sup> to 11.7%. Similar to the previous sets of models predicting research skills, students primarily funded via external fellowships (b=0.27; p<0.001), internal fellowships (b=0.54; p<0.05) and teaching assistantships (b=0.37; p<0.001) reported significantly less likelihood of reporting high teamwork/project management skills because of funding type than students primarily funded via research assistantships. These three variables are still significant with the addition of career alignment in the full model (Table 5, Model 5), which explains an additional 6.7% of the variance in teamwork/project management skills. The coefficient shows that those with reporting high career alignment (i.e., a rating of 4 or higher) of their primary funding type and career goals are nearly four times more likely to report high research skills because of funding type (b=4.20; p<0.001). The final model explains 18.4% of the variance in teamwork/project management skills because of funding type. It should also be noted that Asian students were more likely to report higher teamwork/project management skills even in this final model.

**Peer training and mentoring skills**

The control variables accounted for only 3.1% of the variance in peer training and mentoring skills because of funding type (Table 6, Model 7). The total variance explained increased to 7% with the addition of primary funding type (Table 6, Model 8). Unlike the previous two sets of models on research skills and teamwork/project management skills, students primarily funded via external fellowships (b=0.31; p<0.001) were significantly less likely to report high peer training and mentoring skills because of funding type relative to students funded via research assistantships, whereas those funded primarily by teaching assistantships (b=1.88; p<0.01) were significantly more likely to report high peer training and mentoring skills relative to students funded via research assistantships. In the full model (Table 6, Model 9), both external fellowship (b=0.26; p<0.001) and teaching assistantship (b=2.36; p<0.01) were significant. Additionally, reporting high career alignment (i.e., a rating of 4 or higher) were 2.7 times more likely to report high

**Table 6** Logistic regression of peer training and mentoring skills

n = 719	Model 7	Model 8	Model 9
<i>Gender (ref. = man)</i>			
Woman	1.06 (0.17)	1.19 (0.20)	1.17 (0.20)
<i>Race (ref. = White)</i>			
Asian	1.11 (0.24)	1.12 (0.25)	1.04 (0.24)
Black	0.24* (0.14)	0.27* (0.16)	0.26* (0.16)
Hispanic	0.76 (0.21)	0.86 (0.24)	0.77 (0.23)
<i>Citizenship (ref. = U.S. citizen)</i>			
Non-U.S. citizen	1.24 (0.26)	0.92 (0.21)	0.98 (0.23)
<i>Ph.D. field (ref. = engineering)</i>			
Biological sciences	0.74 (0.20)	0.65 (0.18)	0.64 (0.19)
Math	0.81 (0.27)	0.54 (0.19)	0.54 (0.20)
Physical science	0.83 (0.17)	0.59* (0.13)	0.64* (0.14)
<i>Institution (ref. = public)</i>			
Private	0.72 (0.17)	0.93 (0.23)	0.99 (0.26)
<i>Year in doctoral program (ref. = year 1)</i>			
Year 2	1.09 (0.26)	1.14 (0.28)	0.97 (0.24)
Year 3	1.02 (0.24)	1.17 (0.28)	1.09 (0.27)
Year 4	1.35 (0.34)	1.47 (0.38)	1.39 (0.37)
Year 5	0.99 (0.28)	0.91 (0.27)	0.96 (0.28)
Year 6	1.02 (0.53)	1.09 (0.57)	1.22 (0.66)
Year 7 or more	1.44 (0.84)	1.49 (0.90)	1.31 (0.81)
<i>Research group (ref. = yes)</i>			
No	0.40** (0.13)	0.31*** (0.11)	0.26*** (0.10)
Unsure	0.69 (0.37)	0.66 (0.36)	0.64 (0.35)
<i>Two or more funding sources</i>			
	1.21 (0.27)	1.09 (0.25)	1.16 (0.27)
<i>Primary funding (ref. = research assistantship)</i>			
External fellowship		0.31*** (0.08)	0.26*** (0.07)
Internal fellowship		0.73 (0.16)	0.74 (0.17)
Teaching assistantship		1.88** (0.43)	2.36*** (0.56)
<i>Career alignment</i>			
			2.70*** (0.47)
Constant (intercept)	0.98 (0.21)	1.19 (0.29)	0.74 (0.19)
Pseudo-R <sup>2</sup>	3.1%	7.0%	10.5%

**Table 6** (continued)

In models with engineering doctoral students only, all results are comparable. When interacting primary funding with career alignment there were no significant findings (see Appendix 4)

\*p ≤ 0.05, \*\*p ≤ 0.01, \*\*\*p ≤ 0.001

peer training and mentoring skills (b=2.70; p<0.001). Yet, these results should not be over-interpreted as the full model only explains 10.5% of the variance in peer training/mentoring skills because of funding type. It should also be noted that Black students were less likely to report higher peer training and mentoring skills across all three models.

**Communication skills**

As shown in Table 7, Model 10, the control variables accounted for 6.3% of the variance in communication skills because of funding type. Notably, Asian students (b=2.13; p<0.001) were more likely to report high communication skills and Black students (b=0.31; p<0.05) were less likely in this baseline model. With the addition of primary funding type (Table 7, Model 11), the only significant finding was that those primarily funded by external fellowships (b=0.42; p<0.001) were less likely to report high communication skills compared to those funded by research assistantships. In the full model (Table 7, Model 12), as with the other sets of models, career alignment was significant. Those reporting high career alignment were approximately four times more likely to report high communication skills because of funding type (b=4.32; p<0.001). The final model explained 14.8% of the variance in communications skills. It should also be noted that Asian students were more likely to report higher communication skills across all models. Further, not participating in a research group was not significant in any model of these models.

**Summarizing across models**

Table 8 shows a summary of the significant independent variables by dependent variable. Each cell of the box shows the direction and significance level of the coefficient.

In summary, we found that students primarily funded via external fellowships were significantly more likely to report lesser skill development because of their funding compared to students funded via research assistantships across all skill development areas. We observed mixed results concerning students funded primarily through teaching assistantships, with students being more likely to report higher development in peer training/mentoring skills because of their funding type but lower skills for both research and teamwork/project management

**Table 7** Logistic regression of communication skills

n = 719	Model 10	Model 11	Model 12
<i>Gender (ref. = man)</i>			
Woman	0.73 (0.12)	0.78 (0.13)	0.75 (0.13)
<i>Race (ref. = White)</i>			
Asian	2.13*** (0.47)	2.16*** (0.48)	2.12*** (0.50)
Black	0.31* (0.18)	0.35 (0.21)	0.33 (0.20)
Hispanic	0.80 (0.23)	0.88 (0.25)	0.76 (0.23)
<i>Citizenship (ref. = U.S. citizen)</i>			
Non-U.S. citizen	0.97 (0.21)	0.80 (0.18)	0.88 (0.21)
<i>Ph.D. field (ref. = engineering)</i>			
Biological sciences	0.62 (0.17)	0.60 (0.17)	0.58 (0.18)
Math	0.41* (0.15)	0.38** (0.14)	0.36** (0.14)
Physical science	0.71 (0.15)	0.62* (0.14)	0.70 (0.16)
<i>Institution (ref. = public)</i>			
Private	0.69 (0.17)	0.81 (0.21)	0.88 (0.24)
<i>Year in doctoral program (ref. = year 1)</i>			
Year 2	1.39 (0.34)	1.39 (0.35)	1.12 (0.30)
Year 3	1.46 (0.35)	1.56 (0.38)	1.45 (0.37)
Year 4	1.82* (0.47)	1.89* (0.49)	1.78* (0.49)
Year 5	1.89* (0.55)	1.81* (0.53)	2.11* (0.66)
Year 6	1.62 (0.86)	1.62 (0.86)	2.03 (1.10)
Year 7 or more	1.63 (0.97)	1.51 (0.91)	1.27 (0.81)
<i>Research group (ref. = yes)</i>			
No	0.77 (0.26)	0.73 (0.25)	0.63 (0.23)
Unsure	0.90 (0.49)	0.90 (0.50)	0.90 (0.52)
<i>Two or more funding sources</i>			
	1.28 (0.29)	1.24 (0.28)	1.39 (0.33)
<i>Primary funding (ref. = research assistantship)</i>			
External fellowship		0.42*** (0.11)	0.33*** (0.09)
Internal fellowship		0.68 (0.16)	0.69 (0.17)
Teaching assistantship		0.95 (0.21)	1.28 (0.30)
<i>Career alignment</i>			
			4.32*** (0.78)
Constant (intercept)	0.70 (0.16)	0.90 (0.22)	0.42*** (0.12)
Pseudo-R <sup>2</sup>	6.3%	7.6%	14.8%

**Table 7** (continued)

In models with engineering doctoral students only, all results are comparable. When interacting primary funding with career alignment there were no significant findings (see Appendix 4)

\*p ≤ 0.05, \*\*p ≤ 0.01, \*\*\*p ≤ 0.001

relative to students funded via research assistantships. Lastly, students funded via internal fellowships were less likely to report higher skills for research and teamwork/project management because of their funding type compared to those with research assistantships as their primary funding source.

### Discussion

This study investigated variability in U.S. STEM doctoral students' skill development based on their primary funding type. We found significant differences across funding types for all four skill development areas of focus in our study: research skills, teamwork/project management skills, peer training and mentoring skills, and communication skills. We integrate our findings with prior literature and organize our thoughts around each funding type examined in the study.

### Research assistantships

Our findings mostly align with prior literature on RAs. Students funded primarily through RAs (42% of the sample) reported significantly higher development of research skills because of their funding compared to students funded primarily through external fellowships, internal fellowships and teaching assistantships. This finding is intuitive as RAs provide students with practical research training skills (Rossouw & Niemczyk, 2013), opportunities to produce research (Ampaw & Jaeger, 2012; Knight et al., 2018), publish articles, present at conferences, and identify topics for and make progress on dissertations (Nettles & Millett, 2006; Niemczyk, 2015). Additionally, the vast majority (93%) of research assistants in our study participated in research groups, which suggests these students had opportunities to engage in the research process and hone their research-related skills (Ampaw & Jaeger, 2012; Niemczyk, 2015). Participation in research groups also has been linked with developing doctoral students' teamwork and communication skills (Crede & Borrego, 2012), as most students participate in a research group, regardless of funding type. However, these results demonstrate that research assistants may have more consistent, prescribed involvement compared with students funded by other research-driven funding

**Table 8** Summary of all models—significant independent variables

	External fellowship	Internal fellowship	Teaching assistantship	Career alignment
Research skills <i>Model 3</i>	(-)**	(-)*	(-)**	(+)**
Teamwork/project management skills <i>Model 6</i>	(-)**	(-)*	(-)**	(+)**
Peer training and mentoring skills <i>Model 9</i>	(-)**	n.s.	(+)**	(+)**
Communication skills <i>Model 12</i>	(-)**	n.s.	n.s.	(+)**

(-) indicates a negative regression coefficient and (+) indicates a positive regression coefficient

n.s. not significant

\* $p \leq 0.05$ , \*\* $p \leq 0.01$ , \*\*\* $p \leq 0.001$

types such as external fellowships. Further research is needed to contextualize the types of activities that cultivate differential skill development among STEM doctoral students with research-driven funding mechanisms. Nevertheless, in this study students funded by RAs were found to report the highest levels of research and teamwork/project management skill development because of that funding.

#### External and internal fellowships

Perhaps the most important finding in this study relates to external fellowships. These financial awards are highly sought after for their affordance of autonomy (Mendoza et al., 2014), are deemed as prestigious across STEM disciplines (Mendoza et al., 2014; Szelényi, 2013), and have been positively related to retention and timely degree completion (Herzig, 2004). Unfortunately, our findings indicate that these perceived benefits and advantages may come at a cost for developing career-relevant skills. Students funded by external fellowships reported significantly lesser development in all four skills investigated in the study because of their funding when compared with students funded via RAs. Differences were less considerable for students funded via internal fellowships who reported significantly lesser development of research skills and teamwork/project management skills, but similar development in peer mentoring and training and communication skills because of their funding compared with students funded by RAs. We postulate that the discrepancy in the reported development of research skills, teamwork/project management skills, peer mentoring and training skills, and communication skills may be an unintended consequence of the autonomy so often touted as a prominent benefit of fellowships. For example, even

though research group membership for internal (93%) and external (97%) fellows in our study was similar to research assistants (93%), students funded through external fellowships still lag behind in development opportunities tied to funding across all four career-relevant skills. It may be that students funded by external fellowships are exposed to a narrower set of activities in research groups that do not offer the opportunity to develop teamwork and project management skills to the extent RAs do, a consequence of autonomy and freedom to work individually or across multiple research projects or teams. This assertion would align with Mendoza et al. (2014), who found that fellowships do not provide the same access to research groups as RAs do, which may limit their access to faculty and peer mentors.

These findings also may help inform why Blume-Kohout and Adhikari (2016) found that PhDs in biomedical sciences who were funded by research assistantships were significantly more likely to take research-focused jobs in the United States compared with PhDs funded through fellowships or traineeships. Combining that finding with our own results, perhaps challenges in accessing opportunities for fellowship recipients to develop research skills ultimately could impact subsequent career trajectories in research-related roles. Since our findings rely on self-reported efficacy of skills, it is also plausible that fellowship-funded students, lacking local integration within their department or research group, have fewer opportunities to develop self-confidence in their abilities in research or feel less belonging in their discipline that leads to fewer graduates applying for research posts after graduation. Our findings did, however, contrast with prior findings related to research skills and funding types in another international context. Horta et al. (2018)

compared research productivity of doctoral students funded via PhD grants (similar to fellowships in the U.S. context) with those funded by research project grants (similar to research assistantships in the U.S. context) in Portugal. They found that research productivity was significantly higher among PhD grant recipients compared to research grant recipients. Future research should investigate what belies these contrasting findings, recognizing that our study relies on self-reported development of research skills as a function of funding compared with quantitative investigation of research productivity using publication data. We decided not to include data on students' publications in this study because of our focus on STEM broadly and the widespread variation in publication norms across STEM disciplines.

These studies notwithstanding, very little attention has been paid in prior research to fellowships and their relationship with skill development, nor has any study distinguished between internal and external fellowships, both notable contributions of this study. This lack of attention may, in some part, be a result of the prestige commonly associated with earning a fellowship, which are often awarded based on merit or potential as a scholar (Szelényi, 2013). Our findings largely contradict the widely accepted anecdotal narrative that fellowships should be the most coveted type of funding for STEM doctoral students. We call attention to some potential misalignment of the perceived and realized impacts that fellowship funding can have on STEM doctoral students' experiences, and particularly on their ability to develop career-relevant skills like those included in this study.

Another unique value of this study's design was the distinction between internal and external fellowships, which despite taking a similar form, may be used for different purposes in the recruitment and retention of STEM doctoral students (Wall Bortz et al., 2020). The distinction revealed an important finding—perceived skill development for students funded by internal fellowships was similar to the perceptions of students funded by RAs for peer training and mentoring skills and communication skills. This finding starkly contrasts the pattern for students funded via external fellowships, whose perceived skill development was significantly less than students funded via RAs across all four career-relevant skills.

With a noticeable dearth of research on skill development for doctoral students funded via fellowships generally, our findings suggest that the origin of fellowship funds matters and their differential relationship with skill development need to be considered when making

funding decisions and further investigated in future research. Programs could compare differences in experiences between students funded via internal versus external fellowships to determine whether the unintended consequences of autonomy tied to external fellowships can be corrected following approaches used with recipients of internal fellowships.

#### **Teaching assistantships**

Students funded primarily via TAs reported significantly lesser development of research skills because of their funding compared with students funded by RAs. This finding aligns with some prior research that found TAs were the least desirable funding type because they distract from research, progress towards dissertation work, and subsequently delay time-to-degree (Knight et al., 2018; Nerad & Cerny, 1991; Nettles & Millett, 2006). Our findings contrast with other studies that have found that TA positions do, in some cases, offer extensive research skill development (Feldon et al., 2011; French & Russell, 2002; Trautmann & Krasny, 2006), especially when combined with research duties (Feldon et al., 2011). It is important to note that in our study we focus only on students' primary funding type. It could be that TAs in our study with supplemental funding via research experiences report more development of research skills compared with TAs who do not have any research duties, but we did not collect those data, specifically.

Additionally, much like research skills, teaching assistants also reported lesser development of teamwork and project management skills because of their funding compared with research assistants. Acknowledging the importance of research group membership in developing these skills, as we previously described, we highlight that TAs in this study had less participation in research groups (78%), which may partially explain the lower endorsement of developing teamwork and project management skills. Conversely, these same students reported significantly more development of peer training and mentoring skills compared to students funded via RAs, internal fellowships, and external fellowships. These findings align with prior literature that finds teaching assistantships support students' socialization with faculty and peers (Mendoza et al., 2014), provide teaching and communication experience (Curtis & Jacobe, 2006; Prieto & Meyers, 2001), improve teaching and mentoring skills (Mitchell et al., 2003; Trautmann & Krasny, 2006), and help students develop their abilities to articulate difficult concepts clearly (Mitchell et al., 2003).

## Conclusion and implications

Funding mechanisms relate to STEM doctoral students' development of career-relevant skills. Efforts to align students' funding type with their career goals will enhance the quality of STEM doctoral programs, graduates, and the STEM workforce. The evidence from this study indicates that funding types play a significant role in students' learning and differentially impact skill development tied to funding. Across all four models in this study, funding type significantly related to students' self-reported development of career skills because of their funding, but their perceptions of how well their funding type aligned with their career goals also explained a substantial portion of the variance in their self-reported skill development. Ideally, when deciding on a funding source, STEM doctoral students ought to choose a funding source that most closely aligns with their career goals to maximize how experiences associated with their funding may influence their career development. These findings meaningfully contribute to our understanding of how funding types relate to career-relevant skill development for STEM doctoral students and have multiple implications for students as well as program faculty, staff, and administrators.

First, prospective and current STEM doctoral students should be informed to consider the advantages and disadvantages of their funding source on the opportunities to develop career-relevant skills and how well the funding source aligns with their career goals. Prior research suggests that students consider multiple factors when selecting a funding source, including selecting an advisor and research group/laboratory, the advisor's mentoring style and personality, the potential for relocation, available funding for graduate students, and potential for collegial relationships with peers in the lab (Maher et al., 2020; Wall Bortz et al., 2020). Students and faculty perceive these and other non-monetary factors as being more important when making admissions and enrollment decisions (Wall Bortz et al., 2020) and, based on findings from this study, also should be educated to consider what type of funding mechanism would best facilitate the development of career-relevant skills. This form of transparency could help students more intentionally connect how they plan their graduate school experiences with their career trajectories.

Second, graduate program faculty and staff can use these findings to anticipate gaps in skill development their students may encounter and offer additional programs and services to fill them. For example, our findings suggest that TAs are more likely to self-report lower development of research skills because of their

funding—graduate programs could consider the provision of supplemental research opportunities for TAs over summer and winter terms to increase their access to research skill development opportunities. Similarly, graduate programs could better integrate external fellows into research groups through formalized faculty mentorship plans, peer mentoring groups, and project management opportunities. These programmatic improvements would benefit students and graduate programs in several ways. Employers increasingly seek well-rounded, multifaceted candidates, particularly in the STEM industry and government roles that must routinely evolve and adapt to address complex problems (e.g., Habib & Chimson, 2019). High-level skill development across an array of career-relevant skills provides graduates versatility in career choice. Alternatively, because the career alignment variable main effects significantly related to skill development, and interaction effects with specific funding types were largely insignificant, programs can more intentionally help graduate students recognize the different ways in which funding experiences can be helpful for their career preparation. Perceiving alignment seemed to matter in similar ways across funding types.

Finally, more robust career-relevant skill sets will enhance students' agency and career success, which will subsequently enhance a graduate program's reputation and future recruitment success. We do recognize that these findings and recommendations make some assumptions about student agency of fellowship recipients in our study. Namely, we assume that fellowship recipients need or would want more of these programming opportunities to develop career-relevant skills, when it may be that they are content with the autonomy afforded to them and are not concerned with gains in research, peer mentoring, teamwork/project management, or communication skills. Future research is needed to investigate student agency and career expectations related to fellowship funding, specifically, and what skills these students wish to gain in pursuit of a doctoral degree.

Further, policymakers and external granting agencies will benefit from this work by recognizing that, although external fellowships have many experiential benefits including pay and autonomy, these students may lack access to opportunities to develop important skills critical to future careers in academia, industry, and government. Funding agencies supporting external fellowships could require graduate programs to formalize professional development plans, job descriptions, and career and academic learning outcomes to ensure that their funded students have equitable access to skill development opportunities. Autonomy should not come at the sacrifice of engagement with faculty, peers, research, or professional development opportunities. These

improvements would only strengthen the value and prestige of these awards, providing students the array of career-relevant skills necessary for successful entry into and persistence in the STEM workforce.

Finally, we would be remiss if we did not attend to that matter of equity as related to funding mechanisms and to our sample of institutions. First, for example, if graduate programs use RAs or fellowships as a recruitment tool, will students from certain, more prestigious prior institutions get access to RA opportunities while students with prior degrees from less prestigious institutions only have access to TAs? Additionally, faculty within institutions and programs with plentiful funding of varied types can encourage student agency in pursuing opportunities to gain skills or networking connections through TAs, RAs, or internships (Wall Bortz et al., 2021). Students enrolled at less robustly resourced institutions, departments or programs may instead face instability of funding or lack choice of funding type that restricts students’ agency for skill development (Wall Bortz et al., 2021). Further, if external fellowships are used to recruit women and racially minoritized students into STEM, graduate programs may be perpetuating inequities for these groups given the potential access inequities to career-relevant skill development opportunities that we highlight in this study. Further, the significant finding in our study that Black students reported significantly lower peer mentoring and training skills warrants further investigation using an equity lens. We also acknowledge that the sampling mechanisms of our study narrowed our focus on students enrolled in large and/or selective STEM graduate programs in the United States. Although these programs graduate a large percentage of students earning STEM doctorates in the United States, this sampling plan limited our understanding of minoritized students’ experiences in STEM doctoral programs as evidenced by our low proportions of Black and Hispanic/Latinx student participants. Future research should broaden the scope of this work to a larger institutional sample to include minority-serving institutions, such as Hispanic-serving institutions (HSIs) and Historically Black Colleges and Universities (HBCUs), to help illuminate how funding mechanisms relate to students’ career development across a range of institutional contexts. Graduate programs and funding agencies should be critically minded when examining how they use funding mechanisms to recruit STEM doctoral students and how the allocation of such funding types across students can act to perpetuate systemic inequities.

## Appendices

### Appendix 1

#### Institutional sample of survey respondents

- 
- Carnegie Mellon University
  - Cornell University
  - Georgia Institute of Technology
  - Johns Hopkins University
  - Massachusetts Institute of Technology
  - North Carolina State University
  - Ohio State University
  - Pennsylvania State University
  - Purdue University
  - Texas A&M University
  - University of California Irvine
  - University of California San Diego
  - University of California Los Angeles
  - University of Chicago
  - University of Colorado Boulder
  - University of Florida
  - University of Illinois at Urbana-Champaign
  - University of Maryland
  - University of Michigan
  - University of Pennsylvania
  - University of Texas at Austin
  - University of Washington
  - University of Wisconsin-Madison
  - Virginia Tech
  - Yale University
- 

### Appendix 2

#### Crosstabs table of gender, race/ethnicity, and citizenship by primary funding type

Primary funding	Research assistantship (302)	Teaching assistantship (154)	External fellowship (116)	Internal fellowship (147)
<i>Gender</i>				
Man	0.61	0.60	0.43	0.45
Woman	0.39	0.40	0.57	0.55
<i>Race/ethnicity</i>				
White	0.52	0.56	0.70	0.58
Asian	0.40	0.33	0.12	0.27
Black	0.02	0.02	0.05	0.03
Hispanic	0.06	0.08	0.13	0.12
<i>Citizenship</i>				
US citizen	0.55	0.60	0.92	0.80
Non-US citizen	0.45	0.40	0.08	0.20

Values represent proportions of students for each gender, race/ethnicity, and citizenship status



**Appendix 3**

Pearson correlations of dependent and independent variables

	1	2	3	4	5	6	7	8	9
(1) Research skills									
(2) Teamwork/project management skills	0.51***								
(3) Peer training and mentoring skills	0.26***	0.49***							
(4) Communication skills	0.38***	0.46***	0.45***						
(5) Primary funding: research assistantship	0.29***	0.26***	0.08*	0.15***					
(6) Primary funding: external fellowship	0.03	-0.11**	-0.19***	-0.14***	-0.37***				
(7) Primary funding: internal fellowship	0.03	-0.02	-0.05	-0.06	-0.43***	-0.22***			
(8) Primary funding: teaching assistantship	-0.39***	-0.19***	0.11**	0.00	-0.44***	-0.23***	-0.26**		
(9) Career alignment	0.40***	0.30***	0.17***	0.28***	0.05	0.14***	0.00	-0.19***	

\*p ≤ 0.05, \*\*p ≤ 0.01, \*\*\*p ≤ 0.001

**Appendix 4**

Logistic regression models with interactions for primary funding and career alignment

n = 719	Research skills	Teamwork/project management skills	Peer training and mentoring skills	Communication skills
<i>Gender (ref. = man)</i>				
Woman	0.82 (0.16)	0.89 (0.16)	1.19 (0.20)	0.75 (0.13)
<i>Race (ref. = White)</i>				
Asian	1.51 (0.41)	1.92** (0.47)	1.05 (0.24)	2.10** (0.50)
Black	0.71 (0.39)	0.69 (0.36)	0.26* (0.16)	0.32 (0.20)
Hispanic	0.79 (0.26)	1.59 (0.49)	0.79 (0.23)	0.75 (0.23)
<i>Citizenship (ref. = U.S. citizen)</i>				
Non-U.S. citizen	1.21 (0.33)	1.22 (0.30)	0.99 (0.23)	0.88 (0.21)
<i>Ph.D. field (ref. = engineering)</i>				

n = 719	Research skills	Teamwork/project management skills	Peer training and mentoring skills	Communication skills
Biological sciences	1.19 (0.39)	0.64 (0.20)	0.62 (0.18)	0.55 (0.17)
Math	0.51 (0.22)	0.34** (0.14)	0.56 (0.20)	0.36 (0.14)
Physical science	0.94 (0.24)	0.83 (0.19)	0.62* (0.14)	0.68 (0.16)
<i>Institution (ref. = public)</i>				
Private	0.81 (0.24)	0.94 (0.26)	1.01 (0.27)	0.88 (0.24)
<i>Year in doctoral program (ref. = year 1)</i>				
Year 2	0.94 (0.28)	0.98 (0.26)	0.96 (0.24)	1.10 (0.29)
Year 3	1.27 (0.36)	1.05 (0.28)	1.10 (0.27)	1.48 (0.38)
Year 4	1.96* (0.61)	1.39 (0.39)	1.42 (0.38)	1.83* (0.50)
Year 5	1.47 (0.51)	1.69 (0.54)	0.97 (0.29)	2.17* (0.68)
Year 6	1.57 (0.99)	1.73 (1.01)	1.19 (0.65)	2.10 (1.15)

n = 719	Research skills	Teamwork/ project management skills	Peer training and mentoring skills	Communication skills
Year 7 or more	0.93 (0.67)	0.74 (0.48)	1.31 (0.81)	1.26 (0.81)
<i>Research group (ref. = yes)</i>				
No	0.25*** (0.11)	0.25*** (0.10)	0.29*** (0.10)	0.68 (0.25)
Unsure	0.67 (0.43)	0.58 (0.35)	0.63 (0.35)	0.87 (0.51)
Two or more funding sources	1.05 (0.28)	1.57 (0.39)	1.15 (0.27)	1.39 (0.33)
<i>Primary funding (ref. = research assistantship)</i>				
External fellowship	0.79 (0.31)	0.39* (0.17)	0.22** (0.12)	0.42 (0.21)
Internal fellowship	0.53 (0.17)	0.50* (0.16)	0.70 (0.23)	0.56 (0.20)
Teaching assistantship	0.09*** (0.03)	0.46** (0.14)	2.96*** (0.84)	1.52 (0.44)
Career alignment	8.25*** (2.79)	5.09*** (1.47)	3.00*** (0.74)	4.64*** (1.20)
<i>Interaction (ref. = research assistantship × career alignment)</i>				
External fellowship × career alignment	0.31* (0.17)	0.55 (0.29)	1.16 (0.70)	0.71 (0.41)
Internal fellowship × career alignment	1.05 (0.56)	1.18 (0.56)	1.10 (0.48)	1.45 (0.68)
Teaching assistantship × career alignment	1.25 (0.71)	0.52 (0.26)	0.46 (0.21)	0.58 (0.27)
Constant (intercept)	1.09 (0.33)	0.87 (0.25)	0.70 (0.19)	0.41** (0.12)
Pseudo-R <sup>2</sup>	27.8%	18.7%	10.9%	15.1%

\*p ≤ 0.05, \*\*p ≤ 0.01, \*\*\*p ≤ 0.001

**Abbreviations**

STEM: Science, technology, engineering and mathematics; RAs/RA: Research assistantships/research assistantship; TAs/TA: Teaching assistantships/teaching assistantship.

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**Authors' contributions**

CL and AA reviewed, organized, and authored the literature and theoretical framing sections of the manuscript. DG and AP conducted analyses, interpreted and authored the methods and results sections of the manuscript. DG was lead author of the framing, discussion, implications and conclusion sections of the manuscript. DK and MB reviewed and edited the entire manuscript. All authors read and approved the final manuscript.

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**Availability of data and materials**

The datasets generated during and analyzed during the current study are not publicly available in compliance with IRB protections afforded to participants to preserve their anonymity. A de-identified version of these data, with appropriate exclusions for groups with small sample sizes (< 10), are available from the corresponding author on reasonable request.

**Declarations**

**Competing interests**

The authors declare that they have no competing interests.

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