Tapping Into Early PhD Aspirations to Advance Gender Equity in Computing: Predicting PhD Interest Among Upward Transfer Students

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Abstract

Purpose: Supporting community college transfer students represents a critical strategy for broadening participation in STEM. In addition to being a racially diverse group, students who pursue STEM degrees by way of community college report frequent interests in graduate study and academic careers. Thus, supporting and expanding transfer students' PhD interests can help to diversify the STEM professoriate. This study specifically seeks to identify the experiences that predict PhD interests among students who transferred into the computer science major from a community college.

Methodology: Relying on longitudinal survey data from over 150 community college transfer students throughout their first year at their receiving four-year university, we used regression analysis to identify the post-transfer college experiences that predict early interest in PhDs.

Findings: We found that receiving information about PhDs from a professor had the strongest impact on PhD interest among transfer students. Relationships with other variables indicate that the provision of information about graduate school was more likely to occur for students in undergraduate research experiences than for those participating in internships. Descriptive data document inequities in who has access to these types of experiences.

Originality and Implications: This paper provides new insight into how STEM departments can develop targeted efforts to ensure that information about PhD training is equitably available to all transfer students. Working to ensure that faculty equitably communicate with students about PhD opportunities may go a long way in countering potential deterrents among transfer students who may be interested in such pathways.

Keywords: PhD interests; community college transfer; computer science majors; OLS regression

Tapping Into Early PhD Aspirations to Advance Gender Equity in Computing: Predicting PhD Interest Among Upward Transfer Students

While women's representation in STEM has increased in recent decades, women comprise fewer than 20% of doctorates in computing and remain underrepresented among computer science (CS) faculty (Zweben & Bizot, 2018). Increasing women's representation in the CS professoriate would have critical implications for diversity at all other levels of CS degrees and careers (see Phillips, 2004; Tierney & Sallee, 2008). Further, CS is experiencing a shortage of newly minted PhDs to fill faculty positions (Shein, 2019). Coupled with growing undergraduate interest in CS, this faculty shortage leads many programs to adopt competitive enrollment practices (e.g., restricting admission to the major based on prior experience), which further exacerbates inequity (Nguyen & Lewis, 2020) and reduces the pool of potential CS PhD students who might want to pursue a CS faculty position. Thus, there is an urgent need to increase the number of students following PhD pathways in CS, so that programs can fill open faculty positions and move from competitive enrollment practices to inclusive policies that support all students interested in pursuing CS degrees.

Ongoing efforts to broaden women's participation in CS—at both the undergraduate and graduate level—continue to center women from privileged groups and those who follow direct pathways to CS (e.g., white women with college-educated parents who begin their undergraduate programs immediately after high school; Blaney, 2020). Yet, across the United States, many CS students aspiring to undergraduate and graduate degrees begin their training at community colleges, defined as broad access institutions that typically offer a range of professional certificates and two-year associate's degree programs (Kisker & Cohen, 2023). Indeed, one primary function of American community colleges is to increase access to higher education by providing opportunities for upward or vertical transfer, in which students begin their degree programs at more affordable community colleges and transfer to complete their degrees at four-year universities (Taylor & Jain, 2017). Students who follow these upward transfer pathways in pursuit of STEM degrees are disproportionately first-generation to college, Women of Color, and from low-income backgrounds (Bahr et al., 2017; Blaney, 2020; LaSota & Zumeta, 2016). More specifically, upward transfer women in CS represent an especially high-achieving group and disproportionately express an interest in pursuing PhDs (Blaney & Wofford, 2021). Considering the unique characteristics of upward transfer students—particularly upward transfer women—it would be beneficial to further explore mechanisms that support and foster the academic interests of this diverse and talented group in CS.

Recognizing that PhDs are a prerequisite to many faculty careers, we explored the factors that predict PhD interest among upward transfer students, relying on survey data from N=159 CS majors who transferred from a community college and completed two surveys over the course of their first four months at their receiving campus. Guided by Wang's (2017) upward transfer model and literature on gender equity in CS, we center upward transfer women's experiences, while also considering variation among women. The following questions guided our inquiry:

1. What post-transfer university experiences predict computing PhD interests among upward transfer CS students?
2. To what extent does exposure to those predictors differ by gender?

Guiding Literature and Conceptual Framework

This study bridges research on women's participation in undergraduate computing with studies of STEM graduate school pathways. We briefly review these bodies of literature before presenting our conceptual framework, which extends Wang's (2017) STEM upward transfer model. Overall, we identify critical gaps in the literature on equity and graduate training pathways in computer science, which has not carefully considered experiences and outcomes for students who enter higher education through community colleges.

Gender and women's participation in computer science

Women in CS have historically been robustly underrepresented, typically comprising less than 20% of current members of the computing workforce (NCWIT, 2019), graduate programs (Zweben & Bizot, 2018), and undergraduate degrees (DuBow et al., 2021). Within computing, women routinely report gender discrimination (Barker et al., 2009, 2014) and experience a lower sense of belonging than men (Sax et al., 2018). Women are more likely than men to identify negative outcomes of pursuing a degree or career in CS (Cheryan et al., 2020) and tend to have lower levels of CS self-efficacy and identity, regardless of prior experiences with computing (Cassidy & Eachus, 2002; Wofford, 2023). Collectively, these gender inequities documented within CS may largely be explained by persistent discrimination and false stereotypes about who can succeed in the field. Furthermore, these inequities can be especially harmful for women from racially minoritized groups who encounter multiple stereotypes and forms of discrimination in CS and other STEM spaces (Charleston et al., 2014; Williams, 2023).

In light of pervasive gender inequities in CS, a wealth of recent literature has explored women's success and participation in undergraduate CS programs. It is not surprising that women students report specifically valuing the presence of women faculty within computing programs (Cohoon & Lord, 2007). Further, peer mentoring and peer teaching programs yield positive learning and retention outcomes for women undergraduates, suggesting value in building community and support mechanisms in which women are present and in leadership roles (Morrison et al., 2021). As women are more likely than men to move into a computing major later in their undergraduate career but less likely to be actively recruited to do so (Lehman et al., 2020), deliberate efforts to foster women's computing interests and enhance the visibility of women within computing departments are needed.

While interventions to recruit and support women in computing have gained significant traction (Aspray, 2016; Berry et al., 2022), emerging studies suggest that many existing interventions are not equitably available (or beneficial) to women who navigate degree pathways through community colleges. For example, while university introductory CS courses are often the focus of interventions to promote gender equity, upward transfer women may not enroll in introductory coursework at the university and are thus excluded from interventions within intro courses (Blaney et al., 2022). This is especially concerning, given that students who navigate upward transfer pathways tend to be more racially and ethnically diverse and more frequently represent first-generation students and those from lower income backgrounds, relative to students who enter universities directly from high school (Blaney, 2020). Thus, as part of larger efforts to broaden participation in CS, more research is needed that specifically considers effective support structures for upward transfer students, particularly women.

Broadening accessible pathways to graduate programs

Because we are specifically interested in upward transfer students' interests in PhD study, we were also guided by broader literature on factors contributing to one's interest in graduate school. Consistently documented in prior literature, active mentorship and support from both faculty and peers bolster access to graduate study (Charleston, 2012; Cohoon et al., 2004; Espino, 2014; Hanson et al., 2016) and success in graduate programs (Blaney et al., 2020; Burt, 2017; Griffin et al., 2018). For minoritized students especially, faculty mentorship can shape how students navigate pathways from undergraduate study through successful graduate degree completion by providing access to academic capital and personal support (Griffin et al., 2018; Luna & Prieto, 2009; Phelps-Ward & DeAngelo, 2016). Similarly, co-curricular experiences such as participation in student groups (Szelényi & Inkelas, 2011) and undergraduate research opportunities (Pender et al., 2010) can bolster both students' qualifications for entry to graduate programs and their interest and self-efficacy in pursuing a graduate degree (Adedokun et al., 2013; Eagan et al., 2013). Unfortunately, such opportunities—including access to undergraduate research experiences—may not be equitably available to upward transfer students (Solis & Duran, 2022).

Other research considers graduate school pathways specifically in computing. For instance, across a broad sample of computing undergraduates, one recent study documented that interest in graduate school increased as a function of support received from computing faculty, computing identity, and computing self-efficacy (Wofford et al., 2022). Other studies further underscore the importance of computing self-efficacy in predicting computing students' graduate aspirations, both across the board (Wofford, 2023) and specifically for upward transfer computing students (Blaney & Wofford, 2023). Consistent with broader literature on graduate school pathways across fields, other scholars posit that exposure to undergraduate research, receiving timely information about graduate training opportunities, and access to tailored advising about graduate school preparation may aid in the recruitment of women to computing graduate programs (Cuny & Aspray, 2000).

Researchers have also identified how motivations to transform computing are closely related to one's interest in graduate study, building upon broader literature on why students choose to pursue graduate training across fields (e.g., Espino, 2014; Skakni, 2018). For example, Wofford et al. (2022) identified that feeling dismissed by one's computing department was, counterintuitively, positively associated with graduate school aspirations. Similarly, Blaney and Wofford (2021) found that perceiving a lack of diversity among computing faculty positively predicted upward transfer women's graduate school interests, likely by motivating them to be role models and contribute to diversity among computing faculty. Within related qualitative research, a desire to serve as a role model for women and girls in computing was similarly identified as a source of motivation for upward transfer women considering faculty career pathways (Blaney et al., 2022). Taken together, these findings document that, while supportive computing environments foster more equitable access to graduate training, some students may also be motivated to pursue doctoral programs to address existing inequities and unwelcoming environments in CS departments.

STEM upward transfer model

Guided by the literature reviewed above, we adapted Wang's (2017) model of STEM upward transfer to identify the post-transfer experiences that predict PhD interests among CS majors who began their degree programs at community colleges. Building on social cognitive career theory (Lent et al., 2002), Wang's model outlines the person inputs (e.g., identities, attitudes, and beliefs) that students bring to college, which inform students' experiences and outcomes. Wang's (2017) model further identifies the STEM learning experiences, campus engagement experiences, and broader contexts, which converge to shape upward transfer student decision-making and academic outcomes. Wang's (2019) model also articulates the importance of self-efficacy in shaping student decision-making processes. In the case of our study, which focuses on interests related to PhD study, we considered self-efficacy for graduate training, which refers to students' beliefs in their ability to be successful in graduate school (Borrego et al., 2018).

While Wang's (2017) model focuses primarily on the pre-transfer learning and engagement experiences that predict successful transfer, we focus on post-transfer learning and engagement experiences. This approach builds on recent studies of computing students' post-transfer student success in computing, which document the importance of broader life contexts (e.g., family support) in predicting retention, sense of belonging, and other key outcomes among upward transfer computing students (e.g., Blaney, 2021; Blaney et al., 2022; Blaney & Barrett, 2022). Especially relevant to this work, one recent study applied Wang's model and utilized existing national survey data to examine the factors that predict PhD aspirations among upward transfer students who enroll in computing courses, highlighting the importance of faculty mentorship and perceptions of faculty (Blaney & Wofford, 2021). Despite these recent studies applying Wang's model to computing transfer pathways, much remains unknown about the trajectories that students follow from community colleges to graduate study in computer science. In particular, studies have primarily relied on existing data and examined broader contexts that predict success, while our study extends that work to focus on specific and tangible university experiences that can support and/or constrain upward transfer pathways to PhDs. To further contextualize our application of Wang's model to CS, we draw on other studies that have explored the experiences of CS students enrolled at community colleges (Denner et al., 2014), as well as those that focus on student experiences after they transfer to universities (e.g., Blaney, 2021; Lyon & Denner, 2019).

Methods

We relied on a sample of upward transfer CS majors enrolled across five large, research-intensive universities in California, merging data from two incoming student cohorts who entered their receiving universities in Fall 2021 and Fall 2022. All students completed two surveys. The first survey was administered upon students' arrival at their receiving university and had a response rate of 45% (346 respondents). The second survey was administered at the end of the academic term to baseline respondents who met study eligibility criteria[i] and received a response rate of 50%. This resulted in a longitudinal sample of N=159 students and allowed us to examine PhD interests over the first term that transfer students spent at their universities, which represents a critical time during which transfer students make decisions about their degree trajectories and develop relationships with faculty that can facilitate graduate school interests and successful application (see Solis & Duran, 2022).

Among those in our longitudinal sample, 23.9% were women, 75.5% were men, and 0.6% indicated another gender identity. Fifty-six percent of participants were Asian/Asian American; 24.5% were white; 17.0% were Latina/o/x; 2.5% were Middle Eastern or Persian; 1.3% were Black; and 1.3% were from Native Hawaiian or Pacific Islander groups. Forty-four percent of students spent about two years at their community college, 31.3% spent three years at the community college, while the remaining quarter of students spent four years or more attending community college prior to transfer. The age of participants ranged from 19 to 46 years old, with the majority of participants (73.4%) being 22 or younger.

Measures

To measure PhD interest (dependent variable), the second survey asked students to indicate their agreement with the following on a 5-point scale (1=Strongly disagree; 2=Disagree; 3=Neither agree nor disagree; 4=Agree; 5=Strongly agree): "I am interested in earning a PhD." Gender was measured by asking students to indicate their gender identity as a woman, man, or another identity. Race/ethnicity was measured by asking students to select from the following list: Asian/Asian American; Black; Latina/o/x; Middle Eastern or Persian; Native American or Alaska Native; Native Hawaiian/Pacific Islander; White; Other Identity. Students could select more than one identity on the survey. Due to small cell sizes, our analyses primarily aggregate students into one of three groups: n=80 Asian students; n=32 white students; and n=37 students from all other racial and ethnic groups (n=27 Latina/o/x; n=4 Middle Eastern or Persian; n=2 Black; n=2 Native Hawaiian/Pacific Islander; and n=2 students who selected "Other Identity").

Independent variables were selected using our conceptual framework and are described in the Appendix. Notably, self-efficacy for graduate study was measured through an established composite variable (Borrego et al., 2018) and was treated as a covariate to control for pre-existing differences in disposition toward graduate school. The remaining independent variables were selected to capture 1) post-transfer college experiences (e.g., active learning exposure, participation in research); 2) sources of information about PhD study (e.g., whether or not students received information from faculty, peers, and/or advisors); and 3) perceptions of post-transfer experiences (e.g., peer support in CS, transfer stigma). Table A1 includes a list and description of all independent variables and Table A2 provides further information about how composite variables were created, including information about reliability.

Analysis

Because participants were nested within five universities, we examined intraclass correlations (ICCs) to determine the extent to which variance on key measures could be accounted for by institutional differences. ICCs on key variables were low (ICCs $\leq .06$), though the ICC on the dependent variable could not be calculated due to small variance between institutions. To examine Research Question One, we used OLS regression to identify predictors of PhD interest, entering potential predictors in blocks based on the conceptual framework. Because graduate school self-efficacy at the first time point was selected as a covariate to control for initial differences, it was entered first into the model. All other variables were entered using the stepwise command, and only significant variables were retained. To examine Research Question Two, we used independent samples t-tests to assess mean differences by gender on all theorized predictors of PhD interest. In cases where the theorized predictors were dichotomous variables, chi-square tests were used instead. Additional ANOVAs and crosstabs were used to examine further variation by gender and race/ethnicity together.

Limitations

To contextualize our study, it is important to reflect on several limitations of our inquiry. Our findings focus on students during their first four months at receiving universities; while the first term after transfer is a critical time for fostering career and degree aspirations among upward transfer students (see D'Amico et al., 2014; Thomas et al., 2021), future research should explore PhD interests and aspirations over a longer period. Additionally, our sample size limited statistical power, which restricted our ability to meaningfully assess variation by race/ethnicity and required us to narrow the scope of potential independent variables included in analyses. Our focus on transfer students in CS across research-intensive universities means that more research would be needed to assess the extent to which findings might generalize to students in other disciplines or those who transfer into different types of four-year universities (e.g., liberal arts colleges). Finally, the survey methods used in our analysis do not allow us to make causal inferences, though we mitigated this limitation by controlling for incoming graduate school self-efficacy in our analyses. Still further inquiry is needed, if a goal is to infer causation between independent and dependent variables.

Findings

Research Question One

The first research question asked about the predictors of PhD interests among upward transfer students in CS. Before conducting regression analyses to address this question, we explored descriptive statistics on the dependent variable of PhD interests. We found that 25.8% of students agreed or strongly agreed that they were interested in pursuing a PhD, 34.0% neither agreed or disagreed that they were interested, and 40.3% disagreed or strongly disagreed that they were interested in a PhD. PhD interests did not differ by gender among students in our sample. As a reminder, the dependent variable was measured on the second survey, approximately four months after students entered their receiving university. Overall, it is notable that over a quarter of upward transfer students report some degree of interest in pursuing a PhD during their first year at the university.

As shown in Table I, we identified four significant predictors, which collectively explained 22% of the variance in PhD interests (R^2=.22), though only two variables remained statistically significant in the final model. The strongest positive predictor of PhD interest was, unsurprisingly, incoming graduate school self-efficacy, which was significant at every step of the model. Two variables predicted PhD interest at Step 2: completing an internship negatively predicted PhD interest, while participating in research with a faculty member positively predicted PhD interest.[ii] However, both of these variables became non-significant in the final model (Step 3), after taking faculty interactions into account. More specifically, reporting that a faculty member provided information about PhD programs was a positive predictor of PhD interest in the final model. Variables capturing students' perceptions of their university did not significantly predict PhD interest or enter the model. Taken together, these findings suggest that receiving information about PhD study from a faculty member may be more likely during supervised research than during internship opportunities. Confirming the viability of this interpretation, post hoc chi-squared tests with a dichotomized measure of research participation indicate that the joint likelihood of receiving information about PhDs from a faculty member and participating in research was significantly greater than receiving information from faculty and participating in an internship ($\chi^2 = 12.932$, $p < 0.001$)[iii].

Insert Table I Here

Research Question Two

In an effort to better understand women's pathways from community colleges to PhDs in CS, Research Question Two focused on how exposure to predictors of PhD interest might differ by gender (see Tables II and III). We found that, relative to men, women report more frequently participating in research with a faculty member (p=.017). Though non-significant, women also less frequently reported that a faculty member served as a source of PhD information. While no other variables in the regression model significantly differed by gender, differences emerged on other theorized predictors. Specifically, women reported experiencing more stress about paying for college, relative to men (p=.004), which may have implications for who has access to graduate training. Men also significantly more frequently reported that advisors served as a source of information about PhD programs, pointing to opportunities for advisors to more equitably distribute information about PhDs to upward transfer women.

Insert Tables II and III Here

Additional analyses used crosstabs and one-way ANOVAs to examine differences by gender and race together. Due to the number of comparisons required for these analyses, we used the Bonferroni correction in all post-hoc significance testing, and we only report the significant results that emerged, each related to sources of PhD information. As shown in Table IV, we found that, relative to other groups, white women least frequently reported that a faculty member served as a source of information about PhD programs (only 16.7%). We also found that white women least frequently (33.3%) reported that advisors served as a source of PhD information (though white women did not *significantly* differ from all other groups). These findings provide important nuance to the findings shown in Table III; specifically, gender differences in how students reported accessing different sources of information about PhD study were primarily being driven by patterns for white women and do not necessarily represent the experiences of Women of Color in our sample.

Insert Table IV Here

Discussion

Upward transfer students represent an underrepresented pool of potential doctoral students. Prior research documents how upward transfer students consistently demonstrate high levels of ambition, motivation, achievement, and resilience (Wang, 2017, 2020). While these attributes are highly valued and promote success in graduate school, transfer students may encounter barriers that limit their access to graduate training, and it is imperative that researchers and practitioners consider strategies to provide more equitable access to graduate school pathways. To that end, our study examined the predictors of PhD interest, focusing on the role of gender and women's experiences, adapting Wang's (2017) prior work on upward transfer students. Specifically, we adapted Wang's Upward Transfer Model to determine how *post-transfer* learning and engagement experiences may shape interest in PhD pathways in the context of computer science.

Notably, over one quarter of upward transfer students in the present study were interested in pursuing a PhD. When evaluating relevant predictors of these PhD interests, we found that entering the university with high levels of graduate school self-efficacy and receiving information about PhD programs from CS faculty both positively predicted PhD interest, consistent with other literature on the importance of self-efficacy and faculty interactions in shaping graduate school pathways (Wofford, 2022; Wofford et al., 2023). Unfortunately, other findings suggest inequities among upward transfer CS students. For example, although women reported more frequently participating in research with a faculty member—which is positively associated with PhD interests in our study and PhD matriculation in the broader literature (Adedokun et al., 2013; Eagan et al., 2013)—men more frequently reported receiving information about PhD programs from advisors and faculty (though the latter difference was not statistically significant). While we cannot be certain why women may less frequently receive

PhD information from advisors and faculty, our findings likely point to underlying inequities in who is encouraged to pursue graduate study. Thus, ensuring that faculty and advisors are equitably encouraging women to pursue graduate school—and specifically PhD study—will be a critical step to advancing women's participation in graduate CS programs and faculty pathways.

Based on our conceptual framework, we expected that post-transfer experiences would predict PhD interest. Only one variable capturing post-transfer experiences—namely, receiving information about PhDs from a faculty member—predicted PhD interest in the final regression model. However, two other variables—research participation and internship participation—predicted the dependent variable in the interim model but became non-significant when all variables were considered in combination. Our finding that participating in undergraduate research positively predicted PhD interest reinforces literature documenting a positive association between undergraduate research participation and students' academic career aspirations (e.g., Adedokun et al., 2013; Russell et al., 2007). Conversely, prior literature documents how CS students enter industry internships with the expectation of applying their skills in real-world contexts and often report a sense of satisfaction in task completion, building professional relationships, and affirming individual career paths (Minnes et al., 2021). While these "real world" experiences can be highly valuable, internships may be more effective when they are integrated within coursework and include formal supervision from both a faculty advisor and internship host (e.g., Oh, 2019).

Our current findings suggest the possibility that participation in undergraduate research may, at least in part, provide increased opportunities and perceptions of potential student interest for faculty to share information about doctoral study. Student participation in internships that take them outside an academic or research context may present an opportunity cost, wherein students are less likely to interact directly with faculty in ways that lead to the accrual of graduate school knowledge. Importantly, only 22% of the students in our sample had completed internships at the time of the second survey, suggesting that many more students may become disinterested in PhDs as they gain internship experiences, should faculty not intervene with encouragement to pursue graduate study. In future studies, it may be important to consider the impact of research participation on application, admittance, and matriculation to CS PhD programs.

Gender Specific Differences across Post-Transfer Experiences

We documented gender inequity in post-transfer experiences, which may constrain upward transfer women's access to PhD pathways. As we discussed above, women in our sample less frequently gained information about PhDs from advisors and faculty, despite being more frequently engaged in undergraduate research. Another notable gender difference among participants in our sample was related to financial stress paying for college, which we had theorized as a predictor of PhD interest, though it was non-significant and did not enter in our regression analyses. Still, it is notable that women reported greater financial stress in paying for college, relative to upward transfer men and this finding may have implications for whether or not students actually apply to and pursue PhDs. It is possible that upward transfer students, particularly upward transfer women, may view PhD training as financially inaccessible (Blaney et al., 2022; Singer, 2019). Given that upward transfer women reported more financial stress than upward transfer men, this may be a source of inequity that creates a barrier to CS PhD enrollment.

Implications

Counteracting PhD Deterrents by Increasing Access to Research Opportunities and Graduate School Information

Our findings provide insight into how an important pool of prospective doctoral students, upward transfer students, may consider PhD pathways through various college experiences. We found that students who completed computing-related internships reported less interest in pursuing a PhD, which may be due to learning about industry careers instead of academic careers throughout the internship. Importantly, only 22% of students in our sample had completed internships at the time of the second survey; thus, more students may be deterred from PhD pathways as they complete internships later in their college career. While some CS students will inevitably be drawn to high-paying industry careers, faculty could provide students with research opportunities and information about graduate school, so that students have equitable access to information about both industry and academic career options. Indeed, after accounting for faculty interactions (i.e., receiving PhD information from a faculty member), completing an internship was no longer a negative predictor of PhD interests within our regression model. These findings highlight the critical role faculty can play in ensuring that information about PhD study is as accessible as possible, especially in light of industry career information being readily available during internships. Overall, we call on university leaders to invest in research programs that specifically target transfer students and CS faculty to provide equitable mentorship and advisement about graduate school opportunities and preparation.

Making PhD Study in CS a Viable Option

Prior literature documents how concerns about paying for graduate school, taking on student debt, and experiencing financial insecurity deter students from continuing their education and considering PhD pathways (Blaney et al., 2022; McKinney & Burridge, 2015). While financial stress did not significantly predict PhD interest in our study, we posit that this may be due to our focus on transfer students during their first term at their university. It may be that financial stress and related factors play a larger role over time, as transfer students get closer to completing their undergraduate degrees. Further, we documented a gender difference, such that, relative to men, upward transfer women reported higher levels of financial stress associated with paying for college. We therefore recommend that universities invest in dedicated scholarships and financial supports for upward transfer women to ensure that inequities in financial stress during college do not result in further stratification in degree pathways over time.

We also recommend that graduate programs revisit existing compensation structures, as inadequate stipends likely deter many transfer students who disproportionately care for dependents and have other non-college responsibilities (Blaney, 2020), creating pressure for them to urgently enter the workforce after college to support their families. While a common narrative is that universities cannot compete with high-paying tech careers (Singer, 2019), providing graduate student compensation that simply adequately covers living expenses may aid in recruiting a more diverse group of PhD students, including those who are the first in their families to attend college and those with greater financial stress. Again, as part of revising financial aid policies and compensation for CS PhD students, it is especially important to center the needs of upward transfer women, given their high levels of reported financial stress in our study. Thus, understanding and supporting the financial needs of upward transfer women, who are disproportionately first-generation to college, Women of Color, and from low-income backgrounds (Bahr et al., 2017; Blaney, 2020; LaSota & Zumeta, 2016) likely represents a critical step in diversifying the CS professoriate. Put simply, ensuring that graduate student stipends provide a living wage may go a long way in making PhD training a viable option for upward transfer students.

Centering Transfer Students in Future Studies

A quarter of upward transfer students in our sample had PhD interests, which is considerably greater than we expected, given that the majority of CS majors (regardless of transfer status) are not interested in pursuing graduate school programs of any kind (Wofford et al., 2022). Further, PhD programs seek to admit students who are motivated and resilient, attributes which are commonly found in upward transfer students (Wang, 2020). As upward transfer students develop their PhD interests, supportive environments and faculty mentorship may help students apply for and transition into doctoral programs. Our findings suggest that receiving information about PhD study from a faculty member may be a primary driver of PhD interests among upward transfer computing students. Future research should evaluate the additional factors that support upward transfer students as they develop PhD interests, apply for PhD programs, and matriculate into those programs. Given that our study focused specifically on the early university experiences that predict PhD interests, it will be important to consider the broader contexts and experiences that shape upward transfer pathways to PhD study over a longer period of time. More broadly, our study underscores the need for research on STEM PhD pathways to specifically consider students who began their undergraduate degrees at community colleges, given upward transfer students' frequent PhD interests.

Conclusions

Our findings point to strategies to build equitable pathways to CS PhDs by centering the needs and experiences of students who begin their degrees at community colleges. While upward transfer students frequently have PhD interests, they may be deterred from graduate study as they gain exposure to industry careers, which may be perceived as providing greater job security and compensation, relative to academia. While faculty interactions may counteract those deterrents, we document inequities in how students gain access to information about PhDs from faculty and advisors. Implications include opportunities to make information about the benefits and accessibility of PhD training more equitably available.

Table I. Predictors of PhD Interest Among Upward Transfer Students (*n*=148)

	Step 1: Covariate				Step 2: Post-Transfer Experiences				Step 3: Sources of Information			
	β	B	SE	Sig.	β	B	SE	Sig.	β	B	SE	Sig.
Incoming Self-Efficacy	0.35	0.63	0.14	.000***	0.31	0.57	0.14	.000***	0.29	0.53	0.14	.000***
Internship Participation					-0.16	-0.44	0.21	.038*	-0.11	-0.29	0.21	.160
Research Participation					0.16	0.17	0.08	.046*	0.11	0.11	0.08	.178
Source of Knowledge: Faculty									0.25	0.57	0.18	.002**
R^2	0.12				0.17				0.22			

Note. $^*p<.05$, $^{**}p<.01$, $^{***}p<.001$. This table was created by the authors.

Table II. Gender Differences on Theorized Predictors of PhD Interest

	Men (n=120)		Women (n=38)		
	M	SD	M	SD	t
Covariate					
Incoming Self-Efficacy for Graduate Study	3.69	0.67	3.74	0.43	-0.52
Post-Transfer College Experiences					
Active Learning	3.74	0.43	3.27	0.70	-0.01
Internship participation	0.26	0.60	0.43	0.72	-1.31
Research Participation	1.57	1.00	2.00	1.23	-2.13*
HPW Computing Groups	2.81	1.97	3.06	1.60	-0.68
HPW Non-Computing Groups	2.47	1.70	2.42	1.83	0.17
HPW studying	7.47	2.45	7.91	2.28	-0.95
Financial stress: Paying for college	3.27	1.34	3.86	1.05	-2.74**
Perceptions of post-transfer experiences					
Transfer stigma	2.62	0.95	2.92	0.74	-1.76
Navigational Ease	4.01	0.60	3.78	0.74	1.88
Peer support	3.05	1.00	2.99	0.86	0.37

Note. *p<.05, **p<.01, ***p<.001. Gender differences in research participation were significant at p=.017; gender differences in financial stress were significant at p=.004. This table was created by the authors.

Table III. Gender differences on sources of PhD information

Source of Information	Percent Among		
	Men (n=120)	Women (n=38)	Chi-Square
Faculty	66.67	51.35	2.81
Advisors	68.42	45.95	6.05*
Peers	76.32	75.68	0.01

Note. *p<.05, **p<.01, ***p<.001.

Table IV. Gender differences by race on sources of PhD information (*n*=142)

Primary or Secondary Source of Information	Percent Among					
	White women (a)	Asian women (b)	Black, Latina, Indigenous, and Middle Eastern/ Persian Women (c)	White men (d)	Asian men (e)	Black, Latino, Indigenous, and Middle Eastern/ Persian Men (f)
Faculty	16.67_{cef}	52.17	83.33_{a}	61.11	67.21_{a}	64.29_{a}
Advisors	33.33_{f}	43.48_{ef}	66.67	61.11	68.85_{b}	75.00_{ab}
Peers	66.67	78.26	83.33	83.33	75.41	71.43

Note. Subscripts indicate significant differences at $p<.05$ level. This table was created by the authors.

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Table A1. Summary of Theorized Predictors/Potential Independent Variables

Variable	Variable Description	Range/Coding scheme
Covariate		
Graduate school self-efficacy	Composite variable (see Table A2)	1=Low self-efficacy; 5=High self-efficacy
Post-transfer experiences		
Active learning	Composite variable (see Table A2)	1=Low active learning exposure; 5=High active learning exposure
Internship participation	Single item: Since beginning college, how many computing-related internships or co-ops have you participated in?	0=None; 1=1; 2=2; 3=3; 4=More than 3
Research participation	Single item: Since transferring, how often do you work with an instructor, faculty member, or a researcher at your institution on a research project?	1=Never; 5=Very often
HPW computing student groups	Single item: HPW spent in computing student groups.	1=None; 12=More than 40 hours
HPW non-computing student groups	Single item: HPW spent in non-computing student groups	1=None; 12=More than 40 hours
HPW studying	Single item: HPW spent studying	1=None; 12=More than 40 hours
Sources of graduate school knowledge		
Faculty	Single item: Receive PhD information from faculty	0=Not a source of information; 1=A primary or secondary source of information
Advisors	Single item: Receive PhD information from academic advisors	0=Not a source of information; 1=A primary or secondary source of information
Peers	Single item: Receive PhD information from other students	0=Not a source of information; 1=A primary or secondary source of information
Perceptions of experiences		
Financial stress (paying for college)	Single item: Over the last two years, a source of stress for me has included: Paying for college	1=Strongly disagree; 5=Strongly agree
Transfer stigma	Composite variable (see Table A2)	
Navigational ease	Composite variable (see Table A2)	
Peer support	Composite variable (see Table A2)	

Notes. HPW=hours per week. All HPW items asked students to report time spent by asking: "over the course of this academic year, how much time have you spent during a typical week on the following activities?" Note that internship participation was treated as a dichotomous variable in the regression analyses (0=Has not completed an internship; 1=Completed one or more internships), and this measure does not account for *when* students completed an internship during college. This table was created by the authors.

Table A2. Summary of Composite Variables

Variable	Items	Cronbach's alpha
Graduate school self-efficacy (Borrego et al., 2018)	If I decided to go to graduate school, I would be successful I can see myself as a graduate student My interactions with graduate students have been positive Graduate school is something that other people do, not me (reverse coded) I am comfortable teaching myself how to do things I would be good at research	.793
Active learning (Wang & Lee, 2019)	*How often have you engaged in the following activities within computing classes at your current university?* Presented what I learned to the instructor and my peers Explored key concepts, data, beliefs, or values within small groups Thought about instructors' questions on my own first and then discussed them with peers Identified what I already know, what I needed to know, and how and where to access new information to solve a given problem Considered, compared, and generated multiple potential solutions to a given problem Integrated skills and knowledge learned to solve problems Worked in groups to research necessary background material to solve complex, realistic problems Drew diagrams to visually show the connection between a new concept and other concepts that I already learned Gathered information from a variety of sources Drew conclusions and made decisions given a detailed description of the situation Evaluated peers' written work Worked on real-world problems Worked on my own projects or experiments Chose my own topics or projects to investigate	.907
Transfer stigma (Laanan, 2010)	Because I was a community college transfer, most students tend to underestimate my abilities There is stigma at my university among students for having started at a community college Because I was a community college transfer, most faculty tend to underestimate my abilities	.821
Navigational ease (Hurtado & Guillermo-Wann, 2013)	*At my current college, I have been able to…* Learn what resources are available on campus Find help when I need it Figure out which requirements I need to graduate Find information helpful to me as a transfer student Enroll in the courses I need	.873

	Understand what my professors expect of me academically	
Peer support (adapted from BRAID)	*To what extent is each of the following available to you from students in your academic major at your current university?* People to hang out with People to confide in or talk to about your problems People to get class assignments for you if you are sick People to help you understand difficult homework problems	.865

Note. All composite variables were computed by finding the average of the corresponding survey items. This table was created by the authors.

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[i] To be eligible for the study, students had to indicate on the first survey that they had a major housed in the CS department and that they transferred from a community college.

[ii] Importantly, our measure of research participation specifically asked about whether or not students had participated in research at their universities (i.e., after transferring), while our measure of internship participation more broadly asked if students had completed internships since beginning college (i.e., before or after transferring).

[iii] Only 14 participants (8.8%) reported both supervised research and internship experiences. Data from these individuals was excluded from the chi-square analysis.