

The Chemistry Graduate Student Experience: Findings from an ACS Survey

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ABSTRACT: Graduate training is a key element in producing a scientific workforce that reflects the nation's diversity. This paper examines data from a 2013 American Chemical Society (ACS) survey of 2,544 chemistry masters and doctoral students and reveals barriers to reaching this goal. Multivariate statistical analyses indicate that women reported significantly less supportive relationships with advisors. Women were less likely to plan to finish their degrees, and for PhD students, the discrepancy was larger for students at the start of their graduate program. Women were also less likely to pursue the next level of training, and the gender difference related to postdoctoral plans was greater for those who identified with a racial–ethnic group traditionally underrepresented in chemistry (underrepresented minority, URM). URM students who were beyond the first year of their graduate program reported significantly less supportive relationships with peers. They were also less likely to have funding sufficient to meet their needs and more often used personal resources including loans. Despite these difficulties, URM students were more likely to definitely plan to finish their degrees, and men who identified as URM were more likely to plan to pursue postdoctoral work. Independent of gender and identification as URMs, students in more highly ranked schools reported less advisor support. Extensive open-ended comments indicated that large proportions of the students desired more attention and meaningful feedback from advisors and changes within their programs to promote support for students and advisor accountability. Suggestions for future research are given, and a companion commentary discusses needed directions for change.

KEYWORDS: Graduate Education/Research, Women in Chemistry, Minorities in Chemistry

Numerous authors and organizations have noted the importance of diversity in scientific professions. A scientific workforce that incorporates all segments of society not only enhances the number of people in the field but also the quality of work.^{1–6} Graduate training is a key element in developing this diverse workforce. During this training, students not only learn technical aspects of their chosen areas, but also they develop commitment to the field. However, substantial literature has documented ways in which students of color, women, and those who are the first generation in their families to attend college have less supportive graduate experiences than other students. There appear to be several contributing factors, including the support of academic advisors or mentors,^{1,7,8} support from peers and co-workers, a “sense of belonging” or community,^{1,8–16} subtle negative interactions or “microaggressions,”^{3,17–20} and financial support.^{8,21} Research has also documented the ways in which students' experiences vary across departments with varying levels of prestige.^{12,22}

In 2013, the American Chemical Society (ACS) conducted a survey of graduate student members designed to understand their views of “career plans and preparation, student–advisor relationships, and support mechanisms” with the long-term goal of producing “a more positive and productive graduate student experience.”²³ The survey was administered in August 2013, and a report of the findings was completed later that year. While the ACS report noted significant differences in responses related to gender and identification as a racial–ethnic minority, it did not examine other relationships between

variables, nor the comments given by the students. The ACS graciously provided access to the data so that we could examine, in greater detail, issues related to support and inclusivity in chemistry graduate education.

Recently, using these data, we published a paper that examined the experiences and plans of 1,375 graduate students in the 100 departments that receive the largest amount of federal research support.²⁴ We limited our analysis to students in the middle of their graduate programs, omitting those at the start of their training and those who had been in their program longer than five years. Using multivariate statistical analyses, we found that women, and especially those who identified as members of racial–ethnic groups historically underrepresented in chemistry (underrepresented minority, or URM), were significantly less likely to report positive relationships with their advisors. Issues with adequate advice were especially serious within the most highly ranked departments. Men who identified as URMs were less likely to report supportive interactions with fellow graduate students or postdocs; both men and women who identified as URMs were less likely to have financial support adequate to meet their needs. Women

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were significantly less likely to express commitment to finishing their degree or pursuing a postdoc and entering a professorship at a research university, even when they had more supportive advisors. In contrast, students who identified as URMs were more likely to have these aspirations. Thus, our analysis generally supported the previous literature regarding the difficulties faced by women and people of color in their STEM graduate programs.

This paper expands on the previous analysis by examining a broader sample: both PhD and masters students, students at all colleges and universities represented in the sample, and students at all points in their graduate careers. While our earlier analysis included first-generation student status as a control variable, in this paper we specifically examine the relationship of first-generation status and its intersection with gender and identification as a URM. A substantial proportion of chemistry graduate students are from countries other than the U.S., and we test the extent to which our findings hold when international students are not included in the analysis. We examine whether minority-serving institutions, such as historically Black colleges and universities (HBCUs), might provide more supportive environments.^{25,26} With this expanded sample, we examine, using multivariate statistical techniques, the association of departmental context and students' gender, identification as an URM, and first-generation status with four dependent variables: (1) the quality of the student–advisor relationship, (2) the support received from fellow graduate students and postdocs, (3) the adequacy of funding, and (4) the commitment to completing the degree and pursuing further work. We also examine students' comments regarding (1) their graduate experiences and (2) suggestions for improving chemistry graduate education. (Extensive details of our analysis are in the [Supporting Information](#).) We end with a discussion of our results and suggestions for further research. We believe that our findings have important implications for current policies and practices, and a companion paper addresses this topic in detail.²⁷

METHODOLOGY

Sample and Measures

The sample included 2,544 chemistry graduate students, limited to those who provided information on gender, identification as a URM, and parental education. There were 94% who were in PhD programs. The students were enrolled in 240 different departments, and we examined two measures related to departmental context. (A full list of the institutions and details on sample selection are in the ACS report of the data.²³) Our first contextual measure was the rank of the department in federal research funding as reported by the National Science Foundation in the year of the survey. The departments were grouped into four categories: those in the top 20, those ranked 21–50, those ranked 51–100, and those that were unranked. Because a majority of graduate students were in the higher-ranked departments, this grouping resulted in categories with an approximately equal number of students. The second contextual measure indicated whether the student's university had been designated as a minority-serving institution (MSI) by the U.S. Department of Education, a list that includes HBCUs, tribal colleges, and schools that serve substantial proportions of URM students.²⁸

Most of our statistical analyses focused on four quantitative measures of students' graduate experiences and plans: (1) relationship with their advisor, based on a series of 22 questions including areas such as involvement in research, availability, encouragement, and fair treatment (Cronbach's $\alpha = 0.94$); (2) support from fellow graduate students and postdocs, a dichotomous variable distinguishing those who had the support they desired from those who did not; (3) a five-point scale measuring the extent to which students deemed their financial support "adequate to meet the cost of living" where they lived; and (4) expectations of finishing their degree, a dichotomous variable distinguishing those who definitely planned to finish from others. To supplement these analyses, we examined whether or not students had a primary advisor; the source of their financial support, distinguishing "official" departmental support such as assistantships or fellowships from personal funds, such as jobs or loans; whether they had switched research groups at some point; the extent to which they reported having experienced any "problems directly related to [their] graduate program"; plans for advanced study after finishing their degree; and what they would change if they began their graduate program anew. (See pages 1–3 of [Supporting Information](#) for details on measure construction and content validity.)

Open-ended questions provided additional information on students' graduate experiences including their relationship with advisors, why they had changed a research group, and problems they had encountered related to their graduate program. Others involved thoughts on how the graduate experience could be improved. In total, we examined students' answers to 10 questions. One of the authors carefully read and grouped responses into categories that reflected the nature of students' views as well as understandings from the research literature. Standard techniques of inductive analysis, including multiple sweeps through the data and the use of broad categories, as well as subcategories, were used. All coding was conducted without knowledge of students' sociodemographic characteristics or responses to other questions.

Analysis

Simple bivariate statistics (χ^2 , t tests, and analysis of variance) were used to compare responses of masters and PhD students and those in minority-serving and other institutions. Multiple regression techniques were used to examine the association of students' gender, identification as a URM, first-generation status, year in their program, and department rank with the dependent variables. The multivariate analyses were conducted separately for masters and PhD students. For the masters students, ordinary least-squares (OLS) and logistic regressions were used; for the PhD students, mixed-model regressions, which controlled for the clustering of students within departments, were used. With dichotomous dependent measures, we used logistic regressions and, to help aid interpretation, reported odds ratios rather than the unstandardized regression coefficients, for these analyses. Series of models that included tests of possible interaction effects were examined. This was important to test the presence of intersectionality.²⁹

Our analysis of students' comments and views was descriptive in nature, using the common themes identified in the coding process described above. We looked at the frequency in which various themes were expressed and

common threads in students' descriptions of their experiences and suggestions for change.

FINDINGS

Characteristics of the Sample

About half (48%) of the students were women, but women were more likely to be in masters (59%) than PhD (48%) programs ($\chi^2 = 6.42, p = 0.01$). There were 10% who identified with a race-ethnic group other than Asian or non-Hispanic white, that is, as a URM. A slightly greater percentage of URM students were in masters than PhD programs (14% versus 11%), but this difference was not large enough to be statistically significant. Almost half of the students (47%) reported that both parents had at least a bachelor's degree, while about a third (30%) reported that neither parent had completed college. There was no difference in first-generation status between those in masters or PhD programs. Over half (58%) of the masters students were in their first year, almost one-fifth (19%) were in their second year, and the remainder had been in their program for 3 or more years. The majority (78%) of the PhD students were in their first through fourth years. One-fourth were international students, with the majority (72%) from China, India, and other Asian countries. International students were significantly more likely to be men ($\chi^2 = 38.1, p < 0.001$) and first-generation college graduates ($\chi^2 = 43.07, p < 0.001$). Students who identified as URM, first-generation students, and international students were significantly less likely to be in the top-ranked schools (correlations, respectively, were $-0.05, p < 0.01$; $-0.16, p < 0.001$; and $-0.15, p < 0.001$). Less than 2% of the respondents, representing 11 departments, were in MSIs (Tables S1–S3).

Over 90% of the students, in both masters and PhD programs, reported that they had a primary advisor. Those in MSIs were slightly more likely to have an advisor (94% versus 91%), but this difference was not large enough to be statistically significant. Among PhD students, those in departments ranked in the top 100 were significantly more likely to have a primary advisor (odds ratio = 1.58, $p < 0.05$; Tables S5–S8). Taken together, our descriptive analysis of the sample indicated sufficient variation on all variables to support the use of multivariate analyses of our research question regarding the association of students' graduate experiences with gender, identification as URM, first-generation status, and departmental context.

Statistical Analysis of Students' Experiences

Sections below summarize results of our statistical analyses focused on four major dependent variables: (1) student–advisor relations, (2) peer support, (3) adequacy of funding, and (4) commitment to finishing the degree and pursuing further training.

Relations with Advisors. On average, students rated their relationships with their advisors as slightly positive (mean = 3.63, $sd = 3.80$ on a 5-point scale, Table S1). Students at MSIs viewed their advisors similarly to those of students at other institutions, but PhD students rated their advisors as slightly, but significantly, more supportive than masters students ($M_{\text{PhD}} = 3.64, M_{\text{masters}} = 3.45, t = 2.63, p = 0.009$, Table S4). The multivariate analyses indicated that both masters and PhD students in the first years of their programs were significantly more likely to report that their advisors were supportive. (For masters students, $b = -0.21, p < 0.001$; for PhD students, $b = -0.17, p < 0.001$, Table S11). In addition, among PhD

students, support varied significantly by gender, identification as a URM, and department rank ($b_{\text{female}} = -0.10, p < 0.01$; $b_{\text{URM}} = 0.18, p < 0.01$, and $b_{\text{rank}} = -0.17, p < 0.001$; Table S11). These relationships are depicted in Figure 1. The lowest

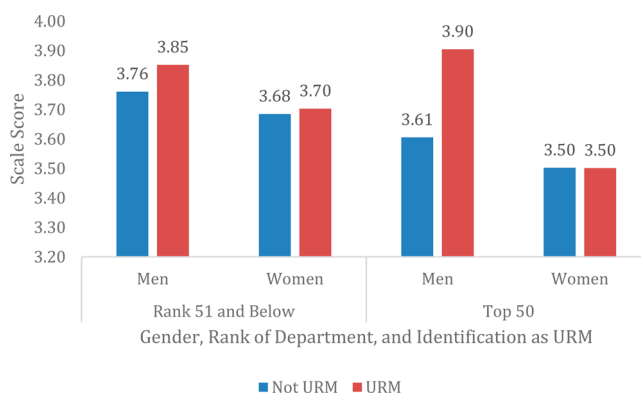


Figure 1. Average scores on scale of advisor support by gender, rank of school and identification as URM. Scale scores ranged from 1 to 5, with 5 indicating the most supportive relationships. There were 1,111 students in departments ranked at 51 or lower (980 non URM and 131 who identified as URM) and 1,225 in the top 50 departments (1,125 non-URM and 100 URM).

levels of support were reported by women (both URM and non-URM) in the top 50 departments, followed by men in those departments. The highest levels were reported by men in the lower-ranked departments and men who identified as a URM in the top 50 departments. However, the interactions of gender, identification as URM, and rank were not statistically significant. These associations remained when international students were omitted from the analysis (Tables S9–S11).

Support from Peers and Postdocs. Almost three-fifths of the students (59%) indicated they had support from peers and postdocs at the level that they would like to receive. There was no significant difference between those at MSIs or other schools, or those in PhD or masters programs. However, there were strong and significant differences between those who did or did not identify as URM. Among masters students, almost two-thirds of the non-URM students (63%) but about half that percentage (37%) of the URM students reported receiving the desired level of support (odds ratio (OR) = 0.27, $p < 0.05$, Table S12). These results were similar for men and women. Among PhD students, the pattern reflected differences associated with the intersection of gender, identification as a URM, and year in their program. (Relevant odds ratios (OR) from the logistic mixed-model regression of receiving desired support were as follows: $OR_{\text{female}} = 0.88, n.s.$; $OR_{\text{URM}=.50}, p < 0.01$; $OR_{\text{firstyr}} = 1.45, p < 0.01$; $OR_{\text{fifthyr+}} = 1.38, p < 0.05$; $OR_{\text{female*URM}} = 2.09, p < 0.01$; $OR_{\text{URM*fifthyr+}} = 0.38, p < 0.05$; Table S14.) These relationships are depicted in Figure 2. On average, students in the earlier years of their PhD program reported having more peer support than those in later years, but the difference was substantially greater for those who identified as URM and other students. Among URM students in the later years of their PhD programs, only half of the women and less than two-fifths of the men (38%) reported having the peer support that they wanted. In contrast, at all points in their program, close to three-fifths or more of the non-URM students, both men and women, reported having the desired support. Results did not differ across departments

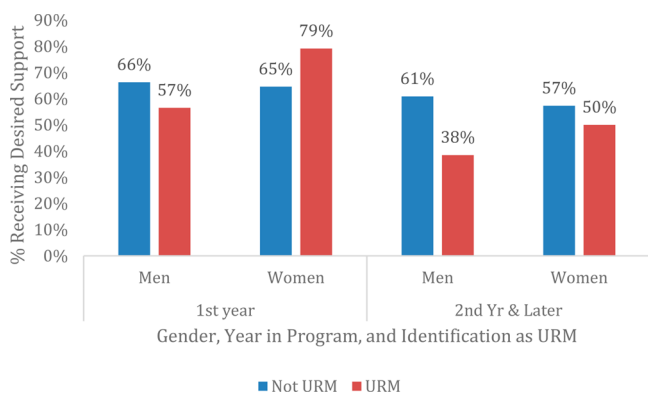


Figure 2. Percentage of PhD students receiving the support that they desired from graduate student peers and postdocs, by gender, identification as URM, and year in program.

of different ranks or when international students were omitted (Tables S12–S14).

Funding. While two-thirds of students agreed that funding was adequate to meet their needs, this response was significantly less common among students in masters programs, at MSIs, or in the nonranked departments (M , on 5 point scale, for masters students = 3.15, sd = 1.19; M for PhD students = 3.67, sd = 1.18, t = 5.32, p < 0.001; at MSIs, M = 2.67, sd = 1.43; at predominantly white institutions (PSIs), M = 3.65, sd = 1.18, t = 5.58, p < 0.001; at nonranked schools, M = 3.30, sd = 1.29; at ranked schools, M = 3.76, sd = 1.12, t = 8.91, p < 0.001). Masters students and those at MSIs were also significantly more likely to rely on personal sources of financial support such as employment, help from families, and loans. (For masters students, M = 36%, sd = 39.0; for PhD students, M = 6%, sd = 15.2, t = 20.83, p < 0.001; for PWI students, M = 8%, sd = 18.9; for MSI students, M = 14%, sd = 22, t = 2.34, p = 0.02; Table S4).

The mixed-model multivariate analyses, which controlled for the rank of departments as well as gender, first-generation status, and year in the program, indicated that PhD students who identified as URM were significantly less likely to see their funding as adequate and more often relied on personal sources of support. However, the analysis also revealed important differences between URM students in the first year of their program and those in later years. Among first-year students, those who identified as URM were slightly more likely than other students to report that their funding was adequate and that a larger proportion of their support came from “official” sources such as RAs, TAs, or fellowships. Among those in their second year or later, the situation sharply reversed with students who identified as URM less likely to report adequate funding, smaller proportions of funds from “official” sources, and greater reliance on personal sources such as loans or family help. (See Figures 3 and 4.) Again, this pattern remained when international students were omitted from the analysis. (In the mixed-model analysis of rating of adequacy of funding, $b_{\text{urm}} = -0.38$, p < 0.001; $b_{\text{1stYear}} = 0.01$, p = 0.90; $b_{\text{URM*1stYear}} = 0.61$, p < 0.001; for two way analysis of variance of percent of funding from personal resources, $F_{\text{interaction}} = 8.24$, p = 0.004, Tables S15–S18.)

Completing the Degree and Further Training. More than three-fourths of the students (77%) reported that they would definitely complete their degree. This response was significantly more common for students at MSIs (94%,

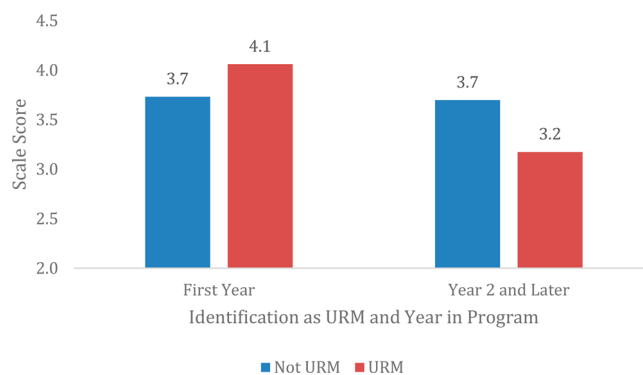


Figure 3. Average rating of adequacy of funding by identification as URM and year in program.

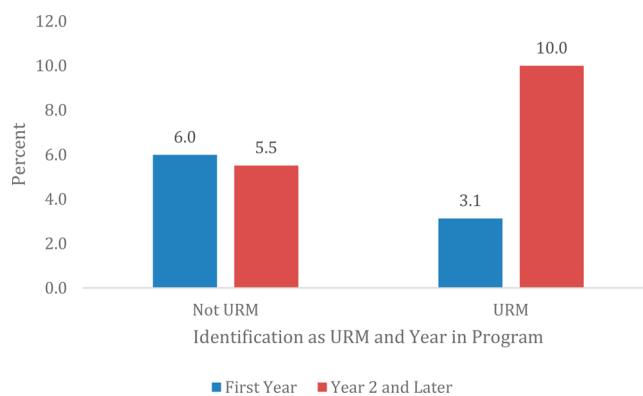


Figure 4. Percent of funding obtained from personal resources, such as loans, family, outside employment, by identification as URM and year in program, PhD students.

compared to 77% for students at PSIs, $\chi^2 = 7.41$, p = 0.006), students in masters programs (86%, compared to 77% for PhD students, $\chi^2 = 7.79$, p = 0.005), and international students (86%, compared to 74% for noninternational students, $\chi^2 = 35.06$, p < 0.001). Multivariate analyses indicated that PhD students were more likely to believe they would definitely complete their degree if they identified as a URM ($OR_{\text{URM}} = 1.52$, p < 0.05) or were a first-generation college graduate ($OR_{\text{1stgen}} = 1.41$, p < 0.01), but less likely to do so if they were women ($OR_{\text{female}} = 0.80$, p < 0.05) or in the first year of their program ($OR_{\text{1styear}} = 0.43$, p < 0.001). The gender difference was substantially stronger among first-year students than more advanced students ($OR_{\text{female*1styr}} = 0.55$, p < 0.01). Independent of these factors, PhD students with more supportive advisors and more supportive peers were more likely to definitely plan to finish ($OR_{\text{supadv}} = 2.22$, p < 0.001; $OR = 1.21_{\text{suppeers}}$, p < 0.10). However, these variables were not related to completion plans of masters students. Department rank was not associated with commitment to finishing for either masters or PhD students, and the general pattern of results remained when international students were omitted.

About a third of the masters students definitely planned to pursue a PhD, and another 42% said that they might do so. Women were slightly less likely than men to plan to continue advanced studies, but this difference declined somewhat when advisor support was included as a control variable (from $OR = 0.43$, p < 0.05 to $OR = 0.47$, p < 0.10). A third of the PhD students planned to seek a postdoctoral fellowship, with those at MSIs and international students more likely to do so (52%

of students at MSIs, compared to 39% for students at PSIs, $\chi^2 = 3.16$, $p = 0.08$; 53% of international students, compared to 35% for noninternational students, $\chi^2 = 58.55$, $p < 0.001$). Results of the mixed-model regressions indicated that students with more supportive advisors were substantially more likely to definitely plan to pursue a postdoc ($OR_{\text{supadv}} = 1.59$, $p < 0.001$). Women were less likely than men to plan a postdoc. This difference was more marked among those who identified as URM and remained significant when support of the advisor was equalized ($OR_{\text{female}} = 0.67$, $p < 0.001$; $OR_{\text{URM}} = 1.98$, $p < 0.01$; $OR_{\text{female*URM}} = 0.40$, $p < 0.01$). Among students in the first year of their programs those who were first-generation college students were significantly more likely to plan postdoctoral training ($OR_{\text{1stgen}} = 1.17$, $p = 0.48$; $OR_{\text{1styear}} = 0.39$, $p < 0.001$; $OR_{\text{1stgen*1styear}} = 2.22$, $p < 0.01$). The rank of department was not significantly associated with postdoctoral plans, and results were virtually identical when international students were omitted (Tables S19–S22).

Students' Experiences and Recommendations: Qualitative Data Analysis

At the end of the survey, students were asked whether, if they were to start their studies again, they might change their field of study, institution, or advisor. Less than a third (31%) of the students indicated they would make no changes, while substantially more (43%) indicated that they would change two or three of these areas, most often their institution or advisor (Table S23). Sixty percent of the students gave open-ended comments, and they provide important insights into their concerns. Students were more likely to give comments if they had less supportive relationships with advisors and peers or less adequate funding, but there was no systematic association of giving comments with students' sociodemographic characteristics or departmental rank. In addition, there were no systematic associations of these variables with the types of comments that were given or the extent to which students would change their graduate careers if they were to start again (Tables S24–S27). In other words, among those who commented (three-fifths of all respondents), men and women students, URM and non-URM students, first-generation and non-first-generation students, and those from ranked and nonranked departments made very similar observations regarding their graduate experiences and needed changes in their departments. Pages in the SI that include the anonymized comments are noted below, and readers are encouraged to peruse that material to sense the intensity with which many students expressed their concerns.

Students' Experiences. About 10% of the students reported that they had switched research groups at some point. Slightly more than half of the reasons for doing so (54%) involved factors such as a shift of research interests, lack of funding, changing programs or institutions, an advisor retiring or moving to another institution, or relatively minor incompatibilities with an advisor, such as differences in preferred management styles and personal dissimilarities. However, over two-fifths (46%) cited more troublesome issues including challenging lab cultures, unenjoyable work, conflict with or feeling unsupported by an advisor, and inappropriate/unprofessional behavior from peers or an advisor (Table S29 and pp 85–92 in Supporting Information).

In describing relations with their advisors, two-fifths of the comments included high praise or relatively neutral sentiments. However, the remainder described negative experiences.

Students reported feeling unsupported: advisor apathy, lack of opportunity for growth, ineffective mentorship, and scant career preparation or advice. Other responses included feeling that their work went unrecognized and that they were not adequately compensated. Several described their advisor as having unrealistic expectations and poor communication and management skills. Respondents also complained about their advisors being too busy and largely unavailable to assist them or provide guidance. Overwhelmingly, it appeared that students desired more attention and more meaningful feedback from their advisors, as well as a system that promotes advisor accountability (Table S28 and pp 47–84).

Sixteen percent of the students indicated that they had experienced "problems directly related to [their] graduate program". In describing these problems, over half of the students mentioned lack of support, financial burdens, and lack of opportunities. Students also felt frustrated by the onerous number and convoluted nature of graduation requirements, the lack of course offerings, the rigor of exams, and the lack of publication assistance. They reported very little guidance and feeling as though their department simply did not care about them. About a quarter of the comments (24%) dealt with treatment by others. They described issues with their advisors including unavailability, poor advising capabilities, unprofessional behavior, unrealistic expectations, little direction, and academic differences. Fewer respondents described difficulties with their peers, but some commented on facing discrimination, harassment, and racism, as well as a general lack of community. Finally, a quarter of the comments involved managerial issues, including a lack of communication between department administration and students, delays in payroll, unclear graduation requirements, undefined rules and regulations, and ambiguous policies. Respondents felt that their departments were too political, had ineffective leadership, and were fiscally irresponsible, which occasionally resulted in students leaving or changing groups. Additionally, students felt that there were insufficient accountability measures for inappropriate behavior (Table S30, pp 93–114 in Supporting Information).

Students' Suggestions for Change. The survey included several opportunities for graduate students to share thoughts on how their departments could be more supportive. Over three-fifths of the students requested additional benefits, most often better health insurance, including dental and vision coverage. Students also wanted better and more affordable parking or transit provisions, help with housing, better maternity and paternity leave, and increased access to childcare facilities, as well as financial help in the form of reduced student fees, lower tuition costs, and larger salaries. Apart from these monetary benefits, some students requested more community building activities and help with career development (Table S31, pp 115–153 in Supporting Information).

Finally, students were asked to provide suggestions on how their department could improve the quality of their experience, and a third did so. Their comments were often extensive and thoughtful, falling into five general categories. Almost half (46%) stressed the need for greater support, both financial, such as higher stipends and help with fees not covered through RA or TA appointments, and social, including building a more inclusive and supportive community. A number called for updating lab equipment and aging infrastructure, altering the curriculum, and providing help with career preparation. Many asked for better feedback, clearer descriptions of requirements

and deadlines, consistency in expectations, and additional ways for students to voice their concerns without retribution. They noted wanting more interaction with faculty and having the opportunity to build relationships with faculty members. Some indicated wanting committee members to be more involved in the student research and academic experience, and several suggested offering management or leadership development courses for faculty (Table S32, pp 174–225 in Supporting Information).

■ SUMMARY AND DIRECTIONS FOR FUTURE RESEARCH

Our analyses provide important insights into inequities in the experiences of chemistry graduate students. The findings also suggest directions for additional research involving each of the key dependent variables, as well as other areas.

First, we found that women were significantly less likely to have supportive relationships with their advisors, and the gender gap was slightly larger for students who identified as URM. The open-ended comments vividly illustrate the wide range of issues students encountered with their advisors. The fact that comments were generally similar across sociodemographic groups, including gender and identification as URM, indicates the extent to which the lack of supportive advising permeates the culture of the discipline and affects all students. Future research could focus on both the elements of a good advisor relationship and how such relationships could be developed and nurtured for all. Special attention should be given to the larger gender gap for students who identified as URM and the greater disadvantages faced by women in this group.

Second, students who identified as URM and were beyond the first year of their program were significantly less likely to receive desired support from peers or postdocs, a disturbing finding given the importance of peer interactions in building future careers and scientific advancements. However, the survey questions that dealt with this topic were relatively general in nature, and future research should delve into this area more thoroughly. Do our results reflect the types of microaggressions that have been documented in other disciplines?^{3,17–20} Why did results differ between first-year students and those later in their programs? Might it involve differences in the nature of graduate programs between the first and later years, or other variables? Our sample was cross-sectional in nature, rather than longitudinal. A design that allows the tracking of individuals over time, such as a panel study, could provide greater understanding.

Third, we found that PhD students who identified as URM and were farther along in their programs were markedly less likely to report adequate funding and more likely to rely on personal resources such as jobs, help from family, or loans. Because our earlier analysis²⁴ focused only on students in the middle of their graduate program, this finding was unforeseen and warrants more attention. We also found no indication that the pattern varied across departments at different ranks, although it would be important to examine other contextual variables. In addition, it is important to study the long-term implications of URM students having to rely more heavily on personal resources to finance their education. Given the vast differences in wealth between families of color and other families in the U.S., as well as documented differences in college debt,³⁰ one could speculate that this differential in graduate funding would only widen the overall gap in financial

resources. Longitudinal research designs would be optimal to illuminate this finding.

Fourth, even though PhD students who identified as URM were less likely to receive peer support or adequate funding (and, if women, less likely to have supportive advisors), they were more likely to definitely plan to finish their degrees and pursue a postdoc. Future research could examine factors that contribute to these students' dedication and resilience in face of challenging circumstances. As well, MSI students, both those who did and who did not identify as URM, were significantly more likely to definitely plan to finish their degree and pursue a postdoc, even though there was no difference in their support from advisors or peers. As the number of students in these schools in our sample was quite small and the departments were diverse in student population and historical traditions, including HBCUs and those that serve largely Latinx populations, it would be important to replicate our work with a larger sample of MSI schools.

Finally, while a growing literature provides compelling evidence that first-generation students face unique challenges in higher education,^{31,32} we found little indication of this pattern among the students in our sample. In fact, like URM students, they were more likely to plan to complete their degree. As detailed in the Supporting Information, we conducted several additional analyses to examine this finding, all resulting in similar conclusions: First-generation students did not report different experiences in their graduate training, at least with the variables we examined, yet did report greater commitment to finishing their degree (Tables S35–S38). There are several possible explanations that deserve additional research. Perhaps chemistry is more welcoming than other disciplines to first-generation students. Perhaps students experienced difficulties in undergraduate years, but these are less common in graduate training either because graduate training differs from undergraduate work or first-generation students who enter chemistry graduate programs differ from other undergraduates in key ways. Alternatively, it is possible that the survey did not adequately tap the issues that are of concern to first-generation students or how their experiences might differ. Longitudinal studies following students of diverse backgrounds from the start of their baccalaureate work might be revealing.

Several limitations to this study deserve mention. First, only a small number of masters students were in the sample, and future work should include a larger sample. This is especially important given the overrepresentation of first-generation students, women, and those who identify as URM within this group. Second, future studies could use sampling plans that would increase the proportion of students who identify as URM, increasing statistical precision of analyses. Third, future studies could examine additional contextual measures, including, but not limited to, the gender and racial–ethnic composition of departmental faculty and student–advisor pairs. Future survey questions should incorporate more contemporary understandings of gender identification and explore how sexual orientation and disability status are associated with graduate experiences. Finally, as the data analyzed here were gathered in 2013, it would be important to examine the extent to which our findings might have changed over time. The ACS recently surveyed graduate students using an instrument similar to the one used for our work, and analysis of those data could be informative.

CONCLUSION

The importance of growing a scientific workforce that reflects the diversity of our nation is widely recognized, and graduate training is a key element in this process.^{33,34} The results of this study, involving over 2,000 graduate students, reveal a number of difficulties faced by women and those who identify with racial–ethnic groups traditionally underrepresented in STEM. Women reported less supportive relationships with advisors and were less likely to plan to finish their degrees or pursue the next level of training. Those who identify as URM reported less supportive relationships with peers and inadequate levels of funding in the later years of their graduate programs. Despite these difficulties, they were more likely to definitely plan to finish their degrees and pursue postdoctoral work. Students from all backgrounds and types of schools had similar descriptions of issues in their programs and presented extensive suggestions for change. The results suggest several directions for future research as well as alterations in practices and policies that can be implemented by graduate students, faculty, departments, funding agencies, and professional organizations. We believe that these changes are so vital that a more extended discussion is given in a companion document.²⁷

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.1c00610>.

Extensive statistical results and all of the open-ended comments (PDF, DOCX)

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Notes

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REFERENCES

- (1) Ferreira, M. Gender issues related to graduate student attrition in two science departments. *International Journal of Science Education* **2003**, *25*, 969–989.
- (2) Riegle-Crumb, C.; King, B.; Irizarry, I. Does STEM stand out? Examining racial/ethnic gaps in persistence across postsecondary fields. *Educ. Researcher* **2019**, *48*, 133–144.
- (3) Puritty, C.; et al. Without inclusion, diversity initiatives may not be enough. *Science* **2017**, *357*, 1101–1102.
- (4) *Women and Minorities in Science, Technology, Engineering, and Mathematics: Upping the Numbers*; Burke, R. J., Mattis, M. C., Eds.; Edward Elgar Publishing Limited: Cheltenham, UK, 2007.
- (5) Phillips, K. W.; et al. How diversity makes us smarter. *Sci. Am.* **2014**, *311*, 42–47.
- (6) Clewell, B. C.; et al. Revitalizing the nation's talent pool in stem science, technology, engineering, and mathematics. Urban Institute, 2006. <http://webarchive.urban.org/publications/311299.html>, accessed 27 May 2021.
- (7) Nolan, S. A.; Buckner, J. P.; Marzabadi, C. H.; Kuck, V. J. Training and mentoring of chemists: A study of gender disparity. *Sex Roles* **2008**, *58*, 235–250.
- (8) Ong, M.; Wright, C.; Espinosa, L. L.; Orfield, G. Inside the double bind: A synthesis of empirical research on undergraduate and graduate women of color in science, technology, engineering, and mathematics. *Harvard Educational Review* **2011**, *81*, 172–208.
- (9) Chang, M. J.; Sharkness, J.; Hurtado, S.; Newman, C. B. What matters in college for retaining aspiring scientists and engineers from underrepresented racial groups. *J. Res. Sci. Teach.* **2014**, *51*, 555–580.
- (10) Curtin, N.; Stewart, A. J.; Ostrove, J. M. Fostering academic self-concept: Advisor support and sense of belonging among international and domestic graduate students. *American Educational Research Journal* **2013**, *50*, 108–137.
- (11) Dasgupta, N. Ingroup experts and peers as social vaccines who inoculate the self-concept: The stereotype inoculation model. *Psychological Inquiry* **2011**, *22*, 231–246.
- (12) Espinosa, L. Pipelines and pathways: Women of color in undergraduate STEM majors and the college experiences that contribute to persistence. *Harvard Educational Review* **2011**, *81*, 209–240.
- (13) Figueroa, T. *Underrepresented Racial/Ethnic Minority Graduate Students in Science, Technology, Engineering, and Math STEM Disciplines: A Cross-Institutional Analysis of their Experiences*; Unpublished Dissertation, UCLA, 2015.
- (14) Good, C.; Rattan, A.; Dweck, C. S. Why do women opt out? Sense of belonging and women's representation in mathematics. *Journal of Personality and Social Psychology* **2012**, *102*, 700–717.
- (15) Lewis, K. L.; et al. Fitting in or opting out: A review of key social-psychological factors influencing a sense of belonging for women in physics. *Physical Review Physics Education Research* **2016**, *12*, 020110.
- (16) Stachl, C. N.; Baranger, A. M. Sense of belonging with the graduate community of a research-focused STEM department: Quantitative assessment using a visual narrative and item response theory. *PLoS One* **2020**, *15*, e0233431.
- (17) Anderson, A. J.; et al. It just weighs in the back of your mind: Microaggressions in science. *Journal of Women and Minorities in Science and Engineering* **2020**, *26*, 1–30.
- (18) Miner, K. N.; Diaz, I.; Rinn, A. N. Incivility, psychological distress, and math self-concept among women and students of color in STEM. *Journal of Women and Minorities in Science and Education* **2017**, *23*, 211–230.
- (19) Moss-Racusin, C. A.; et al. Science faculty's subtle gender biases favor male students. *Proc. Natl. Acad. Sci. U. S. A.* **2012**, *109*, 16474–16497.
- (20) Verdin, D.; Godwin, A. Exploring Latina first-generation college students' multiple identities, self-efficacy, and institutional integration to inform achievement in engineering. *Journal of Women and Minorities in Science and Engineering* **2018**, *24*, 261–290.

(21) Estrada, M.; et al. Improving underrepresented minority student persistence in STEM. *CBE-Life Sciences Education* **2016**, *15*, es5.

(22) Griffith, A. L. Persistence of women and minorities in STEM field majors: Is it the school that matters? *Economics of Education Review* **2010**, *29*, 911–922.

(23) Kuniyoshi, C.; Sostaric, J.; Kirchhoff, M. *ACS Graduate Student Survey*; American Chemical Society: Washington, DC, 2013.

(24) Stockard, J.; Rohlfing, C. M.; Richmond, G. L. Equity for women and underrepresented minorities in STEM: Graduate experiences and career plans in Chemistry. *Proceedings of the National Academy of Sciences* **2018**, *118*, e2020508118 DOI: 10.1073/pnas.2020508118.

(25) Upton, R.; Tanenbaum, C. *The Role of Historically Black Colleges and Universities as Pathway Providers: Institutional Pathways to the STEM PhD among Black Students*; Issues Brief; American Institutes for Research, 2014.

(26) Winkle-Wagner, R.; McCoy, D. L. Feeling like an “alien” or “family”? Comparing students and faculty experiences of diversity in STEM disciplines at a PWI and an HBCU. *Race Ethnicity and Education* **2018**, *21*, 593–606.

(27) Rohlfing, C. M.; Richmond, G. L.; Noviski, M.; Lewis, P.; Stockard, J. Policies and Practices to Improve the Chemistry Graduate Student Experience: Implications of the ACS Survey of Graduate Students. *J. Chem. Educ.* **2021**, DOI: 10.1021/acs.jchemed.1c00611.

(28) United States Department of Education Accredited Postsecondary Minority Institutions. <https://www2.ed.gov/about/offices/list/ocr/edlite-minorityinst-list-tab.html>, accessed 27 May, 2021.

(29) Collins, P. H. *Intersectionality as Critical Social Theory*; Duke University Press: Durham, NC, 2019.

(30) Scott-Clayton, J.; Li, J. Black-white disparity in student loan debt more than triples after graduation. *Evidence Speaks Reports* **2016**, *2* (3), 1–9.

(31) Lang, D. *On Social Mobility: A Brief History of First-Generation College Students at Michigan: 2007 to 2019*; University of Michigan Press: Ann Arbor, 2019.

(32) Lang, D. *Social Class Voices*; University of Michigan Press: Ann Arbor, 2017.

(33) National Academies of Sciences, Engineering, and Medicine. *Graduate STEM Education for the 21st Century*; National Academies Press: Washington, DC, 2018. DOI: 10.17226/25038

(34) American Chemical Society. Graduate Education in the Chemical Sciences: Summary Report of an ACS Presidential Commission. ACS: Washington, DC. <https://www.acs.org/content/dam/acsorg/about/governance/acs-commission-on-graduate-education-summary-report.pdf>