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Consensus, Division, and the Future of Graduate Education in the Chemical Sciences

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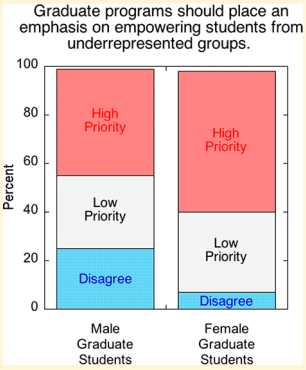
Supporting Information

ABSTRACT: A panel comprising expert members of the chemistry academy, chemical industry, and the government produced a report in 2012 with 32 recommendations to advance graduate education in the chemical sciences. Until now, the target recipients of the study, students, faculty, and administrators, have not been asked if they agree with the recommendations. A survey of the beneficiaries of the 2012 ACS study reveals areas of consensus but also sharp differences in opinion regarding some of the recommendations. Many of these differences in opinion may be attributed to the natural needs and values of the different stakeholder groups. Some of the divisive issues could represent impediments to improving graduate education. The results of the survey are detailed and interpretation is provided. A path forward to advancing graduate education in the chemical sciences is also outlined.



KEYWORDS: *Graduate Education/Research, Professional Development, Curriculum, Standards National/State*

INTRODUCTION

In the 1950s, the ranks of chemistry faculty were overwhelmingly White, male, native-born U.S. citizens, as were the doctoral students who pursued a Ph.D. in chemistry.[1] The dominant approach to doctoral education then (and now) was an apprenticeship model, in which faculty "masters" mentored student "apprentices", shaping and molding apprentices into the next generation of faculty masters.[2] Given the expectation that upon graduation, most students would pursue a position in the academy or conduct foundational research in industry, the model sufficed. Today, however, faculty (to some extent) and doctoral students (to a larger extent) are demographically different from their 1950s counterparts.[3] Further, current doctoral students in the chemical sciences have professional goals that are far more diverse and, some might argue, more ambitious than their earlier counterparts.[4] These changes have for some time required an overhaul of the dominant pedagogical approach taken in the chemical sciences, and, more broadly, STEM graduate education as a whole.[5−9]

Efforts to advance STEM graduate education have been the subject of dozens of national studies.[10] The National Academy of Sciences (NAS) has been at the forefront framing reform efforts, which arguably began with the seminal 1995 NAS study, *Reshaping the Graduate Education of Scientists and Engineers*.[11] Recently, the NAS has revisited the subject in the report *Graduate STEM Education for the 21st Century*.[12] In 2001, a few years after the 1995 NAS study, the Carnegie Foundation undertook the first significant self-examination of graduate education in the sciences, the Carnegie Initiative on the Doctorate (CID). The five-year CID undertaking was intended to be an action and research project to encourage and support departments' efforts to improve the quality of their doctoral programs by designing and implementing new initiatives. Chemistry was one of five fields that were the focus of the study. Several monographs that summarize the findings were written after the CID ended in 2006.[2,13]

At the conclusion of the CID, the Graduate Education Advisory Board of the American Chemical Society (ACS) recommended that the ACS sustain the doctoral-reform initiative,[14] but no concrete action was immediately taken. In 2011, then ACS President-Elect Bassam Shakhashiri charged a commission led by Dr. Larry Faulkner (past President of the University of Texas at Austin) to consider fundamental, comprehensive, and systemic changes in the way graduate students are trained in the chemical sciences. This was significant because few of the prior national studies had focused on a single discipline. We have previously argued this broad focus is problematic in that most general studies do not recognize the unique traditions and challenges associated with particular disciplines.[10] The ACS Presidential Commission, which comprised 22 leaders from the ACS, academia, industry, and government, published its findings in 2012 in a report titled *Advancing Graduate Education in the Chemical Sciences*.[15] However, efforts to facilitate implementation of the three-dozen recommendations of the 2012 ACS study have largely fallen on deaf ears. We have suggested[10] that the lack of

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traction is due in part to the fact that all stakeholders in the graduate-education-reform movement have generally not been consulted or engaged during or after the studies to learn if they agreed with the recommendations.

To advance the conversation, we recently asked the entire community of stakeholders of chemistry doctoral education, undergraduates who plan to go to graduate school, graduate students in various stages of their studies, recent graduates and postdoctoral fellows, faculty, administrators, and employers, to indicate their level of support for the conclusions and the accompanying recommendations of the ACS study.[16] To our knowledge, this is the first time the *entire* graduate-education enterprise has been engaged to probe the path forward to advancing graduate education in a particular discipline. In this publication, we share the results of the survey.

GIVING EVERYONE A VOICE

We initiated our national effort to involve the chemistry community regarding the 2012 ACS study by launching a website during the symposium "Advancing Graduate Education in the Sciences: Opportunities and Challenges" at the National ACS meeting in Washington, DC, on August 20, 2017.[16] The first "Call to Action" at the website was a request for all website visitors and chemical education stakeholders to complete a survey that invited them to participate in prioritizing the recommendations of the 2012 ACS study. The objectives of the survey were to

- Introduce http://chemistry.graduate.education as a vehicle for the dissemination of information (and collect contact information from those who were interested in contributing or using content at the site in the future).
- Help the community (and particularly the Chairs and Graduate Deans who influence policy) become familiar with the 32 recommendations of the report in an activity that took about 10 min to complete.
- Engage groups of stakeholders that were not included during the development of the report (especially students).
- Learn whether the stakeholders agree with the recommendations of the ACS Commission.
- Prioritize the recommendations for future action.

Subsequently, late in August of 2017, we contacted the Chairs of more than 200 chemistry departments (essentially all of the chemistry departments listed in the ACS Directory of Graduate Research),[17] inviting them to encourage their faculty and graduate students to participate in the survey. These letters were followed up at the beginning of September 2017 with a similar letter to the Graduate Deans of the same institutions, with a request that they complete the survey themselves. In October, we partnered with the ACS to "blast" specific e-mails to undergraduates, graduate students, recent graduates, and postdoctorals. We acknowledge that eliciting responses from chemistry students who left their graduate programs may have added valuable insight into our findings; however, because many of those who either have left or intend to leave exhibit a reticence to speak about their doctoral experiences,[18] we believe it is unlikely that this survey would have captured the voices of these former students. We also acknowledge it would have been useful to include employers as a stakeholder group. However, despite correspondence with the Society of Chemical Manufacturing (SOCMA), The American Chemistry Council (ACC), and the Alliance of Chemical Associations (ACA), we had no success in soliciting the assistance of professional organizations to recruit employers to complete the survey, and in the end, despite an extension of our original deadline to improve the number of respondents to the survey that self-identified as employers, only 11 surveys were competed by employers. Because of the low response, employers were not included as a stakeholder group in this report. With the exception of students who left Ph.D. programs and employers of Ph.D. chemists, the eventual stakeholder (Table 1) and geographic coverage[19] of the survey was representative (49 states and most of the HEIs that offer Ph.D. degrees in the chemical sciences), as evidenced by self-identification of the roles of the survey takers and by geocoding of the IP addresses, respectively.

Table 1. Distribution of Survey Respondents by Graduate-Education Role in Chemical Sciences

Demographic Role	Respondents, *N*
Undergraduate student who intends to go to graduate school	266
First-year graduate student	114
Graduate student in the middle of their studies	329
Graduate student who will soon complete their studies	124
Recent Ph.D. graduate	95
Faculty member or mentor	203
Individual who influences graduate-education policy	53
Employer of chemists with Ph.D. degrees	11
Other[a]	42

[a]Respondents who did not self-identify as members of one of the other stakeholder groups were allowed to select "other". The number selecting other is given here, but no attempt was made to include them in the analysis.

We have learned from previous efforts to include students in such surveys as an "at-risk" population, because it is critical that that their privacy be ensured. Accordingly, the survey was conducted anonymously using Qualtrics, although an option to voluntarily provide contact information for follow-up queries was provided. The survey began with a question to determine familiarity with the 2012 ACS study, and a link to the study was provided to allow participants to review the ACS study and related information. This was followed by a question to determine stakeholder-group affiliation (i.e., undergraduate student, first-year graduate student, midstudy graduate student, etc.; Table 1). We used a fine-grained approach to discern stakeholder-group affiliation in anticipation that notable differences in responses might emerge. We also captured gender and nationality demographics and, as described below, found areas in which these demographics provided critical insight into group-specific concerns. Additionally, we separated those who influence policy (e.g., department head and deans) from those who consider themselves "mentors" of graduate students (i.e., research directors), as the roles of these faculty and administrators in chemistry graduate education are markedly different (Table 1). We reached out to employers of Ph.D. chemists, but as noted earlier, our efforts resulted in few responses. We surmise that the low response rate in this stakeholder-group category was either because of a reluctance of individual companies to reveal recruiting practices or perhaps because the stakeholder group is unaccustomed to being included in the conversation about graduate-education reform (Table 1 and vide infra).

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The more than 1200 respondents to the survey revealed that some of the ACS-study recommendations are universally popular, such as teaching additional professional skills to graduate students, which was given a high priority by three-quarters of the respondents regardless of stakeholder-group affiliation (Figures 1 and S4). Others were less popular, such as adding a requirement for at least two research proposals as hurdles to graduation, a recommendation that became even more unpopular with students as they progressed in their studies (Figures 2 and S9). Of particular interest, however, are the controversial recommendations, as disagreement could foretell conflict and therefore barriers to reform. Notably, the recommendation to shorten the average time to Ph.D. degree from the current 6−7 years in chemistry to less than 5 years was strongly supported by students, recent graduates, and administrators, with more than half considering the issue a high priority. In contrast, two-thirds of the faculty disagreed with the recommendation or gave it a low priority (Figures 3 and S5).

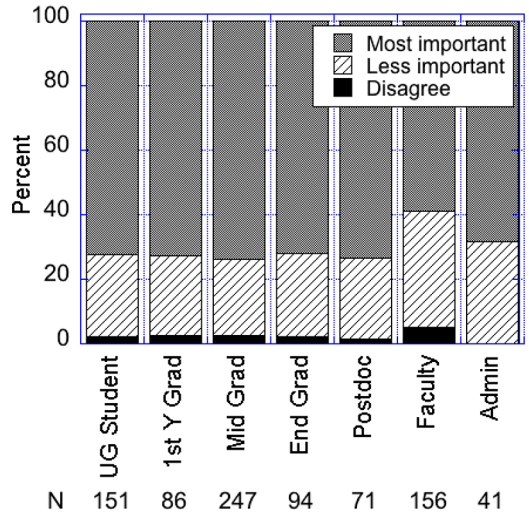

Figure 1. Stakeholder responses to the statement, "Additional professional skills should be incorporated into graduate curricula." Observation: all stakeholder groups agree that incorporating additional professional skills into graduate curricula should be a high priority (although faculty less-so).

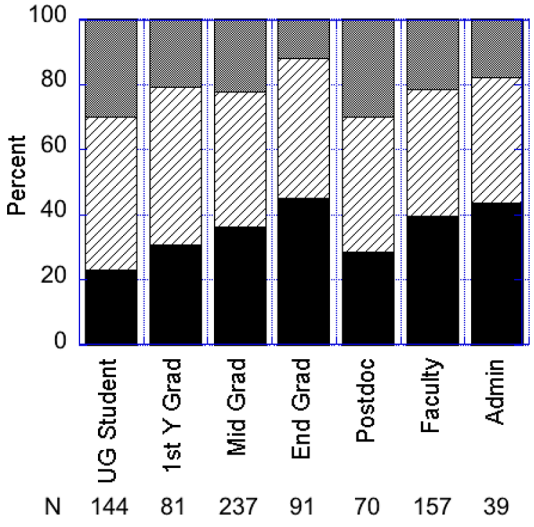

Figure 2. Stakeholder responses to the statement, "Require at least two original research proposals, at least one in the student's immediate field." Observation: there is significant opposition to requiring two (or more) original research proposals, especially from graduate students who are near the end of their studies.

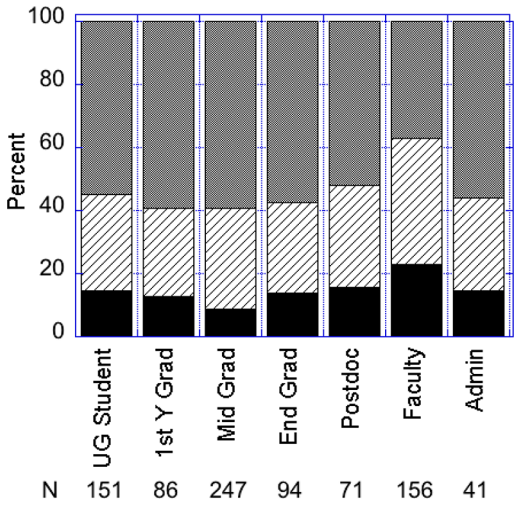

Figure 3. Stakeholder responses to the statement, "Current time to degree (TTD) of 6−7 years should be shortened to less than 5 years." Observation: except for the faculty, all stakeholder groups agree that shortening the TTD should be a high priority.

STAKEHOLDER-GROUP TRENDS

Regarding the overarching conclusions of the study, all stakeholder groups placed an emphasis on providing more educational opportunities and financial support for graduate students (relative to the other three overarching areas that are focused on safety, postdoctorals, and programs; Figure S1). However, the groups students and postdoctorals, faculty, and administrators frequently have very different views regarding the 32 specific recommendations (e.g., Figures S8, S15, S19, S26, and S28). In general, each stakeholder group tends to support the specific recommendations that are potentially beneficial to that stakeholder group, and group members oppose recommendations that would negatively or not significantly impact their stakeholder interests, especially if those recommendations involve investing scarce resources (e.g., Figures S1, S15, S17, S19, S22, and S28).[20] In addition to the seven stakeholder groups that are singled out in the figures, we note that some of the responses were influenced by strong differences of opinion between males and females on key issues.[21] For example, for graduate students who are U.S. residents, males were less likely to support the recommendation that an emphasis be placed on attracting and empowering students from underrepresented groups, with one-quarter of males disagreeing with the recommendation (Figure 4). This difference in perspective between gender groups is particularly salient, because many of these graduate students will later join the academy as faculty and eventually may serve as policy makers within and beyond the academy.[22−25] U.S. and non-U.S. residents also expressed different views on key issues (e.g., Figures S17 and S22). For example, non-U.S. residents were strongly opposed to the recommendation that U.S. graduate programs build their fraction of domestic students (and

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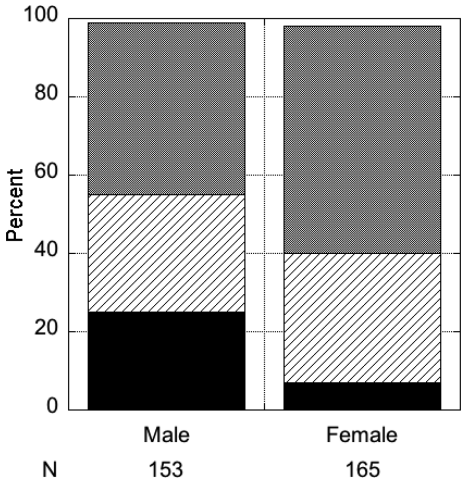

Figure 4. Differences between male and female graduate students who are U.S. residents. Responses to the statement, "Graduate programs should place an emphasis on attracting and empowering students from underrepresented groups." Observation: 44% of males and 58% of females believe the recommendation should be a high priority, whereas 25% and 7% disagree with the recommendation, respectively.

presumable reduce the fraction of international students, Figures 5 and S22).

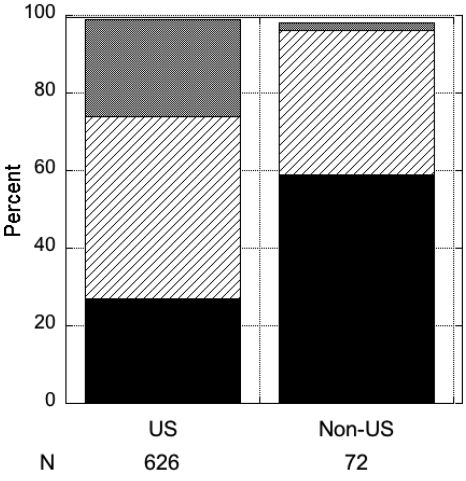

Figure 5. Differences between U.S. and non-U.S. residents. Responses to the statement, "Programs should build the domestic fraction of their graduate enrollments as a high priority." Observation: there is significant opposition to having departments build up their fraction of domestic graduate students; 27% of U.S. residents and 60% of non-U.S. residents disagree with this recommendation.

■ CONSENSUS HIGH-PRIORITY ISSUES

Most of the recommendations that are focused on the mentoring and training of graduate students were identified as high priorities by all stakeholder groups and include

- providing greater oversight over the progress and opportunities of individual graduate students (Figure S2),[26]
- active diagnosis and remediation of deficiencies in the preparation of first-year students[27−29] (especially strongly supported by first-year students and faculty, Figures 6 and S3),

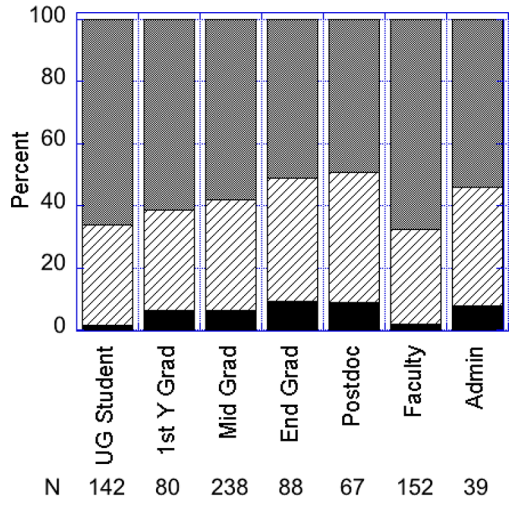

Figure 6. Stakeholder responses to the statement, "There should be more active diagnosing and remediating of deficiencies in the preparation of first-year students." Observation: all stakeholder groups agree that active diagnosing and remediation of deficiencies in the preparation of first-year students should be a high priority (especially first-year students and faculty).

- incorporation of additional professional skills into graduate curricula[30−41] (albeit less supported by faculty, Figures 1 and S4 and vide infra), and
- the use of Individual Development Plans (IDPs) in the graduate-student-mentoring process (particularly supported by administrators, Figure S7).[42]

Although some interest in including entrepreneurial skills in graduate curricula is evident, it is a low priority, especially among graduate students who are nearing the end of their studies, postdoctorals, and faculty (Figure S10). Significant opposition from all stakeholder groups was evident in regard to the recommendation of requiring two (or more) original research proposals, especially from graduate students who are near the end of their studies (Figures 2 and S9).

Most of the recommendations that are focused on the financial support[6,43] of students were also identified as high priorities by all of the stakeholder groups and include

- decoupling student support from specific research projects (Figure S13),
- making more fellowships available after the first year (Figure S16), and
- restructuring timetables and sources of student support (Figure S16).

Repurposing the Department of Education Graduate Assistantships in Areas of National Needs (GAANN) funding received little support, in that a majority of all of the stakeholder groups were either opposed to the recommendation or assigned it low priority (Figure S14). There was, however, strong support for using Graduate Teaching Assistantships (GTAs) more strategically for professional development among all stakeholder groups except faculty and some administrators (Figure S15 and vide infra). Further, the suggestion that international students should receive more financial support from their home countries (rather than the U.S.) had strong opposition by 30% of U.S. residents and 65% of non-U.S. residents, with a majority of all stakeholder groups opposing the recommendation or assigning it low priority (Figure S17).

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POTENTIALLY DIVISIVE ISSUES

Although many of the recommendations of the ACS study have broad support, differences in opinion exist among the stakeholder groups regarding some key recommendations. As we noted earlier, each stakeholder group appears to prioritize the recommendations through the lens of the group members' needs and values. Consequently, we argue that no stakeholder group should be singled out as obstructionists.[10] These different needs and values must eventually be recognized, respected, and addressed in any viable path forward (vide infra). Further, the fluidity of these needs and values that occurs as stakeholder groups change over time is important to acknowledge. This fluidity is most readily evidenced in the trends observed for graduate students. For example, the need to diagnose and remedy the deficiencies of first-year graduate students becomes less of a priority as graduate students approach graduation (Figures 6 and S3). The same trend is observed for graduate students regarding all of the recommendations that concern more training, including the recommendations that Ph.D. projects should include elements of collaboration (Figure S8), that at least two original research proposals be required (Figures 2 and S9), that there should be curricular options in entrepreneurship (Figure S10), and that courses should be developed to prepare students who intend to seek academic employment (Figure S11). On the other hand, as graduation nears, the recommendation that funding agencies should require a mentoring plan for postdoctorals (Figure S26) and the recommendation that funding agencies should re-explore programs for "teaching postdoctoral associates" become more popular with graduate students (Figure S27).

The faculty also signal their needs in evaluating their priorities. For example, the faculty rank diagnosing and remediating first-year graduate student deficiencies higher than any other stakeholder group, including the students themselves (Figures 6 and S3). On the other hand, efforts to provide graduate students with training outside research meets with less enthusiasm by the faculty (cf. Figures S4, S8, S10, and S11). Significantly, a majority of all of the stakeholder groups except the faculty place a high priority on reducing the time to degree (TTD), which is currently 6−7 years, to less than 5 (Figures 3 and S5). It is noteworthy that dozens of national studies over the past several decades have recommended the TTD for STEM Ph.D.s be reduced.[44] Although the survey does not speak to the specific rationale for the faculty position on TTD, the reluctance on the part of the faculty to reduce the TTD is likely related to expectations they have for graduate students relative to the rigor of training or research productivity. Another position that is uniquely held by faculty is with respect to the recommendation that graduate teaching assistantships (GTAs) should be used more strategically for professional development, which is again given the highest priority by every stakeholder group except the faculty (Figure S15).

Furthermore, the proposals that a move be made from a single-mentor (apprentice) model to supervisory committees (Figures 7 and S6) and that departments should adjust graduate program sizes to reflect attractive career opportunities for graduates (Figure S19) meet with the highest disapproval by the faculty. Interestingly, students who were about to graduate with Ph.D. degrees and postdoctorals were the strongest advocates for replacing single mentors with advisory committees (Figures 7 and S6). Perhaps this is not surprising,

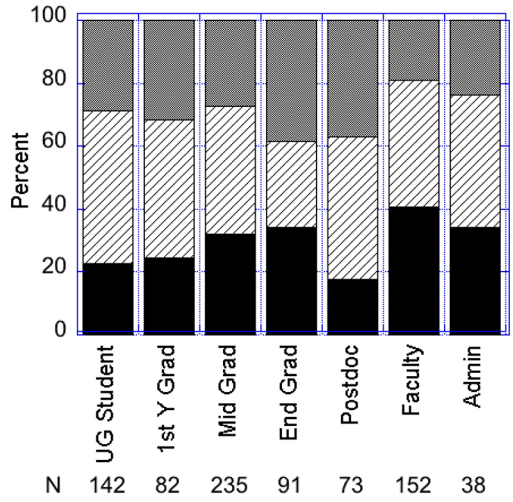

Figure 7. Stakeholder responses to the statement, "Move from single mentor to supervisory committees with more frequent advisory meetings." Observation: most either disagree with moving away from a single-mentor model or believe it should be a low priority.

as it is likely that these stakeholder groups have experienced first hand the limitations of the apprentice-mentorship model.[45] Faculty time is, simply put, a scarce resource that is becoming scarcer.[46] Ever-increasing expectations for scholarly productivity, including the procurement of external funding,[47,48] may leave faculty with little time for the close mentoring that the apprentice model implies.

Administrators and policy-makers also telegraph their pain by placing a higher priority than any other stakeholder group on issues that concern educational opportunities (Figure S1), student mentoring (Figures S7 and S26), institutional competitive advantage (Figure S20), and supporting under-represented groups (Figure S23). On the other hand, they are less enthusiastic relative to other stakeholder groups for recommendations that affect institutional organization, for example, collaboration across disciplines (Figure S8) and linking the size of Ph.D. programs to job availability (Figures 8 and S28).

PATH FORWARD

A common thread in our survey findings is that individuals view the recommendations of national studies on the future of graduate education from the perspective of their immediate needs. Although a first-year graduate student in chemistry might eventually become the dean of a graduate college, the student does not appreciate the pain felt by a graduate dean, and the administrator no longer views the world as a student does. Thus, current faculty and administrators view the needs of students through their experiences in school decades earlier, when the values and needs of students may have been markedly different than at present, and by the needs and pains of their current positions. Although the perspective of each stakeholder group may seem short-sighted, it is entirely natural, and it speaks to one reason that studies have failed to gain traction. Although the studies generally address needs holistically, they do not generally speak to the different needs of those who are impacted by the recommendations. Any plan for reform must meet the needs of everyone who is involved.

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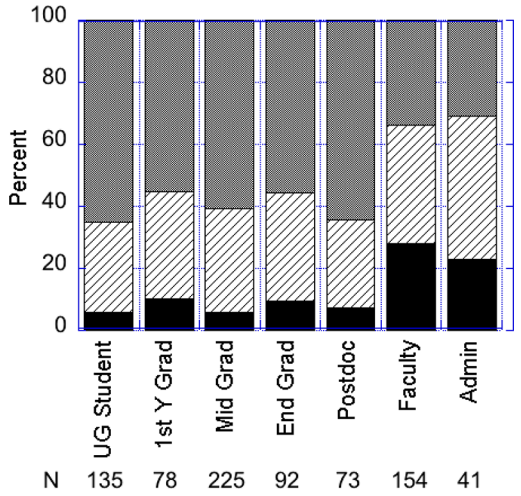

Figure 8. Stakeholder responses to the statement, "Departments should adjust graduate program sizes to reflect attractive career opportunities for graduates." Observation: there is strong support for departments to adjust graduate program sizes to reflect attractive career opportunities for graduates, especially among recent graduates, but less-so among administrators and faculty.

Thus, a natural next step forward in advancing graduate education in the chemical sciences is to explore the tensions that exist between different stakeholder groups that are affected by recommended changes. The survey described herein suggests tensions but does not identify the root causes of the friction. For example, why do the results of the survey suggest that students lose interest in training that would better prepare them for their careers as they progress through their studies, that faculty are not supportive of reducing the TTD, that administrators are opposed to scaling programs to improve the chances of employment of their graduates, and that employers are not engaged in the design of the training of their future employees? Because on their face the goals seem laudable, it is likely that resistance exists because of concerns that values would be compromised or needs not met if the recommendations were adopted. If we are to advance graduate education, it is those values and needs in the context of the recommended changes that must be explored next.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.8b00642.

Analysis and presentation of survey responses (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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