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Setting a Standard for Chemistry Education in the Next Generation: A Retrosynthetic Analysis

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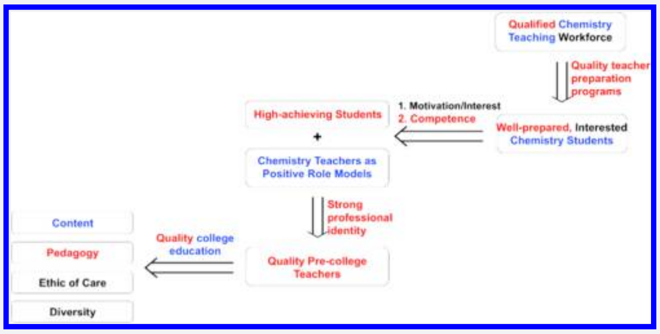
Supporting Information

ABSTRACT: A diverse and highly qualified chemistry teaching workforce is critical for preparing equally diverse, qualified STEM professionals. Here, we analyze National Center for Education Statistics (NCES) Schools and Staffing Survey (SASS) data to provide a demographic comparison of the U.S. secondary chemistry teaching population in high-needs and non-high-needs public schools as well as private schools during the 2011−2012 academic year. Our analysis reveals that the chemistry teaching workforce is predominantly white and significantly lacks in-field degrees or certification across school types, though high-needs and private schools are most affected by this lack of teacher qualification. Given these results, we attempt to retrosynthetically identify the pathway yielding a qualified chemistry teaching workforce to draw attention to the various steps in this scheme where reform efforts on the part of individual faculty, academic institutions, and organizations can be concentrated.



INTRODUCTION

> *Well-educated scientists and engineers drive the technology development that allows the United States to maintain its competitive edge in the global marketplace and improve the well-being of citizens worldwide. Chemistry ... is central to how people address pressing problems at local, national, and global levels. To prepare current and future students with the skills necessary to address rapidly evolving needed technology will require improvement to all levels of STEM (science, technology, engineering, and mathematics) education.*[1]

The contention that chemistry as an enterprise is central to our nation's historical position as an economic and political superpower, as summarized above, is certainly not a new one. More recently, however, the explicit connection between the United States' sustainable global leadership role and the success of the K−12 STEM education system has been made by the National Research Council.[2] In the landmark document from the National Academies, *Rising Above the Gathering Storm, Energizing and Employing America for a Brighter Economic Future*, the committee cited K−12 science and mathematics *teachers* as the critical factor for laying the foundation of a scientifically literate workforce. It is in the context of these national reform documents that we present this study of the U.S. public and private high school chemistry teaching workforce using the latest large-scale sample from the National Center for Education Statistics (NCES).

Nearly two decades have passed since the National Science Education Standards (NSES) and the Benchmarks for Science Literacy challenged our nation's precollege science teachers to shift their pedagogical focus toward fewer, more fundamental disciplinary concepts, explicit instruction on the nature of science, and inquiry-based learning.[3] In light of increasing global economic competition, advances in science and technology, and the latest research from cognitive/neuro-psychology and STEM education studies, the newest reform documents now call for K−12 teachers to simultaneously integrate disciplinary core ideas (DCIs) with science and engineering practices and crosscutting concepts.[4] If successful, as the new K−12 Frameworks argue, our nation's hope for a scientifically literate citizenry and its causal link to a sustainment of fiduciary and political dominance may be secured. Teachers, however, play a key role in whether this goal is achieved:

> *Ultimately, the interactions between teachers and students in individual classrooms are the determining factor in whether students learn science successfully. Thus, teachers are the linchpin in any effort to change K−12 science education.*[5]

As the above excerpt from the Framework articulates, however, it is what happens in the day-to-day events of the

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science classroom that will decide the fate of the extensive resources invested in the STEM education enterprise from both private and public sources. The content and pedagogical demands on the U.S. chemistry teacher are higher than ever,[5] and the success or failure to realize the ideals set out in the Framework depends directly on whether or not those expectations can be met by the current and future workforce. By considering the currently available data on chemistry teacher quality, this current study makes some claims about the readiness of the teaching workforce to deliver on the mandate to prepare students appropriately for college-level STEM coursework. As chemistry teachers are the products of the higher educational system that is tasked with the responsibility to ensure that a diverse student population leaves with a grasp of both the content and epistemological foundations of the discipline, the outcomes of this demographic analysis are relevant to both university chemistry faculty and teacher educators alike.

Previous studies have made compelling arguments regarding the observable impact of specific teacher characteristics on student achievement in STEM. Darling-Hammond reviewed state policy evidence correlating teacher quality to student achievement.[6] From her analysis, she concluded that factors such as degree in the field being taught, certification status, teaching experience, subject matter knowledge, and knowledge of teaching and learning have an influence on teacher quality and, in turn, impact student performance. Of these factors, teachers with full certification as well as in-field degrees have the strongest correlation with student achievement. Additionally, teacher−student race and gender congruity have been linked to increased student performance in STEM. Dee and coworkers reported that the effect of various teacher−student diversity pairings on student performance varied, but congruous pairings were most positively impactful for young women of color.[7]

Recently, we presented a longitudinal analysis of the U.S. public high school chemistry teaching workforce over the twenty-year period between 1987 and 2007.[8] Specifically, we analyzed six nationally representative surveys conducted by the National Center for Education Statistics (NCES) over the two decades between 1987 and 2007 to determine recent historical trends in the makeup of the precollege chemistry teaching workforce in U.S. public high schools. Among the findings of this work was an observed shift in the gender, age, and experience profiles of the American chemistry teacher toward (1) a higher percentage of females than males; (2) a more uniform (and less normal) age distribution; and (3) fewer years of classroom experience. Equally noteworthy was the lack of historical change relative to reported race and in-field tertiary degrees: chemistry was and still is primarily taught by white teachers without any reported chemistry degrees at the postsecondary level. Although disaggregated from teachers of other subjects or grade levels, this previous work did not attempt to characterize chemistry teacher demographics between public schools of differing socioeconomic status and private schools. Further, it did not include information from national survey data collected at the same time that the latest science standards were being released by the NRC. The NCES recently completed the data collection and compilation of the >10,000 schools and >50,000 teachers included in their 2011−2012 Schools and Staffing Survey (SASS), which provides the most up-to-date picture of the three million or so K−12 teachers in the country.[9,10] By analyzing the demographics of the U.S. secondary chemistry teaching population, data-driven decisions can be made regarding the likelihood that the expectations outlined in the NRC's Framework regarding chemistry education are realistic. This study seeks to compare U.S. chemistry teachers in public high-needs and non-high-needs schools to their colleagues in private schools during the 2011−2012 academic year and discusses implications for the chemistry education community regarding student interest and achievement, teacher professionalism, and the discourse between secondary and tertiary academic institutions.

As "high-needs" schools have been a major focus of federal and private educational funding and research efforts (in part to reduce achievement gaps in core academic subjects), we chose to disaggregate public school teachers by the type of school (i.e., high- or non-high-needs) in which they taught. As defined by the No Child Left Behind Act of 2001, high-needs schools fall "within the top quartile of elementary and secondary schools statewide, as ranked by the number of unfilled, available teacher positions; or [are] located in an area where at least 30 percent of students come from families with incomes below the poverty line; or an area with a high percentage of out-of-field-teachers, high teacher turnover rate, or a high percentage of teachers who are not certified or licensed."[11] Several studies have shown that high-needs schools often employ less capably prepared teachers than their more affluent peer institutions, and this is cited as a primary contributor to the observed achievement gap in this country.[12−14]

In order to provide a referential context for the present study, the research questions we investigated complemented those previously discussed with regard to the number, gender, race, age, experience, degree background, certification status, and teaching course workload of the U.S. chemistry teaching population. As the more recent NCES survey questionnaires include detailed information regarding educational background and certification, those data have been analyzed here as well. We also chose to describe the aggregate chemistry teaching workforce, composed of all secondary teachers with at least one chemistry course taught during the survey year, separately from "main assignment" teachers, who taught at least 50% of their classes in chemistry. It is to be noted that the study on main assignments was also attempted on the data collected from private schools teachers, yet, due to the small sample size, the error estimates were too large to be able to make accurate conclusions.

Specifically, the research questions guiding the analyses of high-needs public schools, non-high-needs public schools, and private schools were as follows:

1. To what extent are students in these different school settings taught chemistry and by how many teachers?
2. To what extent is chemistry taught as a main assignment by teachers in these three school settings, and, in cases where chemistry is not the main assignment, what is the main teaching assignment for chemistry teachers?
3. What are the reported degree backgrounds and certification statuses of chemistry teachers across the three educational contexts under consideration?
4. What are (a) the gender and racial profiles and (b) the experience distribution of chemistry teachers in these different schools?

■ RESULTS AND DISCUSSION

Chemistry Teacher/Student Distribution and Main Assignment. Estimates of chemistry teacher and student counts by school type are displayed in Figure 1. In the 2011−2012 academic year, more than three million students were enrolled in U.S. high school chemistry classes led by approximately 48,000 teachers. The number of teachers in high- and non-high-needs schools was equivalent (∼19,000 each), and about twice as many as those in private school settings (∼9500). Students, however, were not as evenly distributed: of the nearly 3 million enrolled in chemistry classes during 2011−2012, almost 50% (1,470,000) were in non-high-needs settings compared to 38% (1,180,000) in high-needs and 13% (410,000) in private schools. In analyzing the teacher−student ratios, we found that each private school chemistry teacher was responsible for about 42 chemistry students each year, while their public school counterparts taught 60 (high-needs) and 80 (non-high-needs) students. These teacher/student ratios are consistent with the teaching assignment distributions that are presented in Figures 2a and 2b. Figure 2a indicates that chemistry teachers in non-high-needs schools teach chemistry as a “main assignment” (i.e., >50% of their classes each day) nearly 70% of the time and more than those in public high-needs schools (58%) and private schools (52%).

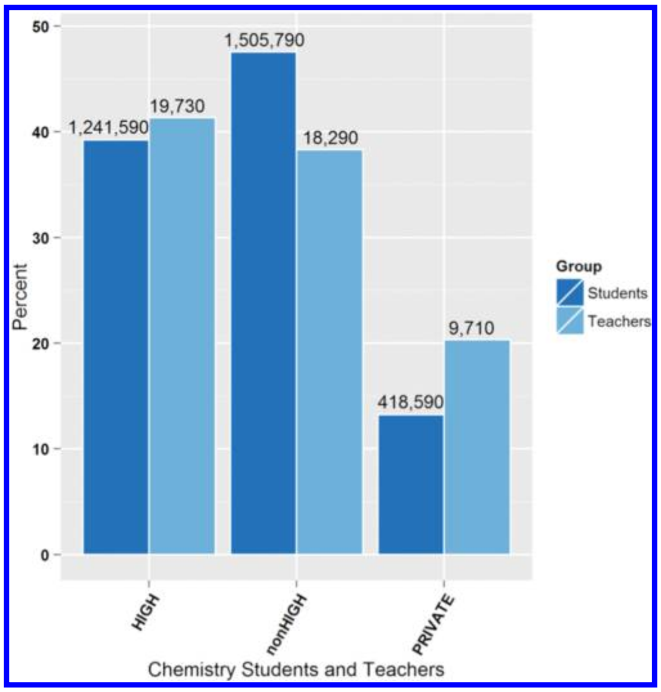


Figure 1. Distribution of 2011 chemistry teacher and chemistry student populations across high-needs, non-high-needs, and private schools. Teacher counts represent weighted counts obtained from the SASS teacher survey. Student counts are weighted counts based on chemistry class enrollment from the same 2011 SASS survey. The standard deviation for teacher counts is ≤2,082 for public and private. The standard deviation for student counts among high-needs and non-high-needs public schools is ≤226,938 and 79,462 for private schools.

For both types of public schools (but not for private schools), chemistry was predominantly taught as a main assignment over all other STEM or non-STEM subjects combined. When chemistry was not reported as the main assignment, nearly all teachers reported their main assignment to be another STEM subject, rather than one in a non-STEM content area (Figure 2b). Within all three school settings, a biological science was the most common main assignment reported outside of chemistry, ranging from about 25% (in high-needs schools) to more than 50% in private schools. In non-high-needs public schools and in private schools, biology was taught as a main assignment considerably more than any other subject, whereas in high-needs public schools, two others (general science and physical science) were also taught to a substantial extent. Taken together, the data from Figures 1, 2a, and 2b indicate that public schools are responsible for teaching 85−90% of America’s chemistry students, and students are taught by 80% of the chemistry teachers who primarily teach chemistry for the majority of their school day. Private schools teach the remaining 10−15% of the chemistry students by 20% of the chemistry teachers who likely teach chemistry or a biological science as their primary assignment.

Disciplinary Background. The reported earned post-secondary degrees by U.S. chemistry teachers during the 2011−2012 school year are shown in Figure 3. For teachers who taught at least one chemistry class, a chemistry degree (i.e., at the undergraduate or graduate level or both) was earned by 35%, 33%, and 30% of those in non-high-needs, high-needs, and private schools, respectively. These values are consistent with the past two decades of SASS data reported previously which also indicated that only about one in three chemistry teachers report earning an in-field degree at any level.[8] Outside of chemistry, biology degrees were most common, ranging from 30 to 33% in the different school types, followed by secondary or science education, which accounted for another 5−10%. Notably, general elementary grades education was a degree reported by up to 5% of the high-needs school and private school teachers (but not in non-high-needs schools).

Public non-high-needs and private school teachers differed from high-needs schools in several ways with regard to earned degrees. First, chemistry represented a significantly greater proportion of the degrees earned in private and non-high-needs settings, whereas biology degrees were still almost as prevalent as chemistry within high-needs environments. Second, teachers in high-needs schools appear to come from more academically diverse backgrounds as they reported twenty-one different disciplinary backgrounds compared to 16 (non-high-needs) and 14 (private).

Certification Status. The certification status for all chemistry teachers during the 2011−2012 school year is shown in Figure 4. For teachers reporting a “regular” certification (i.e., on continuing contracts), the data was further disaggregated as being in-field (chemistry) or out-of-field (i.e., certified, but not to teach chemistry). Public schools, regardless of socioeconomic status, employed regularly certified teachers approximately 90% of the time and <5% of teachers were uncertified, a finding consistent with data from the previous two decades.[8] In contrast, approximately two-thirds of private school chemistry teachers (63%) reported having no certification of any type. For regularly certified teachers in each school setting, however, only about half of the certified teachers reported being certified to teach chemistry, so the proportion of the U.S. chemistry teaching population with a regular, in-field certification is much lower than might otherwise be assumed by looking at teaching status alone. Non-high-needs schools employed the highest proportion of in-field teachers at 55%, followed by high-needs and private schools, at 47% and 17%, respectively.

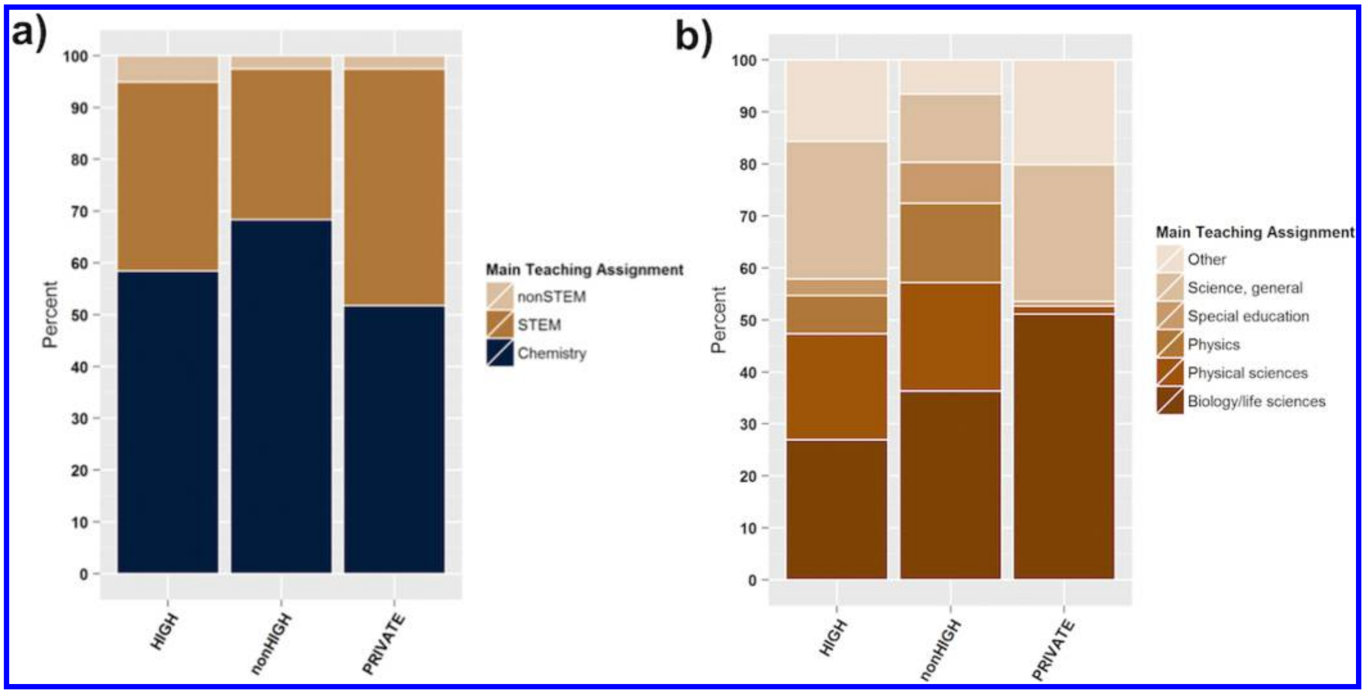


Figure 2. (a) Distribution of main teaching assignment among all chemistry teachers broken into non-STEM, STEM, and chemistry categories. "All" chemistry teachers are defined as any teacher that teaches at least one chemistry class. Each chemistry teacher was asked his or her main teaching assignment. Those responses were then categorized into chemistry, STEM (nonchemistry), and non-STEM (n = 781, standard error: public ≤5.69%, private ≤8.33%). (b) Main teaching assignment among all chemistry teachers whose main assignment is not chemistry. This distribution represents the main assignment response of all teachers that teach at least one chemistry class yet do not consider chemistry their main assignment (n = 327, standard error: public ≤8.92%, private ≤10.67%). Main assignments registering a response of 5% or greater among any of the high-needs, non-high-needs, or private school categories were included. All other responses were aggregated and categorized as "other".

The proportion of all chemistry teachers by school settings that reported entering the profession through an alternative certification program (rather than traditional routes) was also determined. In an effort to address the shortage of and need for highly qualified teachers, many states have authorized alternative routes to obtaining certification.[15,16] These programs are often much shorter than traditional certification pathways and can appoint alternatively certified teachers to full-time positions following incomplete preparation.[17] Since the vast majority of private school teachers reported not having earned a certification of any kind, we have chosen only to discuss teachers in the public schools. Approximately one-third of high-needs public school chemistry teachers reported entering teaching outside of a traditional university preparation program, compared to about one-quarter of non-high-needs teachers.

Race and Gender. While the proportion of undergraduate degrees in chemistry has been relatively balanced between the genders (48% bachelor's degrees in chemistry awarded to females in 2012),[18] the disparity in educational achievement in chemistry at the undergraduate level between minority and white students is alarming. The NSF reports that, in 2012, the percentages of bachelor's degrees in chemistry earned by white, black, Asian/Pacific Islander, and Hispanic students were 59%, 7%, 14%, and 8%, respectively, while these groups made up 77%, 13%, 6%, and 16%, of the total population, respectively.[18] Asian students, in particular, are pursuing chemistry degrees at higher rates, however black and Hispanic students are still significantly underrepresented in the field. Professional organizations within the chemistry community have recognized the spillover effect that this lack of diversity at the undergraduate level has had on the chemistry workforce. The American Chemical Society (ACS) and its Committee on Minority Affairs in particular have cited the critical need to increase the number and participation of underrepresented minorities in the field.[19] The distribution of race across school type that emerges from our analysis speaks to the ongoing importance of such initiatives (Figure 5a). Non-high-needs public schools and the private schools employed a chemistry teaching workforce that was more than 90% white in 2011−2012 and less than 5% black. High-needs schools were more diverse, reporting an average of 74% white, 19% black, and 6% other. The data for the non-high-needs public and private schools are consistent with what was seen previously between 1987 and 2007, with chemistry teaching being a white, male-dominated profession and less diverse than other STEM or non-STEM teaching at the secondary level.[8] In high-needs schools, chemistry teachers are more racially diverse, but not nearly to the same extent as the underlying student populations; in 2011−2012, 60% of students and 6% of chemistry teachers in high-needs schools were black while 21% of students and 75% of teachers in high-needs schools were white.[20,21]

Gender distributions for all chemistry teachers are shown in Figure 5b with the ratio being almost identical (at the alpha = 0.05 level) across school types, with ~40−45% male and ~55−60% female. Over the past two decades prior to the 2011−2012 school year, U.S. public high school chemistry teaching shifted from a male- to a female-dominated profession, but has shown stability around the 55:45 female-to-male ratio for the past two survey years (i.e., 2007 and 2011).[8] It is promising to observe the perceived gender equality between males and females in the profession, which may validate the efforts to address this disparity over the past few decades

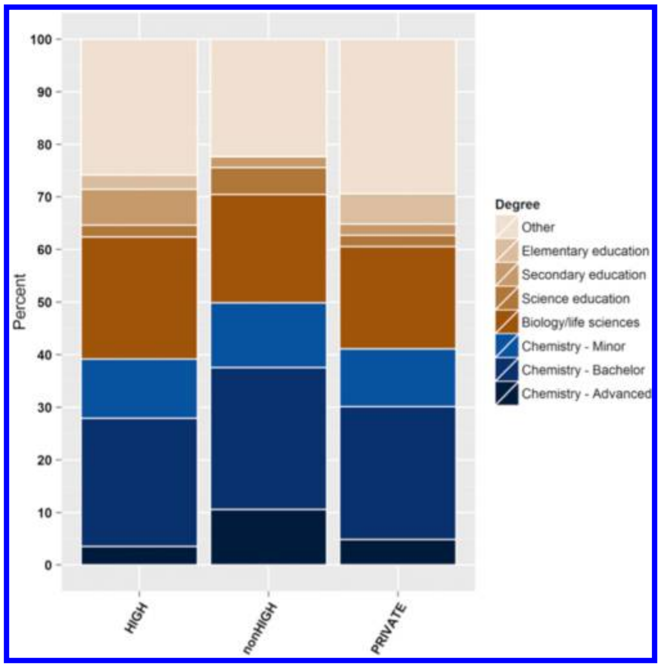


Figure 3. Distribution of degrees among all chemistry teachers reporting a chemistry "minor" over any other degree ($n = 781$, standard error: public $\leq 4.51\%$, private $\leq 8.58\%$). This distribution represents the prevalence of degrees among all chemistry teachers. However, in this instance, any respondent with a minor or associate's degree in chemistry is represented in the "minor" category even if they possess a more advanced degree in another subject. For example, a chemistry teacher with a doctorate in biology, but a minor in chemistry, would be represented in the "minor" category as opposed to "biology". This breakdown offers insight into the full picture of chemistry knowledge among all chemistry teachers.

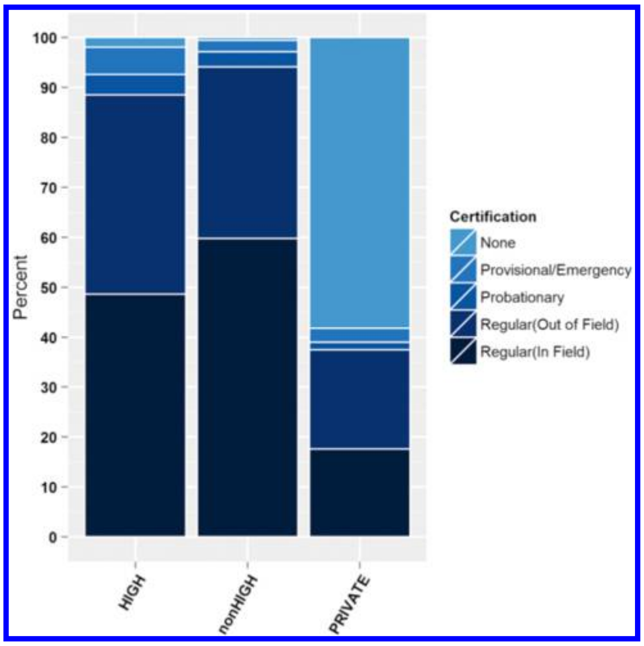


Figure 4. Reported certification type of all chemistry teachers. For teachers reporting a "regular" certification (i.e., on continuing contracts), the data was further disaggregated as being in-field (chemistry) or out-of-field (i.e., certified, but not to teach chemistry).

Experience. The experience distribution of chemistry teachers across the three school types is shown in Figure 6. All three settings have teachers with similar experience modality (approximately five years) but differ with regard to the relative proportion of features in the tails. High-needs schools employed a greater proportion of teachers with less than ten years of experience than the other school types but about the same proportion with more than 20 years as non-high-needs public schools. Public non-high-needs schools show a second relative maximum around 12 years experience, indicating a larger proportion of teachers with between ten and 15 years experience than the other two school types. Private schools had a similar experience distribution as high-needs public schools for early career teachers but a higher proportion with more than 25 years experience than either of the other school types.

Toward a Definition of "High Quality" Chemistry Teacher. If significant progress in the direction of chemistry education reform is to take place, there must be a contingent of teachers able to lead this effort.[22] In light of the existing literature on teacher quality described in the Introduction regarding its link to student performance in STEM,[6,7] we propose that a starting point for a discussion about developing a pool of chemistry teacher leaders would be to identify those in the population with characteristics consistent with those associated with improved student achievement. The three "quality markers" that were chosen for this analysis were (a) in-field (i.e., chemistry) certification; (b) at least a bachelor's degree in the content area; and (c) five or more years teaching experience. Figure 7 shows the relative proportions of U.S. public and private school chemistry teachers reporting zero, one, two, and three quality markers. Certification for private school teachers is often not a requirement, and we have excluded these teachers from the analysis to avoid misrepresentation in our comparison. The data demonstrate a clear disparity in quality markers between teachers in these settings; non-high-needs schools contain a significantly larger percentage of higher-quality teachers (approximately 70% with any combination of two or all three quality makers) than their high-needs counterparts (approximately 50%).

Our results indicate that chemistry is being taught by predominantly white teachers without in-field degrees or certification across school types, though high-needs and private schools are most affected by the lack of teacher qualification. At the same time, national reform efforts are demanding more from teachers than ever before in classrooms with increasingly diverse student populations, which speaks to the need for a similarly diverse, highly qualified teaching workforce.[2,5,24] The potential pool of teacher leaders (i.e., highly qualified teachers with ample experience) to offer innovative practices and mentor their colleagues is quite limited in our non-high-needs schools and even more so in our high-needs ones. Diversity in teacher race, likely critical for the recruitment of a diverse chemistry workforce,[7] significantly trails behind the student population in all school settings studied.

Given the current condition of the chemistry teaching community, a retrosynthetic analysis is proposed for designing a system that prepares a highly qualified workforce. By identifying this pathway, we draw attention to various steps in this scheme where reform efforts on the part of individual faculty, academic institutions, and organizations can be concentrated. The areas requiring specific attention (i.e., improving qualifications and diversity of the chemistry teaching workforce) are largely derived from the presented data, while these recommendations themselves are not.

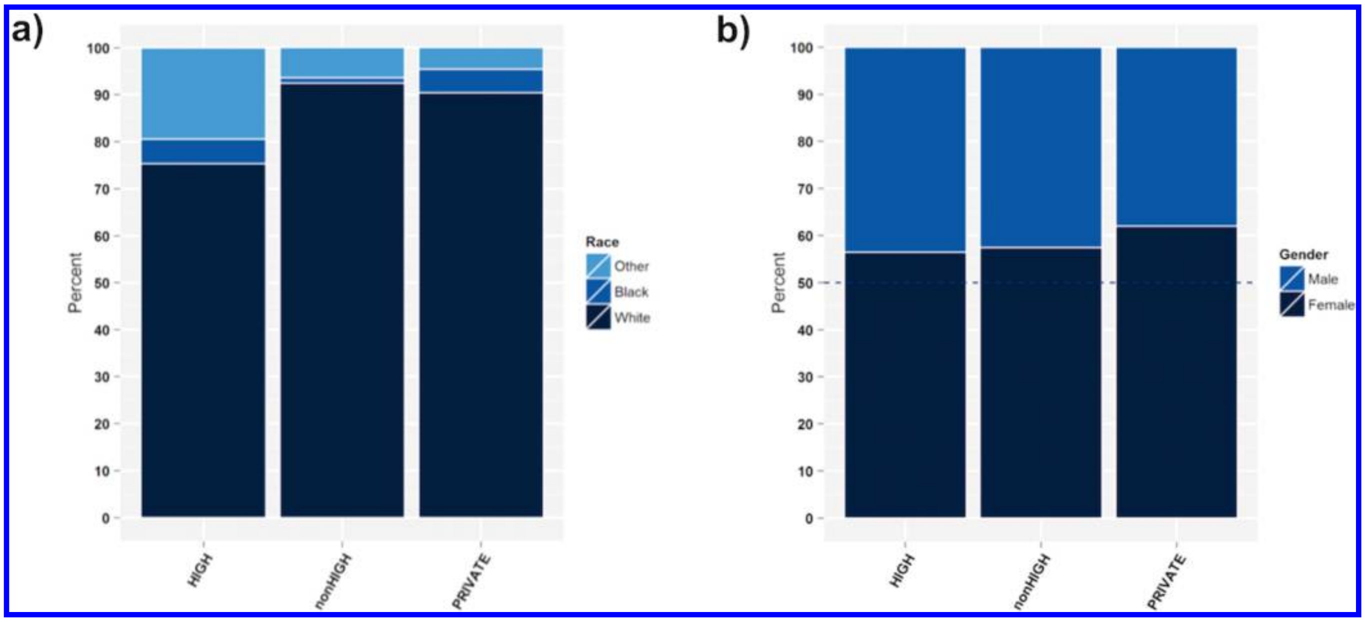


Figure 5. (a) Distribution of race among all chemistry teachers (n = 781, standard error: public ≤5.15%, private ≤4.84%). (b) Distribution of gender among all chemistry teachers (n = 781, standard error: public ≤5.33%, private ≤8.13%).

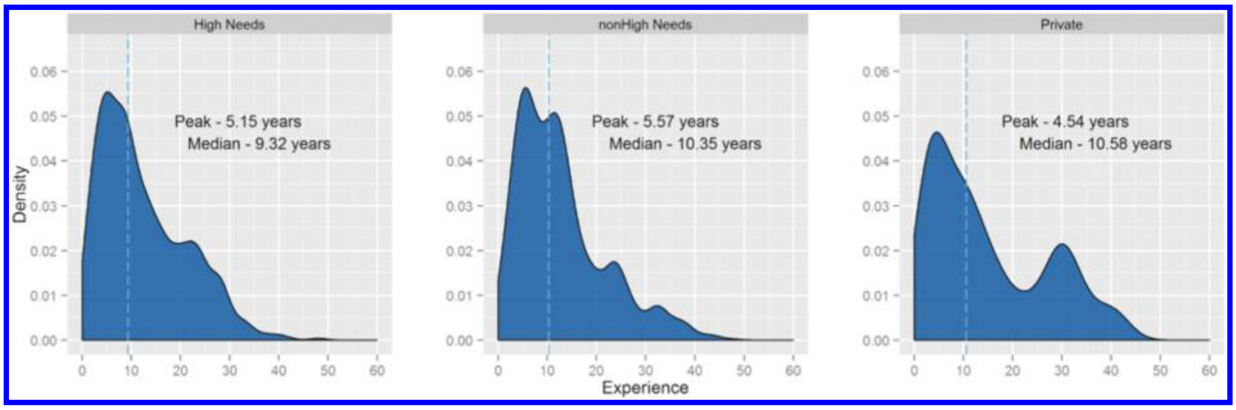


Figure 6. Kernel density plots of experience of all chemistry teachers for high-needs and non-high-needs public schools and private schools (n = 781). The variable for experience was also categorized into five year intervals (i.e., 0−5, 6−10, etc.). When doing so, the standard error for experience was ≤5.30% for public and ≤8.37% for private school teachers. The vertical lines represent median experience. Density peaks are also noted.

Without a strong background in the subject matter, many chemistry teachers may begin their careers without the confidence or self-efficacy to enact innovative, progressive lessons that are envisioned by the NRC Framework.[25] Further, without a well-formed identity as a chemistry teacher, professional growth in either the content or pedagogy will be slowed as teachers will be less likely to pursue opportunities that will challenge (and perhaps weaken) this fragile sense of self.[26] Teachers without in-field certification or with certifications from alternative routes to the profession often lack the coursework to prepare them to teach chemistry, likely resulting in an underdeveloped pedagogical content knowledge (PCK).[25] This PCK, conceived as the content knowledge needed for teaching, can develop more slowly without adequate teacher preparation, further delaying the realization of quality instruction in the classroom. Students in classes without strong STEM role models are less likely to identify with or take interest in the subject matter and pursue future courses in that discipline.[27]

Although the complexity of the U.S. K−12 educational system provides a challenging environment for accomplishing significant and lasting improvements, the professional chemistry community holds the key to solving many of the teacher quality issues observed and discussed above. While changing certification requirements and requiring more rigorous preparation for chemistry teachers are not within the direct purview of university chemistry faculty or the American Chemical Society (ACS), other policy decisions do fall within their grasp. Almost all chemistry teachers will take some college-level chemistry courses, even if their degrees will be earned in another field (e.g., biology). In the absence of formal chemistry teacher preparation, the default mode of instruction will be the imitation of the instructional practices that were modeled to them by the perceived "experts", namely, their college professors.[28] If the standard of teaching and learning experienced by these educators as college chemistry students themselves featured active learning approaches, inquiry laboratories, scientific argumentation, particulate-level representations, an emphasis on disciplinary core ideas, and conceptual understanding, then they will be more likely to incorporate these strategies into their own classrooms. In contrast, if they remember passively taking notes from a

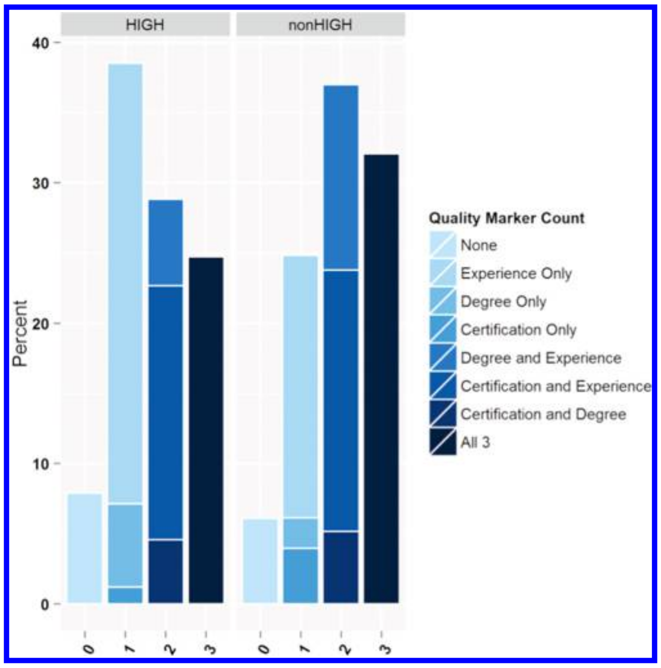
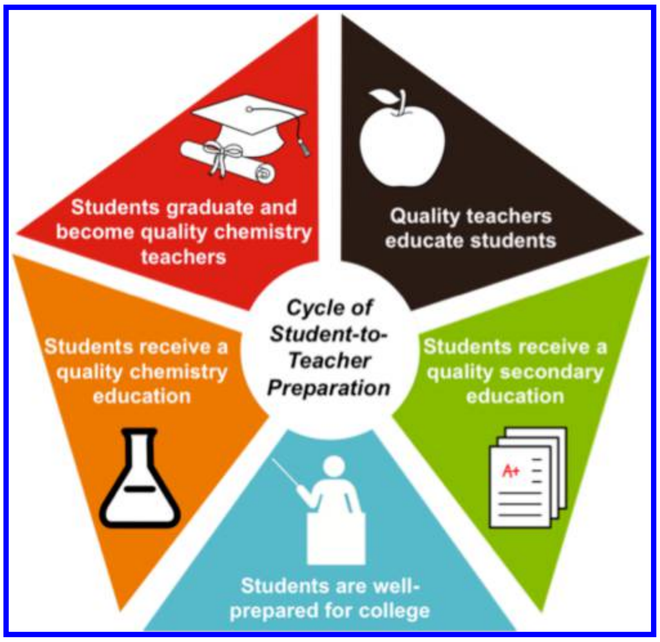


Figure 7. Quality marker counts among all public school chemistry teachers. The quality markers include (i) five or more years of experience, (ii) an in-field (chemistry) certification, and (iii) a chemistry degree (minor or above). This distribution represents chemistry teachers who meet only 1 of these qualifications, 2 of these qualifications, or all 3 (n = 686, standard error ≤5.05%). For each count (0−3) the breakdown within that count is given to further illustrate the qualification differences between chemistry teachers in high-needs and non-high-needs schools. Private school teachers were excluded from this analysis. Certification is often required for public school teachers, but often not required for private school teachers.[23] Therefore, it was determined that it would be unreasonable to compare private school teachers to public on this basis; doing so may misrepresent the quality of private school teachers. As such they were excluded.

Scheme 1. Cycle of Student-to-Teacher Preparation



whiteboard or slides presented by a professor engaged in monologue, those impressions will likely dictate how they enact instruction in their own "lecture halls". The more courses where they can observe and experience content presented in ways that they will be expected to communicate to younger students, the more likely that the U.S. high school chemistry classroom will reflect the practices advocated by the NRC and others. Facilitating this change will require college faculty to recognize the link between their own instructional choices and the effect they have on the preparedness of the future educators that they teach (Scheme 1).

Once in the classroom, chemistry teachers will need regular, ongoing support to accommodate the challenges that face them in the form of increasing cultural and linguistic student diversity; heterogeneity in science backgrounds and skills; and integrating chemistry with literacy, technology, and social responsibility. The scarcity of experienced, diverse, well-prepared colleagues (Figure 7) raises the need for intentional leadership development in all settings, but especially in the high-needs environments (Figures 3 and 5). Large-scale, online professional development (PD) communities may present an ongoing, cost-effective means of offering this type of support to teachers and may serve to connect teachers (especially those teaching in isolation or in high-need districts) with other members of the profession.[29] In these settings, individuals with expertise can offer guidance and support to those in need as part of a larger community, where a variation in members' skills are appreciated in a way that they may not be at the school or district level. Online PD platforms may even improve teacher persistence where it has been historically low by providing a sustainable, easily accessible means of connecting at-risk individuals with the broader, discipline specific community. Additionally, professional chemistry societies, such as ACS, and industrial partners can develop programs to identify and groom potential teacher leaders who contribute innovative practices and empower their communities to do the same. Leveraging the social capital of leaders in an organizational network like the chemistry teaching community can provide a safe, stable environment where needed professional growth can happen.

The lack of underrepresented minority (URM) representation in the chemistry teaching workforce likely requires a concerted effort on several fronts to overcome.[30,31] STEM teacher recruitment initiatives often aim to improve teacher quality for students in high-poverty districts by supporting high-achieving STEM majors as they pursue teaching careers in high-needs areas. However, it is likely that a high-achieving chemistry major from a background of perceived privilege, however knowledgeable in the content, may not be able to effectively teach in a high-needs setting because they lack the culturally relevant pedagogy needed to do so.[32,33] We, therefore, recommend that these initiatives make an intentional effort to recruit students from the same high-needs communities they aim to serve. While minority-serving institutions are integral in this process, they are likely too small in size and number to overcome these trends alone. Local academic or industrial institutions could invest in summer camps or research internships focused on engaging URM students in the field to more significantly combat the lack of diversity among chemistry majors and the teaching workforce.[34]

In summary, the chemistry teaching workforce, at present, falls short of being highly qualified across all school types. While chemistry teachers in our nation's high-needs schools are the most underprepared and inexperienced, considerable reform efforts are needed on the part of individuals, institutions, and organizations within the community to address the lack of teacher quality across the board. The disparity in the racial distribution between chemistry teacher and student populations may be a reflection of the significant difference in teacher preparedness between high-needs (where the underlying student population is more diverse) and non-high-needs schools,[12,14,20,35] and reflects a need to improve STEM diversity initiatives at both the student and teacher levels. Our retrosynthetic analysis of producing a qualified chemistry teaching workforce offers insights into several aspects of the synthetic scheme where diversity and education reform initiatives could be directed to better prepare our nation's students for increasingly critical careers in STEM.

Improving the condition of the workforce requires a concerted effort on the part of institutions of higher education and their individual faculty members, professional chemistry societies, chemical industry, and STEM recruitment initiatives. Future research investigations should focus on determining how chemistry teacher demographics vary across both geographies and districts and the extent to which existing reform efforts have been successful to better guide future policy, reform, and research initiatives in this area. Studies aimed at developing ongoing, sustainable, and cost-effective PD efforts will likely be critical for improving teacher persistence and ultimately student achievement, particularly in high-needs and low socioeconomic status districts. Overall, we hope that the members of the larger chemistry community will realize their unique and essential roles in this important process.

■ METHODS

The primary source of data included in this analysis is the 2011−2012 release of the Schools and Staffing Survey (SASS) administered since 1987 by the National Center for Education Statistics (NCES). The survey system is the largest, most extensive survey of K−12 school districts, schools, teachers, and administrators in the United States today.[36] The SASS survey system is designed to provide detailed descriptive information about a wide range of topics directly related to the school such as teacher demand, teacher and principal characteristics, and information about the school environment, as well as additional information about the school system. The analysis leveraged survey responses from the 2011 Public and Private School Teacher surveys. The teachers are randomly selected from the schools included in the survey system. The system of surveys utilizes a complex sampling design which requires weighting to account for the probability of selection, to reduce bias, and to improve the precision of the sample estimates. The complex survey design and sample weights must also be incorporated into the analytical methods. The analysis compares the demographics of the population of high school teachers that are responsible for chemistry courses across three different settings: high-needs public schools, non-high-needs public schools, and private schools. The sample estimates reported incorporate the sample weights provided by the survey. The typical estimates of the standard error taught in most elementary statistics courses assume a simple random sample, but this estimate will typically underestimate the standard errors. The reported standard errors are calculated using the Balanced Repeated Replication (BRR) for variance estimation, which requires a series of replicates to be provided for each survey response. The replicate weights are provided by the SASS survey system. The p-values reported leverage the Rao−Scott chi-squared test[37−39] that is similar to Pearson's chi-squared test for independence. The null hypothesis, in general, is no association between the variables and is evaluated by comparing the observed to the expected frequencies assuming that the null is true through a modified version of Pearson's chi-squared test. The test statistic can be divided by the degrees of freedom to produce a test statistic with an F distribution, which is a better approximation of the underlying population.

It is important to note that the analysis is exploratory in nature intended to examine differences between the populations that teach at the various school types. The specific comparisons were not planned before conducting the analysis but were done as part of the study exploring potentially interesting features of the population. With that in mind, there is no control on the familywise error rate to account for the repeated hypothesis testing. The reported p-values are the results as available from SAS version 9.3 using the procedure SurveyFreq.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acscentsci.6b00216.

Statistical variables for analyzed demographics and detailed methodology for presented data (PDF)

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Notes

The authors declare no competing financial interest.

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