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Labor and skills gap analysis of the biomedical research workforce

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ABSTRACT: The United States has experienced an unsustainable increase of the biomedical research workforce over the past 3 decades. This expansion has led to a myriad of consequences, including an imbalance in the number of researchers and available tenure-track faculty positions, extended postdoctoral training periods, increasing age of investigators at first U.S. National Institutes of Health R01 grant, and exodus of talented individuals seeking careers beyond traditional academe. Without accurate data on the biomedical research labor market, challenges will remain in resolving these problems and in advising trainees of viable career options and the skills necessary to be productive in their careers. We analyzed workforce trends, integrating both traditional labor market information and real-time job data. We generated a profile of the current biomedical research workforce, performed labor gap analyses of occupations in the workforce at regional and national levels, and assessed skill transferability between core and complementary occupations. We conclude that although supply into the workforce and the number of job postings for occupations within that workforce have grown over the past decade, supply continues to outstrip demand. Moreover, we identify practical skill sets from real-time job postings to optimally equip trainees for an array of careers to effectively meet future workforce demand.—Mason, J. L., Johnston, E., Berndt, S., Segal, K., Lei, M., Wiest, J. S. Labor and skills gap analysis of the biomedical research workforce. FASEB J. 30, 000–000 (2016). www.fasebj.org

KEY WORDS: training · education · occupation · graduate students · postdoctoral fellows

The U.S. biomedical research ecosystem has been described as one in structural disequilibrium and is the latest example of an enterprise subjected to an alarm, boom, bust cycle after the 1998–2003 doubling and subsequent flattening of the U. S. National Institutes of Health (NIH) budget (1, 2). Although the current constrained fiscal climate has contributed to the instability of our biomedical research infrastructure, current workforce challenges are also a product of unsustainable expansion, decades long in the making. The United States has seen a doubling in the number of students receiving doctorates in basic biomedical sciences since the 1970s, and a commensurate rise in the number of postdoctoral fellows in these fields, many of whom remain in protracted postdoctoral training periods (3). In recent years, the percentage of biologic and life science postdoctoral fellows aged 35–44 yr has grown, whereas the proportion of fellows under the age of 35 has dropped (4). In addition, the average age of first-time Ph.D. principal investigators on NIH R01-equivalent grants has steadily risen and stabilized at 42 yr of age (5), whereas the percentage of available tenure or tenure-track faculty positions in academia has steadily declined (3).

A series of recommendations to reconfigure the strained system have been suggested, which include adjustments in research funding mechanisms, changes to peer review, and workforce reform (3, 6–8). Restructuring the workforce may include offering dedicated research specialist awards to stably support staff scientists and rethinking graduate education and postdoctoral training to broaden career paths for emerging scientists. One step toward diversifying career opportunities is identifying biomedical research career outcomes. Postdoctoral fellows and trainees lack knowledge of the existence of many careers outside academia requiring scientific training, and they lack information on the types of jobs for which they may be qualified (9). Only recently have substantial national-level efforts been made to further enhance the collection of scientific workforce outcomes data (10, 11). Thus, data on the job market and the skills, experiences, and attributes essential for careers inside and outside of traditional academe are needed for informed career decision making (12).

ABBREVIATIONS: BEST, Broadening Experiences in Scientific Training; BLS, Bureau of Labor Statistics; CIP, classification of instructional programs; DoL, Department of Labor; EMSI, Economic Modeling Systems, Inc.; LMI, labor market information; MSA, metropolitan statistical area; NCES, National Center for Education Statistics; NSF, National Science Foundation; SOC, standard occupational classification

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The NIH has begun addressing concerns within the research infrastructure. NIH has implemented the Broadening Experiences in Scientific Training (BEST) program in response to the need to prepare graduate students and postdoctoral fellows for a breadth of careers in the biomedical research enterprise. This program enables institutions to build the infrastructure, curriculum, internships, and training opportunities to expose trainees to a myriad of career options in research and associated career tracks, while emphasizing workforce sustainability through evaluation of outcomes (13). Although the BEST program is achieving success in addressing gaps in the training experience for careers beyond the bench, additional information is needed to understand supply and demand in the workforce. As such, in 2013 the NIH National Cancer Institute (NCI) explored the feasibility of performing a labor gap analysis of the cancer research workforce, relying on stakeholder interviews and quantitative analysis of personnel and grant tracking data on NCI's extramural and intramural workforce. Building on that feasibility study, we used a regional approach and coupled traditional labor market information (LMI) with real-time job posting data to explore the extent of the perceived labor gap in the biomedical research workforce. We further extended our findings to the national level and identified skill sets sought by employers for a host of career opportunities.

MATERIALS AND METHODS

All U.S. workers are classified into ~840 occupations based on standard occupational classification (SOC) codes. These codes are used by Federal statistical reporting agencies to categorize, collect, and disseminate data on the workforce. Occupations deemed relevant to the biomedical research workforce were researched and identified by SOC code (14, 15) and further refined by analysis of job title, task descriptions, educational requirements, and experience by using the Occupational Information Network from the U. S. Department of Labor's (DoL's) Employment and Training Administration.

Metropolitan statistical areas (MSAs) are delineated by the Office of Management and Budget for use by Federal agencies, and there are >380 such areas in the United States. They typically consist of an urban core and adjacent cities and counties that are socially and economically integrated. We selected 10 MSAs (listed in Results) as geographic hot spots in the biomedical research workforce based on a confluence of factors, including total NCI and NIH funding and location of NCI-designated cancer centers (16), business research and development expenditures (17), work locations of the Federal Executive Branch (18), and venture capital funding and life sciences patents (19).

Demographic data and traditional LMI were obtained from Economic Modeling Systems, Inc. (EMSI; Moscow, ID, USA), a proprietary data clearinghouse that repackages traditional LMI from more than 90 Federal, state, and private sources. Market supply data for calendar year 2014, including educational program completions, were also from EMSI.

The U.S. Department of Education's National Center for Education Statistics (NCES) established a taxonomic scheme, the Classification of Instructional Programs (CIP), to support tracking and reporting of educational fields of study and program completions. NCES and the Bureau of Labor Statistics (BLS) developed a crosswalk between CIP and SOC codes to map educational program data to occupational data and the labor market. This crosswalk uses BLS and EMSI data to estimate the quantity and academic background of graduates entering each occupation. Using EMSI and NIH field knowledge, we further distributed CIP graduates to their likely occupations based on the occupations' relative size in the biomedical research workforce. Specifically, completions by CIP code were apportioned to their relevant SOC codes by multiplying the percentage of students entering each SOC occupation by the total number of completions in that CIP code and determining a sum for each occupation, inclusive of all the CIP codes that feed into it.

Real-time job posting data were extracted from Labor Insight, Burning Glass Technologies, (Boston, MA, USA). Labor Insight is a webcrawler that amasses information from 40,000 job boards, newspapers, and employer websites daily and uses artificial intelligence to de-duplicate job advertisements and extract more than 70 elements per advertisement to create a repository of jobs data. De-duplication occurs once at the website level, to avoid counting the same posting that recurs across multiple days, and once at the aggregate level, to eliminate the same posting advertised on multiple sites. Labor Insight data were collected from January 1, 2014, through December 31, 2014, for all 10 MSAs and for the nation.

The estimated number of U.S. postdoctorates was obtained from the National Science Foundation (NSF)–NIH Survey of Graduate Students and Postdoctorates in Science and Engineering, 2014 (20). This survey covers 564 U.S. academic institutions that grant research-based Master's or doctorates. The postdoctorates included in this analysis were U.S. citizens, permanent residents, and temporary visa holders at academic institutions with degrees in the following fields: anatomy, biochemistry, biology, biometry and epidemiology, biophysics, cell biology, ecology, entomology and parasitology, genetics, microbiology, immunology, and virology, nutrition, pathology, pharmacology, physiology, zoology, biologic science, mathematics and applied mathematics, statistics, neuroscience, biomedical engineering, and endocrinology.

The U.S. DoL collects data on worker attributes and job characteristics for the hundreds of occupations categorized by SOC codes, and EMSI produces a compatibility index ranging between 1 and 100 for each of the SOC-coded occupations. The compatibility index is based on occupational similarities in knowledge, skills, and abilities. For the skills gap analysis, we focused on occupations inside (core occupations) and outside (target occupations) the biomedical research workforce with a compatibility index of 93 or greater, complimentary wage rates, and similar educational requirements. The specialized and foundational skills that we identified were based on Labor Insight's definitions. Labor Insight defines specialized skills as occupation-specific skills that are technical in nature, and it defines baseline skills as cross-cutting or foundational skills across occupations and industries.

RESULTS

Workforce profile

We defined the core biomedical research workforce by the following 8 SOC codes for the purpose of this analysis: biochemists and biophysicists (19-1021); microbiologists (19-1022); biological scientists, all other (19-1029); epidemiologists (19-1041); medical scientists, except epidemiologists (19-1042), subsequently referred to as medical scientists; biomedical engineers (17-2031); statisticians (15-2041); and natural science managers (11-9121). Selected examples of job titles within these 8 occupations, as drawn from Labor Insight, are shown in **Table 1**. The MSAs in the analysis were in the following locations: Seattle-Tacoma-Bellevue,

TABLE 1. *Selected examples of job titles within the SOC categories*

SOC	Examples of job titles
Biochemists and biophysicists	Biochemist, toxicologist, quality control associate, staff biochemist, research associate
Biological scientists, all other	Biologist, bioinformatics scientist, mouse geneticist, molecular biology scientist, postdoctoral associate
Biomedical engineers	Biomedical engineer, systems engineer, senior staff imaging scientist, data mining engineer, analytical services senior scientist/supervisor
Epidemiologists	Epidemiologist, research analyst, infection control practitioner, epidemiology postdoctoral fellow, expert practitioner
Medical scientists	Research associate, research associate professor, postdoctoral fellow, clinical manager, research assistant
Microbiologists	Microbiologist, research microbiologist, microbiology supervisor, assistant professor of microbiology, microbiology laboratory manager
Natural science managers	Director of product development, director of core laboratory services, clinical trial manager, health sciences consultant, development associate
Statisticians	Statistician, statistical analyst, clinical statistician, bioinformatics director, director of modeling and simulation

WA; San Francisco-Oakland-Fremont, CA; Los Angeles-Long Beach-Santa Ana, CA; San Diego-Carlsbad-San Marcos, CA; Chicago-Joliet-Naperville, IL,-IN-WI; Houston-Sugar Land-Baytown, TX; Philadelphia-Camden-Wilmington, PA-NJ-DE-MD; New York-Northern New Jersey-Long Island, NY-NJ-PA; Washington-Arlington-Alexandria, DC-VA-MD-WV; and Boston-Cambridge-Quincy, MA-NH. Both SOC codes and MSAs are established taxonomies that crosswalk data collected by multiple U.S. reporting agencies and commercial sources of LMI.

Across the United States, >305,500 individuals were employed in the biomedical research workforce in 2014 (**Table 2**). Just over 42% (129,347) of this group were located within the 10 key MSA regions identified in this analysis. Approximately 69% of the biomedical research workforce nationwide was white, 19% Asian, 5% Hispanic/Latino, 5% black, 1% two or more races, 0.2% Pacific Islander, and 0.2% American Indian. Compared to the U.S. population, underrepresented races and ethnicities (Pacific Islander or American Indian, black, and Hispanic) comprised a disproportionately small component of the workforce, an observation also noted in the pool of NIH-funded principal investigators on research grants (21). There was a relatively even split between the sexes (between 45–55% for most occupations) within the workforce. However, proportionately fewer women were represented in natural science management (38% women) and in biomedical engineering (14% women), whereas the highest proportion of women appeared in epidemiology (55%). Half of the workforce was 35–54 yr of age, and approximately 30% was 25–34 yr of age. Slightly less than 20% of the workforce was 55 yr or older. Overall, 60% of the workforce had earned Master's degrees or higher, with just over 30% of the total workforce earning a Ph.D. or other advanced professional degree. More than 90% of workers in the medical scientist and epidemiology SOCs held Master's degrees or higher.

Biomedical research workers across the United States received average median earnings of $39.45/h and an average median annual salary of $82,051. These are somewhat lower than earnings reported for physical scientists ($44.95/h), mathematicians ($49.30/h), and computer and information research scientists ($51.04/h)

TABLE 2. *Total 2014 employment in the biomedical research workforce by SOC code, nationally and in the 10 MSA regions*

SOC	National jobs count 2014	MSA jobs count 2014
Biochemists and biophysicists	30,979	15,005
Biological scientists, all other	35,051	13,039
Biomedical engineers	21,662	8303
Epidemiologists	5610	1707
Medical scientists	107,332	49,464
Microbiologists	20,987	8904
Natural sciences managers	53,517	20,397
Statisticians	30,396	12,528
Total	305,534	129,347

in the United States. However, wages varied among geographical regions because of differences in the cost of living and in specific occupational mixes. For example, biomedical research workers in San Francisco, Philadelphia, and Washington, DC, MSAs earned the highest wages ($55.53/h, $51.59/h, and $49.73/h, respectively), whereas workers in the Seattle and Houston MSAs collected the lowest earnings ($35.89/h and $36.18/h, respectively) of the 10 MSAs. Salary disparities were based on occupation in the combined 10 geographies and at the national level. Epidemiologists received the lowest compensation, with a median annual salary of $66,498 across the nation ($73,445 within the 10 MSAs), whereas natural science managers were the highest paid, with a median annual salary of $116,834 across the nation ($151,403 within the 10 MSAs).

Labor gap

We used educational program completion data to represent potential labor supply in the biomedical research workforce. We analyzed the top 50 CIP codes supplying graduates to the 8 occupations in the biomedical research workforce. **Figure 1***A* displays the top 15 programs in the 10 MSAs at all degree levels, by CIP code, that fed into the workforce in 2014. The fields with the greatest total number of combined undergraduate and graduate completions in the 10 MSAs were biology/biologic sciences, biologic and physical sciences, mathematics, chemistry, public health, bioengineering and biomedical engineering, biochemistry, and statistics. At the Master's level and higher, within the 10 MSAs, the fields with the greatest number of completions were public health, chemistry, biology/biologic sciences, mathematics, statistics, bioengineering and biomedical engineering, epidemiology, and biomedical sciences (Fig. 1*B*). These fields were consistent with national data for completions (data not shown). All the fields were matched to the corresponding occupations to estimate potential graduates entering into each SOC code. **Table 3** shows the numbers of graduates at all degree levels, by graduate degree and by Ph.D. in the 10 MSAs. The greatest number of graduates with Ph.D.s mapped to medical scientists , followed by biologic scientists–all other, and natural sciences managers.

As a proxy for demand, we examined unique, real-time job postings for the 8 relevant occupations across the 10 MSAs using Labor Insight for the calendar year, to capture data for all 2014 graduations. An estimated 80–90% of job openings for candidates with at least a Bachelor's degree are posted online (22), and online job postings are a leading indicator of actual hires (23). Across the occupations in the 10 MSAs, job postings requiring at least a Bachelor's degree were collected and later filtered for postings requiring

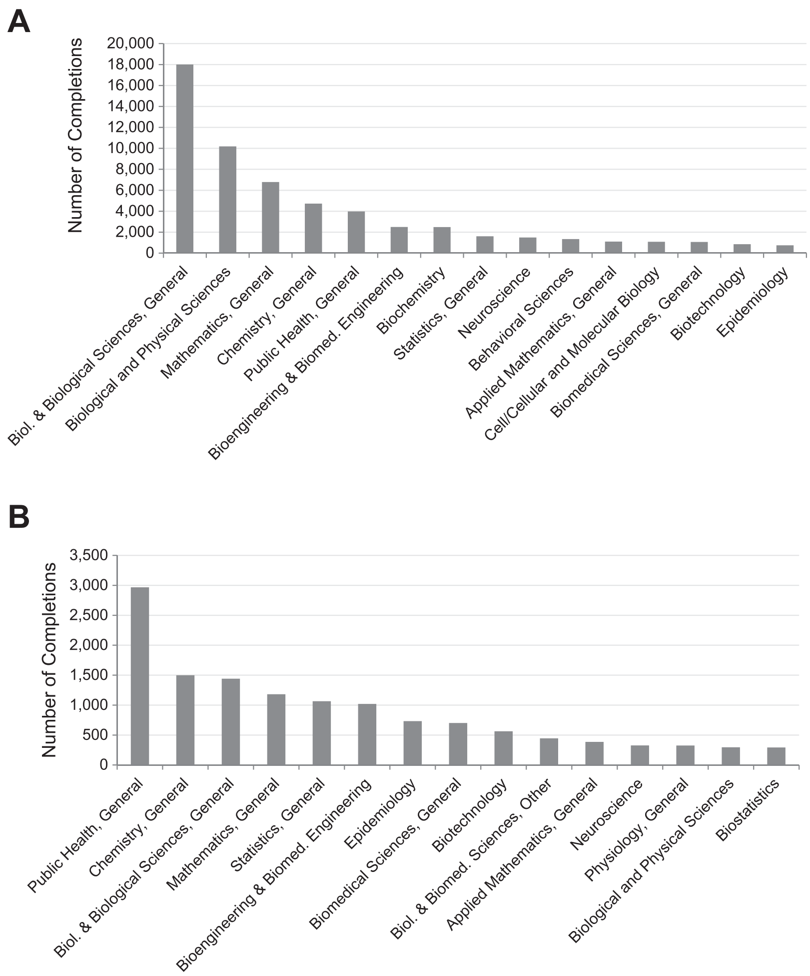

Figure 1. Top 15 CIP codes supplying 2014 graduates into the biomedical research workforce in the 10 MSAs. *A*) The total number includes both undergraduate and graduate degree holders. *B*) Top 15 CIP codes for Master's graduates and higher.

TABLE 3. *2014 Completions by degree type and core occupation in the 10 MSA regions*

Occupation	All degree completions	Graduate degrees	Ph.D. only
Biochemists and biophysicists	1870	617	354
Biological scientists, all other	12,375	2145	785
Biomedical engineers	2575	1083	372
Epidemiologists	815	475	74
Medical scientists	12,191	6246	1140
Microbiologists	576	331	197
Natural sciences managers	26,513	2266	648
Statisticians	5923	2419	437
Total	62,838	15,582	4007

a graduate-level degree or higher. **Table 4** shows the estimated supply and demand and the resultant gap (demand minus supply) for occupations across the 10 MSAs, at all degree levels. When scanning across all degree levels, we found a gap of −19,180, indicating an oversupply of graduates compared to annual job postings in these MSAs. Our investigation of only graduate-level degree holders showed that the directionality and size of the gap shifted, suggesting an undersupply (slightly more than 4000) of graduate degree-level holders compared to advertised demand in the 10 MSA regions. As discussed later, this gap is likely attributable to high workforce demand in these 10 MSAs. In fact, further analysis showed that these regions are the top 10 MSAs based on the sheer number of job postings for the biomedical research workforce across the nation (data not shown). The locations of the 10 MSAs are consistent with many of the major destination states where Ph.D. recipients relocate for postgraduation employment; just over 34% of U.S. doctoral recipients remain either in-state or within 50 miles of the university from which they graduate (24).

Recognizing that a labor market with imposed geographic boundaries concentrated on 10 urban hubs cannot represent the dynamic, expansive nature of the U.S. biomedical research workforce as a whole, we further explored the labor gap at the national level. The number of 2014 graduates from educational programs across the United States that fed into the 8 occupations in the biomedical research workforce were calculated. Similarly, real-time job postings for the 8 occupations across the entire United States in 2014 were determined. There was a large gap (−127,880) between individuals at all degree levels and jobs in the biomedical research workforce across the United States (**Table 5**). Yet, in contrast to the perceived undersupply of graduate degree holders in the delineated MSAs, at the national level, there was an oversupply of graduate degree holders entering into the biomedical research workforce compared to the number of jobs advertised for those requiring at least a Master's degree (−3,435). Moreover, we expect these available jobs to attract both newly minted Master's and Ph.D. holders, as well as postdoctoral research fellows seeking employment or currently unemployed. Therefore, we incorporated postdoctoral appointees in the United States with doctoral degrees in fields relevant to this workforce into our calculated labor market supply. The postdoctorates we included were enumerated in the National Science Foundation-National Institutes of Health (NSF–NIH) Survey of Graduate Students and Postdoctorates in Science and Engineering and were further selected by discipline similarity to CIP code and the NIH classification of biomedical sciences (25). See Materials and Methods for a listing of specific fields covered. The number of postdoctorates in our calculation was based on the assumption that the average Ph.D. holder in biomedical research spends approximately 4.5 yr in a postdoctoral fellowship (26), and thus, in a given year, between one quarter and one fifth of postdoctoral fellows seek employment. Once postdoctoral fellows were added to our calculation of supply, as expected, the gap widened further (−8378).

National supply and demand growth trends

The labor gaps capture a static snapshot of estimated supply and demand in a limited time frame. We examined

TABLE 4. *Labor gap for all-degree holders and graduate-level degree holders in the 10 MSA regions*

	All degrees			Graduate-level degrees		
Occupation	Demand	Supply	Gap	Demand	Supply	Gap
Biochemists and biophysicists	1002	1870	−868	522	617	−95
Biological scientists, all other	1622	12,375	−10,753	1104	2145	−1041
Biomedical engineers	462	2575	−2113	124	1083	−959
Epidemiologists	574	815	−241	336	475	−139
Medical scientists	27,549	12,191	15,358	12,816	6246	6570
Microbiologists	1103	576	527	330	331	−1
Natural sciences managers	5107	26,513	−21,406	1540	2266	−726
Statisticians	6239	5923	316	2885	2419	466
Total	43,658	62,838	−19,180	19,657	15,582	4075

TABLE 5. *Labor gap for all-degree holders and graduate-level degree holders across the United States*

Occupation	All degrees			Graduate-level degrees		
	Demand	Supply	Gap	Demand	Supply	Gap
Biochemists and biophysicists	1886	7555	−5669	879	1743	−864
Biological scientists, all other	3769	52,968	−49,199	2690	5785	−3095
Biomedical engineers	1255	8656	−7401	293	3077	−2784
Epidemiologists	1,875	2,023	−148	1086	1213	−127
Medical scientists	62,878	43,540	19,338	25,995	18,248	7747
Microbiologists	3551	3271	280	929	965	−36
Natural sciences managers	12,317	92,340	−80,023	3587	6958	−3371
Statisticians	14,002	19,060	−558	5744	6649	−905
Total	101,533	229,413	−127,880	41,203	44,638	−3435
Total (with postdoctorates)				41,203	49,581	−8378

educational supply and job posting growth rates in the biomedical research workforce over time across the United States. Figure 2 displays supply and demand for all degree completions (Fig. 2*A*), graduate degree holders (Fig. 2*B*), and graduate degree holders plus applicable postdoctorates (Fig. 2*C*). The supply data are shown for the past decade, but job postings data are limited to 2010 through 2014, because of the relative newness of online job posting data. Educational program completions increased in fields supporting all 8 SOCs over the past decade. In addition, job postings increased in number over the past 5 yr in all 8 SOCs, both at the national level (Fig. 2) and within the 10 MSAs (data not shown). The gaps between supply and demand have persisted over time at all educational levels, with no indication of gaps narrowing. U.S. BLS data predict slower than average growth in employment of microbiologists and natural science managers from 2012 through 2022 (3–7%) and no growth for biological scientists, all other (−2–2%), whereas statisticians and biomedical engineers are forecasted to experience much faster than average growth (≥22%) over the same period. The projected average growth rate for all U.S. occupations (biomedical research and all other) is just under 11% (27).

Skills gap analysis

Thus far, using empirical data, we have presented a collective view of the U.S. biomedical research labor market, which has been experiencing an oversupply in recent years. What these data do not reveal is how individual graduates and trainees in the workforce should be equipped for this job market reality. Recent reports have called attention to the need to better understand human capital in the labor market, including the skills and competencies that are increasingly critical prerequisites to success (28). There are few data indicating what skills employers require of new graduates entering the workforce; however, there is evidence to suggest that, despite their education, graduates' skill levels may be inadequate, particularly in a global labor market (29). We sought to understand the knowledge, skills, and abilities that could be developed to enable these individuals to be competitive for jobs within and outside the U.S. biomedical research workforce. Specifically, we investigated whether there are skills gaps, and if so, in which areas. To this end, we capitalized on the rich data Labor Insight captures from each real-time job posting and the tool's ability to code this information. We analyzed both specialized skills and foundational or "soft skills" for a variety of occupations.

Two proof-of-concept examples of this skills comparison are illustrated in **Figs. 3** and **4**, which depict the percentage of job postings in which the top 15 skills are stipulated. Figure 3*A, B* juxtaposes the required specialized skills list for medical scientists or statisticians (core workforce occupations) to the skills list for natural science managers (also a core occupation but of a different nature) or operations research analysts (target occupation). Skills gaps were found between medical scientists and natural science managers in areas including medical technology, product management, and business administration and development. Although job ads for statisticians and operations research analysts both requested candidates possessing skills in mathematics, economics, Structured Query Language (SQL; standard language for searching and updating databases), and data analysis, a larger proportion of job ads for operations research analysts required skills in accounting, operations analysis, understanding of business processes, and financial analysis (Fig. 3).

Furthermore, we examined the foundational skills requested in job postings for these occupations (Fig. 4). Scanning across the career pathways, potential skills gaps included organizational skills, planning, project management, problem solving, and Microsoft Office software (Fig. 4). When viewed in isolation, these skills gaps may not be surprising, but after analyzing skills across ~40 different occupational pathways, recurring gaps emerged. **Table 6** highlights common sets of skills identified from the skills gap analyses of these pathways. In-demand skills where gaps were found were in categories such as financial and process improvement (financial analysis, economics), project management (planning, budgeting), leadership development (collaboration, supervisory skills), business acumen (business development and administration), communication (writing, negotiation), policy and regulation (risk management, compliance), academic culture (mentoring, curriculum development), programming languages (PERL, SQL), and statistical analysis (SAS, SPSS, data analysis).

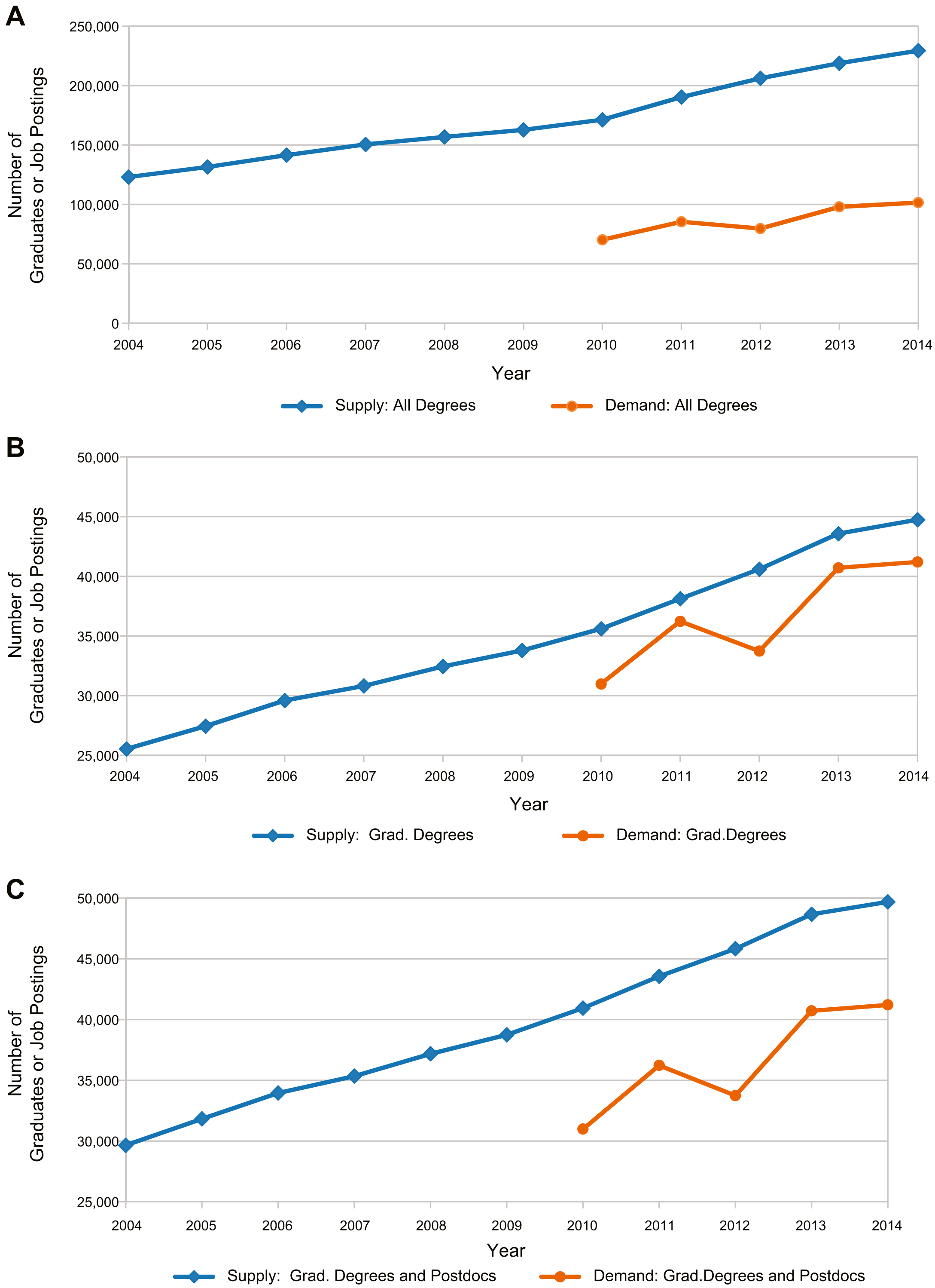

Figure 2. Growth in supply and demand in the U.S. biomedical research workforce from 2004 through 2014. Supply is estimated by the number of U.S. educational program completions, or U.S. educational program completions added to the number of relevant postdoctorates in the United States. Demand is calculated from the number of unique job postings across the nation. *A*) Supply and demand for graduates at all degree levels. *B*) Supply and demand for graduates with a Master's degree or higher. *C*) Supply and demand for graduates with a Master's degree or higher plus relevant postdoctoral fellows.

DISCUSSION

This analysis demonstrates the often cited, but not quantified, mismatch between supply and demand in the U.S. biomedical research labor market and extends the findings to identify sought-after skills for jobs in the workforce and in complementary occupations. We provide the first empirical analysis that couples traditional LMI with real-time job data to determine the labor gap between the educational pipeline in the U.S. biomedical research workforce

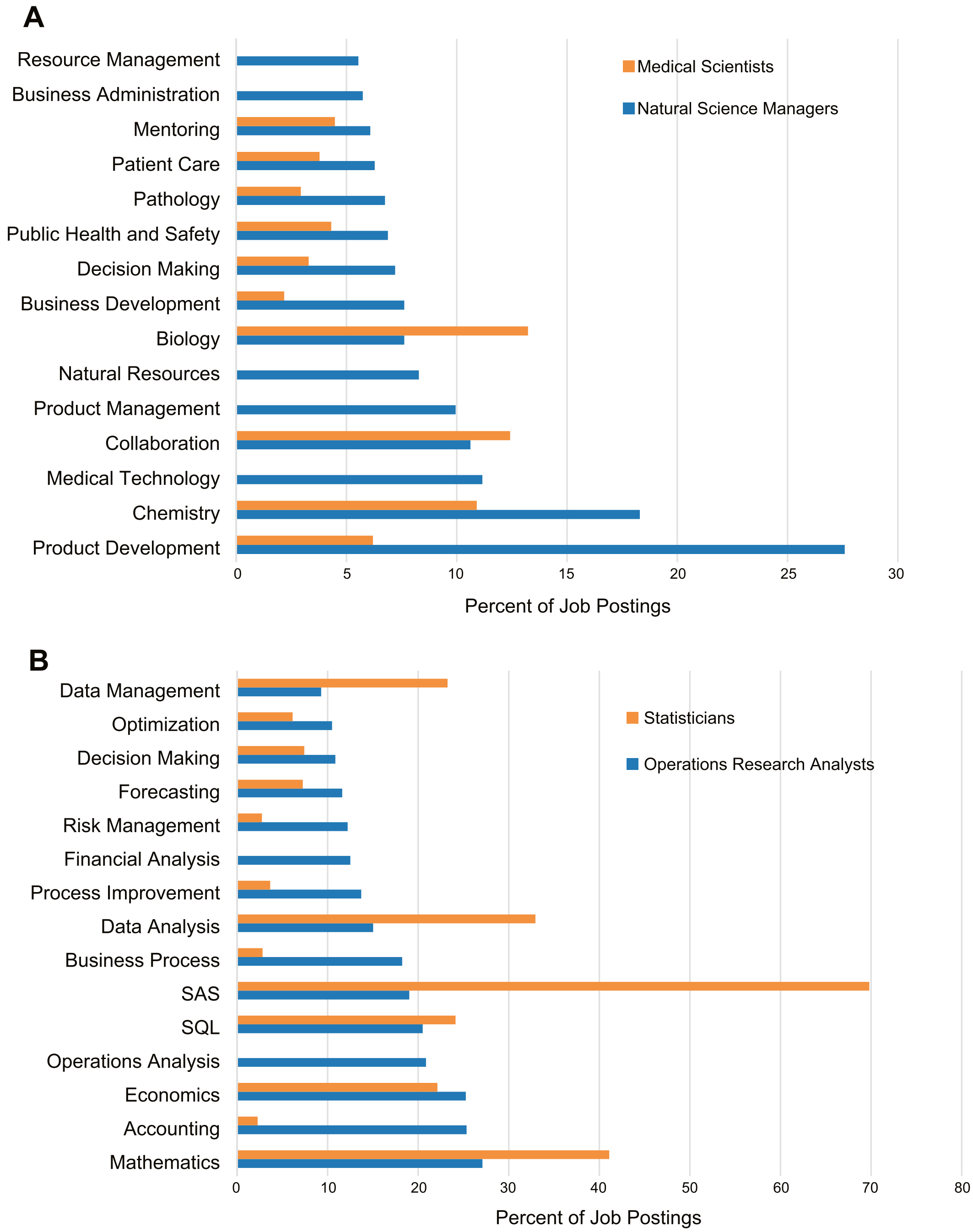

Figure 3. Top 15 specialized skills by frequency of occurrence in job postings for occupations within and related to the U.S. biomedical research workforce. *A*) Percentage of job ads for medical scientists and natural science managers requesting the indicated specialized skills. *B*) Percentage of job ads for statisticians and operations research analysts requesting the indicated specialized skills.

and demand for occupations within that workforce. In the U.S. biomedical research workforce defined in this study, at all degree levels and at the graduate degree level, there was a gap between supply and demand in 2014.

We observed substantially more total degrees conferred (combining all degree levels) than number of available jobs with this educational requirement within the 10 MSAs. The directionality and size of the labor gap shifted when only graduate degree holders were examined, but that was not the case when we explored the entire U.S. biomedical workforce, where we witnessed oversupply at all degree levels, including only the graduate degree holders. The MSA region-specific undersupply in the graduate-level population is not surprising, given that nearly half of total U.S. biomedical workforce demand originated from the 10 MSAs (48% of job postings for graduate degree holders), but only slightly more than a third (35%) of total U.S. supply (graduate-level educational program completions) derived from those 10 geographic entities. The data highlight the workforce mobility necessary for securing jobs in the biomedical research workforce.

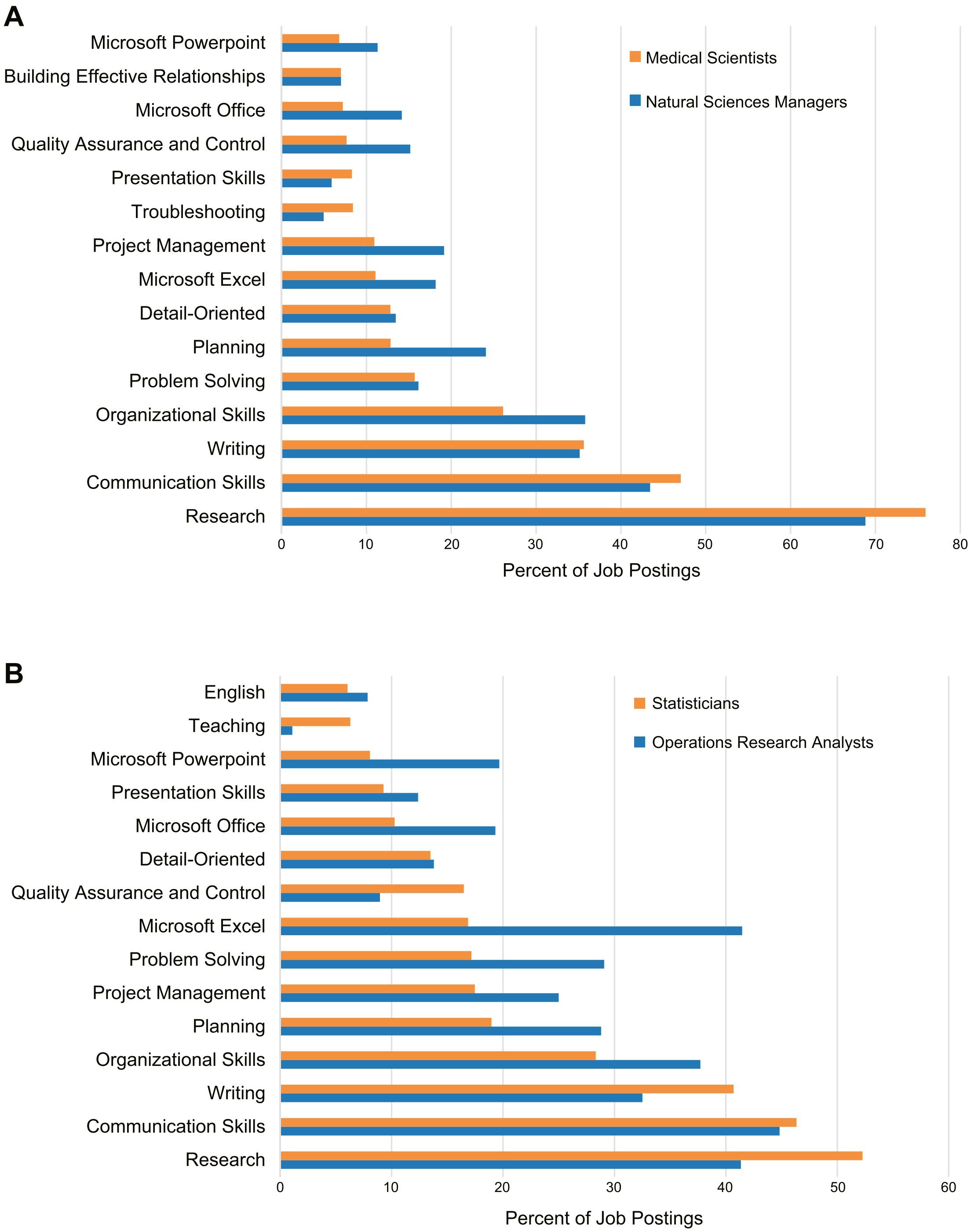

Figure 4. Top 15 baseline or foundational skills by frequency of occurrence in job postings for occupations within and related to the U.S. biomedical research workforce. *A*) Percentage of job ads for medical scientists and natural science managers requesting the indicated baseline skills. *B*) Percentage of job ads for statisticians and operations research analysts requesting the indicated baseline skills.

The number of graduates entering the U.S. biomedical research workforce rose from 2004 through 2014, regardless of educational level. At the same time, first-time graduate school enrollment in the United States experienced an average annual increase of 9.8%, particularly fueled by the fields of mathematics and computer sciences, health sciences, and engineering (30). Awarded doctoral degrees increased by 5.8% at public and private institutions. Our estimation of supply, derived from educational program completions and postdoctoral fellow enumeration, represents the conservative lower bounds and likely underestimates the total supply. Our analysis did not incorporate educational program completions from foreign institutions or postdoctorates entering the United States from abroad, because these data are either nonexistent or lack the specificity and nomenclature to be compatible with U.S. labor market data. Although the NSF–NIH Survey of Graduate Students and Postdoctorates in Science and Engineering is the most reliable and authoritative source for capturing U.S. postdoctorates in academia, our estimates

TABLE 6. *Summary of potential skills gaps in the biomedical research workforce, as identified from job postings*

Skill category	Skills
Financial and process improvement	Accounting, operations analysis, financial analysis, economics
Project management	Planning, budgeting, organizational skills, problem-solving
Leadership development	Collaboration, mentoring, supervisory skills
Business acumen	Business development, business administration, business management
Communication	Writing, presentation skills, negotiation, and persuasion
Policy and regulation	Risk management, compliance, product and drug development
Academic culture	Mentoring, academic advisement, curriculum development, grant writing
Programming languages	JAVA, PERL, Linux, Python, C++, SQL
Statistical analysis	Data analysis, SPSS, SAS

did not include postdoctorates in other employment sectors such as private industry or government, or in academic institutions not covered by the survey. Therefore, our estimates underrepresent the total potential postdoctorate supply. Thus, the labor gap is likely larger than depicted in this study. However, it is interesting to note that, since 2010, the postdoctoral population in the United States has been declining (31), and if the trend continues, it may portend changes in overall labor supply.

Demand in the United States, as estimated by advertised job openings, increased over the past 5 yr. It is possible that our estimates of growing demand were influenced by employers shifting from marketing open positions in print advertisements to online media to extend their outreach beyond local labor markets in the past decade (22). Nonetheless, online job ads are valuable sources for tracking employment over time and can detect shifting demand sooner than traditional LMI (22). It is also important to emphasize that a unique job posting does not necessarily equate to a job hire. Advertised positions may go unfilled for a host of reasons.

In our analysis of job ads requiring graduate degrees, we were unable to disaggregate postings requiring a Ph.D. (or equivalent) from those specifying a Master's degree, because many of the job postings in the workforce that we examined specified either a Master's degree (with or without experience) or a Ph.D. The proliferation of Master's degree–granting programs and Professional Science Master's degree programs has resulted in credible opportunities for producing candidates possessing both rigorous scientific knowledge and training in business, policy, law, or communications. Without a concentrated focus in a doctoral program that primarily prepares them for academic research, these individuals could be competitive in a diverse set of career options.

The purpose of this labor gap analysis was not to forecast the correct number of graduate degree holders in biomedical science, nor was it to model and predict the future dynamics of a fluid global research workforce. Rather, it represents a snapshot of a closed system, intended to present estimations of national supply and demand in the biomedical research workforce while identifying transferrable skill sets that could prepare trainees for other important career paths. Individual trainees may not have control over the ebb and flow of the biomedical research labor market, but they do have responsibility for, and ownership of, the skills they cultivate as they embark upon their educational journey and future career path. Thus, in addition to continued specialized research training, leaders of graduate research training programs are encouraged to consider integrating broader elements, such as those skills identified in this analysis, to best prepare trainees for the workforce demands of tomorrow. This analysis highlights areas for up-skilling, such as finance, economics, collaboration, mentoring, business administration, project management, communication, policy, and decision-making, and lends credence to the recommendations to broaden graduate education through professional skills development, and to expand graduate educational program options (32, 33). Our skills analysis also supports the development of a solid foundation of baseline skills that may prepare scientists for careers outside the pathways in which they were initially educated and trained. With these skills, early-career scientists can be poised for career mobility, even when specialized up-skilling is necessary. Furthermore, this analysis demonstrates from real job advertisements that these skills are requested and required for many of today's occupations in the broader biomedical enterprise. Trainees who master ancillary skills may be more competitive for the emerging job market in a variety of positions that are either core professions or complementary occupations in the biomedical research enterprise. Courses, workshops, or experiential learning may provide the necessary exposure to these skills and serve as a bridge to opportunities outside of what has been a narrowly defined research workforce. The NIH-funded BEST consortia are already implementing a series of measures aimed at identifying best practices in graduate and postdoctoral training for diverse career options (13). Expanding these skill-building efforts and continuing to elevate awareness of today's job market realities could lead to a more sustainable workforce. FJ

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