PERSPECTIVE

Toward a sustainable biomedical research enterprise: Finding consensus and implementing recommendations

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The US research enterprise is under significant strain due to stagnant funding, an expanding workforce, and complex regulations that increase costs and slow the pace of research. In response, a number of groups have analyzed the problems and offered recommendations for resolving these issues. However, many of these recommendations lacked follow-up implementation, allowing the damage of stagnant funding and outdated policies to persist. Here, we analyze nine reports published since the beginning of 2012 and consolidate over 250 suggestions into eight consensus recommendations made by the majority of the reports. We then propose how to implement these consensus recommendations, and we identify critical issues, such as improving workforce diversity and stakeholder interactions, on which the community has yet to achieve consensus.

biomedical workforce | research funding | research regulation | graduate training | postdoc training

The problems of the US biomedical research enterprise have been well-documented. Stagnant federal funding since 2003 has reduced grant success rates, eroded grant purchasing power, and reduced employment (1–3). In addition, young scientists often are not aware of, or trained for, the breadth of careers available (4); burdensome regulations detract from research productivity (5); and technology transfer and intellectual property rights remain divisive issues for academia, industry, and government (6). These conditions may cause a substantial fraction of the next generation of scientists to conduct research abroad or leave science altogether (7). We must resolve these challenges and move the US research enterprise onto a more sustainable path that balances workforce size with available research funding while continuing to cultivate world-class scientific talent and produce breathtaking discoveries (8).

More than half a dozen groups have analyzed the problems confronting the enterprise and made recommendations for improvement. For a variety of reasons, however, implementation of these recommendations has been slow. For example, partisan politics can impede the progress of necessary legislation, and relevant federal agencies lack either the willingness or legal authority to make needed changes. Furthermore, the lack of a unified authority over university policies and practices can lead to patchwork change with variable results. Together, these attributes may have led to a false sense that the community has not yet achieved consensus around actionable improvements, thereby impeding implementation of actions that would improve the research enterprise.

To identify areas where action should be taken immediately, we analyzed hundreds of recommendations made by various groups, and we identified eight recommendations that were endorsed by a majority of leading representatives of the scientific community (Table 1) (9–17). We advocate that the community implement these consensus recommendations, offer straightforward implementation plans, and identify additional critical issues that must be resolved to continue moving the enterprise onto a more sustainable path.

Consensus Recommendations

We systematically searched for reports, meeting summaries, and opinion pieces published since 2012 that addressed sustainability problems confronting the research enterprise. Reports published before 2012 were excluded because recommendations made before then were often obsolete, and multiple groups representing different constituencies have weighed in on these issues since then. We also excluded reports that made recommendations that affected only a subset of the biomedical research enterprise.

The nine reports that fit these criteria made a total of 267 recommendations, which were consolidated to produce 54 "unique" recommendations (Dataset S1) (9–17). Eight of the 54 recommendations appeared in a majority of the nine reports and were termed "consensus" recommendations (*SI Appendix*, Table 1). All of the reports emphasized the importance of strengthening individual, investigator-initiated research and rigorous scientific training, and implementation of the eight consensus recommendations should proceed with these goals in mind.

Consensus Recommendation 1: The Federal Government Should Make Research Funding Predictable and Sustainable

Five reports made this recommendation and four specifically suggested that scientists and scientific societies work with federal agencies to develop a cross-agency, multiyear budget plan (Table 1) (9, 10, 13, 17). Although the specifics of a long-term budget plan did not meet our consensus threshold, the most common recommendations were that funding

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Table 1. Consensus recommendations and implementation plans

Recommendation	Implementation*	References†
1. The federal government should make research funding predictable and sustainable.	Federal agencies and scientific community: Develop long-term science budget with reasonable and sustainable funding goals.	9, 10, 12, 17
2. The federal government should increase overall research funding.	Federal agencies and scientific community: Determine appropriate research funding level with 3% of GDP as a starting point. Scientific community: Advocate for sustainable federal research funding as described in long-term budget plan. Federal government: Change policies to encourage R&D investment from nongovernmental sectors.	9–11, 13, 17
3. Federal agencies should harmonize, streamline, or eliminate burdensome regulations.	Scientific community: Advocate for passage of H.R. 1119. Scientific community: Develop list of onerous regulations for review by federal interagency panel.	10, 11, 13, 15–17
4. Institutions and federal agencies should increase compensation for postdoctoral scholars.	NIH: Increase the postdoc pay scale, with $50,000 as a starting point for new postdocs. Institutions: Conform to NIH postdoc pay scale for all postdocs regardless of funding source.	9, 10, 12, 14, 15
5. Institutions and federal agencies should reduce graduate student and postdoc training periods.	NIH: Limit graduate student support from all NIH grants to 5 y. Postdocs receive an additional 5 y. Institutions: Pilot and implement methods to provide rigorous scientific training in a shorter time.	9, 10, 13–15, 17
6. Institutions and federal agencies should train students and postdocs for the breadth of careers available to them.	Institutions: Develop programs to expose all trainees to the variety of available careers. NIH: Disseminate innovative training approaches as learned through the BEST program.	9–15, 17
7. Institutions and federal agencies should shift support of trainees toward training grants and fellowships.	NIH: Increase training budget to accommodate higher postdoc pay while maintaining the number of trainee slots. NIH: Amend peer-review processes to value quality training of all students at an institution, regardless of funding source. NIH: Determine target number of trainees to support by training grants and fellowships, with 17% of all postdocs and 37% of all graduate students as starting points.	9, 10, 12, 13, 15, 17
8. Institutions and federal agencies should increase the use of staff scientists.	Institutions: Create staff scientist positions with compensation commensurate with the position. NIH: Modify peer-review criteria to encourage use of staff scientists.	9–12, 14, 15, 17

*Implementation plans include recommendations specified in reports and the authors' suggestions. See the text for a more detailed explanation of the implementation plans.
†The reports that support the recommendation.

requirements be projected for at least 5 y, be revised annually, and include research infrastructure needs. We also suggest including projections of the size and composition of the research workforce in the budget plan. Although obtaining such data may be difficult, an accurate assessment of workforce needs is critical for a sustainable research enterprise. As suggested by some reports, creating a system that tracks all researchers funded by federal grants may aid the collection of workforce data (12, 14, 15). This long-term budget plan will provide a roadmap for predictable and sustainable research funding and improve the transparency of agency spending.

Consensus Recommendation 2: The Federal Government Should Increase Overall Research Funding

In 2014, the United States invested approximately $465 billion, or 2.8% of its gross domestic product (GDP), in research and development (R&D) (18). Industry-funded R&D was responsible for two-thirds of this spending, federally funded R&D accounted for one-quarter, and the remainder came from academia, nonprofits, and other funders (18). Five reports recommended increasing research and development funding, and three specifically advocated for increasing investment to three percent or more of US gross domestic product (Table 1) (10, 13, 17). R&D investments are an important driver of US GDP growth, but increasing R&D spending to 3% of GDP did not reach our threshold for consensus. However, this funding level is a useful starting point for the discussion. Additionally, two of the reports specified that basic research should be the primary beneficiary of funding increases (10, 13). We suggest using the long-term science budget framework described above to refine spending targets and research areas for investment and to ensure that investments are in line with workforce and infrastructure needs. Increasing R&D spending to 3% of GDP or beyond will also require a significant investment increase by industry, nonprofits, and other funders (18). One approach for encouraging increased investment is tax reform, particularly making the Research and Experimentation Tax Credit permanent (10, 13, 17, 19).

Consensus Recommendation 3: Federal Agencies Should Streamline, Harmonize, or Eliminate Burdensome Regulations

House Bill 1119 (H.R. 1119), the proposed Research and Development Efficiency Act of 2015, would establish a federal interagency working group to identify burdensome or outdated regulations and recommend ways to relieve this burden (20). Given the consensus on reducing regulations, the benefit to scientists, and the political will to address this issue, the community should advocate for passage of H.R. 1119 (Table 1). This bill also directs the interagency working group to work with the scientific community to identify onerous regulations, and the community should prepare to offer such recommendations.

Consensus Recommendation 4: Institutions and Federal Agencies Should Increase Compensation for Postdoctoral Scholars

Five reports recommended increasing compensation for postdoctoral scholars (postdocs) to reflect better their training and critical contributions to the research enterprise, but only one proposed a specific pay level for beginning postdocs—$50,000 (Table 1) (14). Although the community has not yet reached consensus on how much salaries should increase, $50,000 is a reasonable starting point for discussion. In addition, we recommend that institutions match the NIH postdoc pay scale and that salary increases be phased in at a rate that outpaces inflation. Only one report suggested that graduate student stipends be increased (11). Despite the lack of consensus, graduate student stipend levels should be assessed on a regular basis to ensure fair compensation and sustainability.

Consensus Recommendation 5: Institutions and Federal Agencies Should Reduce Graduate Student and Postdoc Training Periods

PhD training periods now average over 6.5 y, and postdoc periods are expanding (21, 22). These trends are contributing to the decades-long increase in the average age of tenure-track and tenured faculty members (15). Six reports recommended reducing training periods, but the reports did not specify how this goal should be accomplished or to what extent (Table 1). One possibility is to limit graduate students to 5 y of total funding on federal grants, including training grants, fellowships, and research grants, and postdocs to an additional 5 y. These limitations should be phased in over multiple years, and exceptions should be made for extraordinary circumstances, such as parental leave. Because trainees funded by research grants are considered institutional employees, institutions and the NIH would have to work together to enact workable policies and ensure that non-federal funds are not used to lengthen training periods unnecessarily. As with consensus recommendation 1, a system that tracks researchers funded by federal grants may aid implementation.

Consensus Recommendation 6: Institutions and Federal Agencies Should Train Students and Postdocs for the Breadth of Careers Available to Them

Biomedical PhD graduates have been opting for nonacademic careers in increasing numbers for three decades (11, 15). Academic institutions and federal funding agencies should therefore increase opportunities for students to explore careers other than academic research, while maintaining rigorous scientific training. Many institutions have begun to implement such expanded training programs, and the NIH's Broadening Experiences in Scientific Training (BEST) program recently awarded grants to support such endeavors (23). Institutions should model expanded training programs on successful BEST programs. The NIH also now requires individual development plans for each supported trainee, and institutions should strongly encourage and support their thoughtful use in career planning (24, 25).

Consensus Recommendation 7: Institutions and Federal Agencies Should Shift Support of Trainees Toward Fellowships and Training Grants

Four of the six reports supporting consensus recommendation 7 argued that training will be strengthened by a greater decoupling of training and research activity, and by giving federal agencies more oversight of training programs through peer review (Table 1) (9, 10, 13, 15). In 2012, 9.6% of postdocs and 32% of full-time graduate students were supported by federal training grants and fellowships (26, 27). Although the reports did not come to consensus on how many trainees should be funded by training grants and fellowships, the NIH should begin to gradually increase the number of graduate students and postdocs funded by these mechanisms. We note that, in 1998 before the NIH budget doubling, the percentages of postdocs and graduate students funded by training grants and fellowships were ~17% and 37%, respectively, and these levels are a useful starting point for discussion (26, 27). These discussions should also consider some shortcomings of current training mechanisms. For example, only permanent residents are eligible for this funding, the mechanisms do not fully cover training costs, and efforts to control the supply and demand of PhDs and postdocs are controversial (see *Conclusion*).

Consensus Recommendation 8: Institutions and Federal Agencies Should Increase the Use of Staff Scientists

The seven reports supporting consensus recommendation 8 argued that adding more stable staff scientists will have several benefits, including improved long-term laboratory stability and increased productivity (Table 1). Institutions should establish formal positions with pay scales that are attractive enough to make this career path desirable and viable, not just a default step for senior postdocs. In parallel, federal funding agencies should amend peer-review policies to encourage grant applications that include staff scientists. The National Cancer Institute has recently launched a program to fund staff scientists, which will serve as a useful test case (28).

Issues Requiring Further Consideration

Implementing the above consensus recommendations will not solve all of the problems in the research enterprise, and each of the reports made many more recommendations that did not reach our consensus threshold. Moreover, several very important topics were not adequately addressed by these reports, some of which are highlighted here.

Workforce Diversity. Diverse groups often solve problems more effectively than homogeneous groups, yet women and many racial and ethnic groups are underrepresented in the research enterprise (29, 30). However, only one report in our analysis addressed this issue in any depth (10). Diversity must be part of any reform discussion because workforce changes, including implementing consensus recommendations 4 through 8, will inevitably affect diversification efforts. Increasing minority participation in research must go beyond enhancing kindergarten-to-twelfth grade (K–12) science, technology, engineering, and mathematics (STEM) education programs for underrepresented minority students (31, 32). The scientific community must also move quickly to identify and reform structural inequities such as unconscious bias in hiring and peer review and institutional cultures that select against women and underrepresented minorities (33–36).

Stakeholder Interactions. The analyzed reports focused primarily on academic science, but the interactions among academia, industry, and government also play key roles in the research enterprise. Indirect cost recovery rates and allowable uses of these funds require further discussions between government and academia (37). The Bayh–Dole Act of 1980 laid the foundation for the current state of technology transfer and innovation licensing (38). However, technology transfer and intellectual property issues still impede the seamless flow of ideas and materials (39). The reproducibility of academic science as it relates to drug development is also a point of contention between academia and industry (40). Greater engagement among academia, industry, and government is required to address these concerns and other critical interstakeholder issues. The National Academy of Sciences' Government-University-Industry Research Roundtable provides a natural forum for these discussions, and stakeholders should use this council and additional avenues to improve stakeholder interactions.

Grant-Funding Mechanisms. Six of the nine analyzed reports proposed new grant-funding mechanisms but differed on the constituencies they should target. Some target groups included young scientists, senior scientists, physician scientists, and those in need of bridge funding (11, 12, 15, 17). Mechanisms for funding new fields, collaborative research, and alternatives to animal research were also suggested (13, 16, 17). Each report makes important points in support of these proposed mechanisms, but the lack of consensus indicates a requirement for further discussion.

Conclusion

Multiple groups have identified problems and made recommendations that would improve the research enterprise while strengthening independent, investigator-initiated research, broadening the rigorous training of young scientists, and maintaining innovation. Many of these recommendations have been discussed for years, and we propose that the scientific community begins implementation of the eight recommendations on which there is broad consensus.

The eight consensus recommendations identified here are complementary, and there are advantages to simultaneous implementation. For example, long-term budget planning can provide the transparency needed to stabilize and increase research funding. Similarly, concomitantly increasing postdoc pay, restricting training periods, and broadening training experiences will tend to reduce graduate student and postdoc populations and may allow the NIH to passively increase the percentage of trainees funded by training grants and fellowships.

Although concomitant implementation of the consensus recommendations is advisable, it must still be done with care. Any increases in costs associated with implementation should ideally be covered by increased congressional appropriations and should not be taken from research project grants, which are already significantly strained. Care should also be taken to ensure that actions such as shifting trainee support toward training grants and fellowships do not unduly harm programs at smaller or less prestigious institutions that cannot compete effectively for these grants. All of the consensus recommendations will have effects on the research enterprise and should therefore be monitored closely, with federal agencies and the scientific community jointly defining the metrics for success.

Young scientists bring vital, fresh ideas and perspectives to the research enterprise, and improving graduate student and postdoc training will strengthen the research enterprise. However, the reports do not agree on whether academia is producing too many PhDs, and there is a relative lack of data assessing supply and demand of PhDs and market capacity. Nevertheless, implementing consensus recommendations 4 through 8 will likely reduce the number of trainees and shift the research enterprise toward a more balanced mix of trainees and staff scientists.

In summary, stakeholders are rightly concerned that taking specific actions may damage the enterprise. However, a "do no harm" approach ignores the fact that doing nothing has exacerbated the current situation and will be even more harmful in the future. Our community must therefore now act to reinvigorate the US scientific enterprise and ensure that we remain a global leader in research.

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