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PERSPECTIVE ESSAY

Strategic policy options to improve quality and productivity of biomedical research

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Abstract
Emerging societal expectations from biomedical research and intensifying international scientific competition are becoming existential matters. Based on a review of pertinent evidence, this article analyzes challenges and formulates public policy recommendations for improving productivity and impact of life sciences. Critical risks include widespread quality defects of research, particularly non-reproducible results, and narrow access to scientifically sound information giving advantage to health misinformation. In funding life sciences, the simultaneous shift to nondemocratic societies is an added challenge. Simply spending more on research will not be enough in the global competition. Considering the pacesetter role of the federal government, five national policy recommendations are put forward: (i) funding projects with comprehensive expectations of reproducibility; (ii) public–private partnerships for contemporaneous quality support in laboratories; (iii) making research institutions accountable for quality control; (iv) supporting new quality filtering standards for scientific journals and repositories, and (v) establishing a new network of centers for scientific health communications.

Keywords: international scientific competition; quality and reproducibility; health misinformation; health communication; public policy; biomedical research

Introduction

Research in life sciences has produced many astonishing discoveries leading to major improvements in public health as well as economic progress. Meanwhile, the outstanding discoveries are coming from a growing stream of publications that also carry large amounts of marginal and questionable results. Considering the major societal interest in greater scientific progress, it is important to look into the driving forces of change.

The partnership of democracy and scientific progress is facing unprecedented challenges

The history of modern science shows that freedom and democracy represent the fertile ground for productive research and resulting major scientific discoveries. Not just vast amounts of published research results but also 98% of Nobel prize-winning discoveries come from highly developed economies of democratic societies (Table 1).

When democracy is absent or destroyed, scientific research is also impaired. Until 1933, Germany was the number one producer of Nobel Prize-winning discoveries, but after the Nazi rise to power, there was a dramatic shift of research productivity to democracies, primarily to the United States. Apparently, wide-ranging, successful scientific progress cannot flourish on the narrow understanding of authoritarians.

Table 1. Country affiliation of 21st century STEM Nobel laureates at the time of the award (Nobel Prize Organization, 2023)

Country	Physics	Chemistry	Medicine	Total
United States	33	35	31	99
United Kingdom	4	4	9	17
Japan	6	5	4	15
France	3	2	3	8
Germany	3	3	1	7
Switzerland	2	2	0	4
Israel	0	4	0	4
Australia	1	0	2	3
Canada	2	0	1	3
Norway	0	0	2	2
China	1	0	1	2
Russia	2	0	0	2
Sweden	0	0	1	1
Belgium	1	0	0	1
Italy	1	0	0	1
The Netherlands	0	1	0	1

Dictatorships can concentrate unparalleled resources for accelerated progress in prioritized promising fields. The jet engine development in Nazi Germany and the remarkably successful early space program of the Soviet Union are some of these examples. However, the full breath of scientific progress, game-changing role of accidental discoveries, and breathtaking progress in unexpected areas are more clearly happening in democracies.

Scientific progress is not just the product of freedom and democracy but also the primary defender of these values. Scientific discoveries and subsequent technological achievements are essential for not only economic progress but also serve as the vital resources for democracy. A recent article in Nature pointed out that the concept of "arsenal of democracy" remains as relevant now as it was 83 years ago, but now it relies on data, analytics, and many other innovations (Janicke & Brown, 2022). Therefore, increased investment should drive production, research, and innovation.

Although the physical, chemical, and information sciences have received the most attention in recent decades, it is broadly anticipated that biological and life sciences will play an increasingly influential role in the future. The recently launched Congressional National Security Commission on Emerging Biotechnology recognizes the momentous changes in this field. Accelerating progress of life sciences should be among the preeminent strategic priorities in democratic societies.

Widespread deficiencies of research quality and non-reproducible results

In recent decades, biomedical research has produced many major discoveries and public health improvements but there are also alarming reports as to the ineffectiveness of the research enterprise.

Table 2 summarizes several of the highest impact scholarly studies presenting evidence on the pervasive quality defects and non-reproducibility in biomedical research. The results of these publications have been corroborated by many synergistic studies. To achieve improvement in these deficiencies, four policy recommendations are directly addressing points of intervention at the level of research funding, institutional action, laboratory level action, and publication phase quality filtering are addressed and advanced below.

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Table 2. Major quality deficiencies and their estimated frequencies in biomedical research

Defect	Evidence	References
High rate of non-reproducible preclinical research results in studies (79%–89%)	Bayer scientists were able to reproduce only 21% of 67 target-validation projects Amgen scientists found only 11% reproducible in among 53 studies	Begley and Ellis (2012), Prinz et al. (2011)
Frequent design and conduct deficiencies of preclinical research (22%–82%)	In study design category, missing power calculation 82.3%) In cell line category, mixed contamination 22.4% In analysis category, the use of chi-square test when expected cells <5 frequency 15.7% In reporting category, failure to state number of tails 65%	Mansour (2020)
Between 40% and 74% of clinical trials provide uninformative results that are not meaningful for patient care, research, or policy-making	The avoidable waste due to inadequate clinical trial methods was estimated at 42% The proportion of clinical trials meeting four conditions for informativeness was only 26.4%	Hutchinson et al. (2022), Yordanov et al. (2015)
More than half of clinical trials become unfinished or non-reported.	Among completed trials, almost a third not published in the peer-reviewed literature after 4 years. More than half of clinical trials yielding negative results remain unpublished	Ioannidis et al. (2014), Rees et al. (2019)

Of course, research hypotheses often turn out to be incorrect, but that is normal reflection of our understanding of nature, definitely not an error. Especially, in basic research, one may not always know in the beginning how initial hypotheses will be confirmed or denied at the end. Surely, when the hypothesis is logical based on what we know but turns out to be false in the experiment that is not a quality deficiency. Nobel Laureate John Gurdon's frog experiment with the unique gene illustrates the value of unexpected "non-reproducibility" that became the starting point of a valuable discovery.

On the other hand, complexities of the life sciences research process make it prone to deficiencies. Many research projects show signs of fatal but completely avoidable deficiencies like corrupted reagents or gender biased samples. A rapidly growing number of studies identified the various causes of quality defects that threaten reproducibility, credibility, and rigor of biomedical research. As Table 2 summarizes, quality defects in biomedical research are ubiquitous and originate from a multitude of sources.

Publishing non-reproducible results (i.e., giving the appearance that the results are reproducible) is a serious quality defect that must be avoided. Such non-reproducible research results represent a significant threat not only to the integrity of science but also to effective implementation for health care improvement derailing industry progress and causing vast economic losses.

Based on abundant evidence, quality defects invalidate more than half of scientific research and publication. However, this major shortcoming is still underestimated by our society and often overlooked by the research community. Although systematic quality improvement efforts are lacking, measuring the prevalence of quality deficiencies is gradually becoming more frequent.

The societal impact of research defects

The severity and frequency of errors in life science research are sources of a multitude of societal and public health harms. Experiments can lead to negative but valuable and publishable results. However, major research defects make any kind of study useless, regardless of positive or negative outcome. The harms go far beyond missed opportunities for beneficial discoveries, new treatments for major diseases, better understanding of nature, or improvements in overall wellness and life expectancy.

Most noticeably, useless participation and sacrifice of study participants raise significant ethical concerns. A study showed that 29% of registered clinical trials remain unpublished, and these trials had

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an estimated total enrollment of nearly 300,000 participants (Jones et al., 2013). Adding to this number, the published but flawed trials in the range of 32–53% (Balas et al., 2024), participation in defective trials probably impacts twice as many people who are unnecessarily exposed to varying levels of risks and inconveniences.

Publication of untrustworthy clinical trial results can also mislead subsequent clinical practice guidelines and degrade the effectiveness of health care. For example, it was recommended that tranexamic acid should be given preventively to everyone undergoing a caesarean based on the results of 36 clinical trials. Later, a large US-led trial with 11,000 people reported no statistically significant benefits (Pacheco et al., 2023). Moreover, it turned out that many of the originally analyzed 36 clinical trials were untrustworthy (Van Noorden, 2023).

Defective biomedical research can also drain and mislead subsequent scientific studies. A survey of cancer researchers indicated that 50% of respondents had experienced at least one episode of inability to reproduce published data (Mobley, 2013). According to an analysis, 788 retracted English-language papers were further cited over 5000 times by other researchers and over 70,501 patients were enrolled in 851 secondary studies citing the retracted papers.

The expenses associated with wasted research are also astounding. It is estimated that unreliable preclinical research generates direct costs nearly $28 billion annually in the United States alone (Freedman et al., 2015). For example, more than a hundred million animals are used in laboratory experiments every year (i.e., frogs, mice, rats, hamsters, dogs, etc.) The ratio of useless sacrifice of animals is probably more frequent than fruitless participation in human experiments (Kilkenny et al., 2009). Adding to the losses of unreliable preclinical research projects, the costs of non-reproducible clinical research studies further increase the financial losses.

Tectonic shift in the production of life sciences

When the number of research publications is the measure, a definite change can be observed in scientific production on the global scale. The NIH National Library of Medicine applies rigorous criteria for the selection of biomedical research journals to be indexed in its PubMed Medline database. In recent years, a major shift can be observed in the production of Medline indexed scientific articles based on the institutional affiliation and country location of the first author (Table 3 based on the PubMed Database, 2023). The illustrative Medline term "stroke" shows that not only the volume of articles is growing but the sources of such articles are also rapidly shifting. Considering the benefits of cultural diversity in scientific investigations, the essential role of independent replications, and the need to meet needs in many more countries, global diversification of the scientific enterprise is a desirable trend but also has competitive implications.

Obviously, the number of research publications cannot be equated with innovation resulting from scientific discoveries. The number of articles on COVID-19 and the vaccines developed by the same country as registered by the World Health Organization show major discrepancies. Several European and North American countries have been sources of comparatively fewer publications but still highly successful in vaccine development, particularly mRNA type vaccines. Meanwhile, China and Japan have been very active in publishing research on COVID but much less successful in vaccine development.

These and other discrepancies should further highlight the quality attribute of research that is essential for success but not captured by simply counting the number of published scientific articles. Meaningful innovation in key technological areas requires important but less obvious qualities, far beyond any bean counting of research production.

Scientific evidence is out of sight while misinformation puts lives at risk

In the midst of research production challenges, the general public or taxpayers lack meaningful access to the latest and best scientific evidence. With the exception of publications behind paywalls,

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Table 3. Shifting sources of research production: "Stroke"[MeSH Term] more than 50 articles

2012		2017		2021	
Harvard = 103	United States	Harvard = 160	United States	Capital Medical University = 206	China
University of California = 86	United States	Capital Medical University = 133	China	Harvard = 144	United States
Charité = 81	Germany	University of California = 126	United States	University of California = 114	United States
Massachusetts General Hospital = 64	United States	Massachusetts General Hospital = 109	United States	Beijing Tiantan Hospital = 106	China
Utrecht University = 62	the Netherlands	Mayo Clinic = 97	United States	Mayo Clinic = 101	United States
Karolinska Institute = 54	Sweden	University of Toronto = 87	Canada	Massachusetts General Hospital = 95	United States
		University of Calgary = 84	Canada	University of Calgary = 77	Canada
		Utrecht University = 81	the Netherlands	Hamburg-Eppendorf University = 71	Germany
		Duke University = 79	United States	Stanford University = 68	United States
		Stanford University = 69	United States	University of Toronto = 65	Canada
		Charité = 65	Germany	Sichuan University = 64	China
		Medical University of South Carolina = 65	United States	Utrecht University = 63	the Netherlands
		Beijing Tiantan Hospital = 61	China	Fudan University = 61	China
		University of Birmingham = 58	United States	University of Melbourne = 55	Australia
		University of Oxford = 55	England	West China Hospital = 55	China
		Karolinska Institute = 54	Sweden	Karolinska Institute = 54	Sweden
				University of Oxford = 53	England
				Washington University = 53	United States
				Monash University = 51	Australia
				Charité = 51	Germany

competent health professionals and researchers can find relevant scientific information. However, obscure websites, nonpractical search engines, highly technical language, and inconsistencies of scientific reporting make essential information largely inaccessible to the general public. Health misinformation is spreading fast and easily but scientifically sound information is often difficult to find and hard to understand.

In spite of good science being the key to better health, it is often pushed aside and crowded out by misinformation on social media and other popular sources of information. Health misinformation is

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Table 4. Major sources and risks of health misinformation

Defect	Evidence	References
High frequency of misinformation	Health misinformation was most prevalent related to smoking products and drugs such as opioids and marijuana (87%), vaccines (43%), diets or eating disorder (36%), non-communicable diseases and pandemics (40%), and medical treatments (30%).	Suarez-Lledo and Alvarez-Galvez (2021)
High frequency of misinformation	Among 800 vaccine-related Pinterest posts 74% were anti-vaccine in sentiment	Guidry et al. (2015)
Rapid spread of misinformation	Misinformation about Zika was three times more likely to be shared than verified stories on social media, with half of the top 10 news stories regarding Zika were misinformation.	Sommariva et al. (2018)
Misinformation by peers is most difficult to correct	A meta-analysis of social media interventions designed to correct health-related misinformation found that interventions were more effective when misinformation was distributed by news organizations (versus peers) and when debunked by experts (versus nonexperts).	Walter et al. (2021)

defined as a health-related claim that is based on anecdotal evidence, false, or misleading owing to the disregard for existing scientific knowledge (Chou et al., 2018).

Receiving harmful health misinformation became a frequent experience for most internet and social media users (Office of the Surgeon General, 2021; Wang et al., 2019). The examples are almost endless: anorexia popularized as fashion and ideal beauty, Zika virus portrayed as a bioweapon, misleading portrayal of health effects of tobacco to generate positive image of smoking, fraudulent linkage of MMR vaccine to autism, dubious and unsubstantiated "treatments" for cancer, diabetes, heart disease, and others (Table 4). Occasionally celebrities add credibility to worthless or harmful health misinformation.

Apparently, false and misleading health information spreads more easily than scientific knowledge through social media (Vosoughi et al., 2018). False news stories were 70% more likely to be shared on social media than accurate information. According to an analysis of health misinformation on social media, the frequency was the highest on Twitter and on issues of smoking products and drugs with vaccines and major diseases following (Suarez-Liedo, 2021). Misinformation is often more popular than factual messages (Wang et al., 2019). The rise of false information has created an urgent threat and it is literally putting lives at risk.

Under the NIH Public Access Policy, there is open access to published results of NIH-funded research at the NIH NLM PMC website, a free digital archive (NIH, 2024). NIH-funded investigators are required to submit to PMC an electronic version of the final, peer-reviewed manuscript upon acceptance for publication. In the prevailing absence of plain language summaries, even openly available scientific literature has major limitations in supporting access by the general public.

Simply spending more on research will not be enough in the global competition

The common public policy response to the need for more research and more discoveries is more funding. The call for more funding comes not only from the research community but also from the general public and political leaders. A 2022 survey commissioned by Research!America found that more than 9 in 10 Americans (92%) agree investing in research is important to finding new ways of preventing, treating, and curing illnesses.

Indeed, the budget of the NIH was doubled by Congress between 1998 and 2003. The funding increases have led to more research and expansion of the research enterprise with some variability over time. In return, more investment in science increased the number of valuable results and strengthened competitiveness. According to Azoulay et al. (2019), for every $10 million of funding, NIH-supported

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research has generated a net increase of 2.7 patents. Furthermore, NIH-funded articles have greater journal impact factors than non-NIH-funded articles (5.76 versus 3.71, Lyubarova et al., 2009).

According to the NSF, the share of global R&D performed by the United States declined from 29% to 27%, whereas the share by China increased from 15% to 22% between 2010 and 2019 (Burke et al., 2022). The Chinese economy is projected to overtake the US economy in 2030 (Jenkins, 2022). Research and development expenditures as percentage of GDP were 2.40% in China and 3.45% in the United States in 2020, with the former growing more rapidly (Zhou, 2024).

Without major adjustments in research growth strategies, any country relying only on the spending model of growing research will inevitably end up in a second-class role. "The Chinese economy is probably going to be at least twice as big as the US' economy, maybe three times," summed up Elon Musk at the Air Warfare Symposium in Orlando, Florida in 2020. "If you're not innovative, you're going to lose." The only way to compete is improvement in quality, effectiveness, productivity, and overall innovativeness of scientific research.

It should also be noted that the rigid reliance on the traditional peer review system and the usual university promotion and tenure measures of scientific productivity limit improvements of research quality. For example, the serious limitations of peer review have multiple components: it is based only on inspection of the final product, the scientific manuscript. Just like auto manufacturing quality cannot be accurately judged or improved based on inspection in the dealer's showroom, peer review is also limited. Submitted manuscripts have only what the authors want to communicate, and often essential details and underlying data are missing. Most reviewers are overloaded, and the review process itself is almost entirely voluntary.

There have been several meritorious attempts to go beyond publications and define a fuller range of scientific products in assessing the productivity of research (e.g., Bernard Becker, 2014). However, none of these efforts have been successful in changing the mainstream of research productivity evaluations.

While each of the above described deficiencies of the biomedical research enterprise deserves many more studies and focused actions, the already accumulating evidence is more than enough to urge formulation of national policies that can not only advance relevant studies but also likely to improve the quality and availability of research results. What is becoming obvious is that the overwhelming majority of quality defects are produced in the research process prior to publication. Therefore, the focus should remain on improving the research process itself.

Lines of policy actions to improve quality and productivity of research

In response to the recognition of quality deficiencies in research, numerous national and local efforts have been initiated. Some involved addressing the elected aspects of quality and rigor (e.g., gender representation in samples, reagent authentication). Others include monitoring of retractions in the scientific literature. It is also hoped that the launching of Advanced Research Projects Agency for Health will bring new energies into the production of impactful research and development activities. Although these and other efforts are meritorious, they are by no means sufficient to address the multitude of quality and productivity problems in the research enterprise.

Effectiveness of the entire life sciences research enterprise must be regularly examined and improved continuously. Occasionally, counter-intuitive but very effective legislative changes can make a huge difference as exemplified by the highly successful Bayh-Dole Act in making intellectual property from university research available for technology innovation (Mowery et al., 2001). The following is a list of national policy actions in major directions of research quality improvement:

Support research with higher expectations of quality and reproducibility

Continued funding increases that exceed inflation remain essential and also promise good return on investment. The calls are multiplying that funders should be clearer in expecting quality and reproducible research results (Moher et al., 2016).

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While studies showed that spending on research generates considerable economic activity and therefore contributes to economic growth but the results should be trustworthy and reproducible (Macilwain, 2010). To provide a better foundation for the development of new technologies and greater economic activity, research project solicitations, requests for applications and requests for proposals, should set not only research priorities but also research quality expectations, including quality control, waste reduction, and reuse of results (Moher et al., 2016). Federal funding is also needed for research effectiveness studies, including but not limited to science of science studies on prevention of non-reproducibility and development of practically applicable research results.

At the federal level, there should be an Office of Research Quality and Participant Protection to comprehensively monitor quality control, promote availability of results, and protect the value of investment in scientific research. This could be somewhat analogous with the quality control of health care by the Center for Clinical Standards and Quality in the Medicare and Medicaid programs (CMS, 2024). The Office should present an annual report to Congress on value, reproducibility, and effectiveness of federally funded research, develop recommendation to improve quality, and oversee the representation of interests of research subjects. This Office should be separate from the Office of Research Integrity that oversees and directs Public Health Service research integrity activities on behalf of the Secretary of Health and Human Services. The problem of research misconduct should be kept separate from the genuine and comprehensive quality improvement efforts.

Public–private partnerships for contemporaneous quality control support in research laboratories

The epicenter of research innovation is the creative researcher working in the laboratory. Several authors have directed attention to the central importance of laboratories in reducing waste from biomedical research (Ioannidis et al., 2014; Stroth, 2016); Obviously, it is essential to improve research quality and reporting at the time of production rather than afterward. It would be important to engage basic and clinical scientists, including early-stage researchers, in the discussions about quality control measures. There is a great need to gain a better understanding of correctable errors, including those that are unrecognizable in the scientific review process of final reports. In partnership with the private sector, the federal government should support the development of systems and services for on-the-go quality support in biomedical research laboratories.

Experience in several industries shows that quality cannot be meaningfully assessed just by inspecting the final product. For example, the Food and Drug Administration that is responsible for assuring the quality and safety of new treatments requires not only the presentation of product samples and clinical test results but also access to the manufacturing facilities to make sure that the production process maintains quality and delivers consistent product (FDA, 2024). Nothing like that exists in the research enterprise. Consequently, the entire research documentation process should be reformed by not just making it more transparent but also smarter in terms of guiding advising researchers about the steps to follow or avoid at various important decision points of biomedical research.

Make research institutions accountable for production quality and reproducibility

Research universities have a significant responsibility for maintaining excellence in research quality and output. Consequently, they need to foster an environment that supports scholarly work, research faculty creativity, and the opportunity to conduct advanced projects (Vernon et al., 2018). Among others, core research instrumentation services, like electron microscopes, mass spectrometers, and NMR machines, are pivotal components of a university's research infrastructure, enabling groundbreaking science by providing access not only to cutting-edge technologies but also quality control and collaborative environments that drive innovation and knowledge creation.

Institutions that receive significant federal support for facilities and administration expenses should take ownership of quality assessment and improvement efforts at the institutional level. Deficiencies,

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especially those leading to non-reproducible results are often hard to recognize and manage at the level of individual research laboratories. Although individual research projects may show many variations and exceptions, improving recruitment of patients and completion rates of randomized clinical trials need to be institutional priorities (Finkelstein et al., 2015; Robishaw et al., 2020). Research institutions should be encouraged to assess the quality of intramural research, launch improvement initiatives, and use new metrics of societal impact and outcome assessment.

Increasing the practical impact of research urges shift in evaluation of scientific productivity toward more impact-oriented assessments of research. It is believed that fewer than half of faculty inventions with commercial potential are disclosed to their employing universities (Jensen et al., 2003). The San Francisco Declaration on Research Assessment, released by a group of editors and endorsed by more than 23,000 signatories in 161 countries, advocated for moving away from evaluating researchers using journal-based metrics toward recognition for data sets, software, and influence on policy (Pain, 2023). The current system of research assessment that relies primarily on the number of publications and research grants received is no longer justifiable.

The procedural measures should be regularly supplemented and in some extent, replaced with outcome measures of practical impact that include, for example, licensable intellectual property and use of research results by practitioners (Balas & Elkin, 2013). Such demonstrations of beneficial research outcomes should by no means disadvantage curiosity-driven research as illustrated by most Nobel prize-winning discoveries of recent decades that led to large number of patents, new clinical services, changed practice guidelines, and many other important outcome improvements.

Expect stated quality filtering standards from scientific journals and repositories

Peer review of scientific reports at the time of publication is not the only step of quality control but remains an important milestone. The already emerging trend requiring simultaneous data publication and reliance on internationally accepted research standards, or collections of such standards like EQUATOR network, should be greatly expanded to increase transparency and improve quality control of the research process (Altman & Simera, 2016). Eventually, reported research should become auditable by independent reviewers.

Several interventions have been proposed and studied to improve the quality of peer review in scientific publishing, among them providing training and guidelines for peer reviewers, utilizing checklists or structured review forms, implementing open peer review practices, and exploring post-publication peer review. The peer review process could be greatly strengthened with more structured quality assessments. Although some interventions have shown promise, more rigorous research is needed to establish evidence-based practices for improving the quality of prepublication review (Bruce et al., 2016).

With the move toward open access and easy publication through the internet, the primary function of scientific publishing is protection of research integrity and quality control of research results. In indexing and acceptance, federal agencies and research funders should prioritize journals with acceptable quality control processes and should set standards for such filtering. Such efforts should cover not only the traditional scientific journals but also the rapidly growing scientific data repositories that are at risk of being inundated with questionable submissions (Husen et al., 2017). Journals and publishers of research results, including scientific data repositories, that disseminate federally funded research should publish regularly updated statements regarding quality expectations, quality control, preservation, and security measures.

Launching a network of centers for scientific health communications

The fight against health misinformation should start with better communication of sound science and evidence. It is not sufficient just to produce scientific evidence, but funders should spend more effort on

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getting it to the users and the public. Patients, families, and communities should be served with not just more science but also easy-to-understand communication of the most impactful discoveries. Currently, several institutions provide scientifically sound patient information, but these efforts do not receive federal support and cannot be fully comprehensive or up to date on the latest developments (e.g., Cleveland, 2024; Mayo, 2024).

Perhaps through a targeted grant program, federal investment is needed to launch and support scientific evidence centers serving various constituent communities. Obviously, no government agency can serve as the trusted source of plain language scientific information. However, federally funded centers could collect appropriately processed evidence and communicate plain language summaries to major patient groups and key communities. Multiple evidence centers could avoid the impression of government-mandated or endorsed scientific evidence.

These centers for scientific health communications should produce and disseminate plain language communications (FitzGibbon et al., 2020; Rosenberg et al., 2021). The plain language messages should be clear, nontechnical, and easily understandable descriptions of medical and scientific evidence. Graphical summaries, medium-complexity text summaries, and videos appear to be effective. The centers could serve, for example, K-12 education, major disease groups, local community leaders, employee wellness programs, and many others.

Apparently, many people like plain language lists as they can guide practical actions. To preserve connection with good science, it remains important to have links to at least one but preferably more peer-reviewed research publications with substantiating evidence. Of course, many action lists could include items coming from experience and not from research, but acknowledging them accordingly would add to the credibility of scientific communications.

In conclusion, improving the quality and productivity of biomedical research is becoming an ethical, scientific, health care effectiveness, public health, budgetary, and national security imperative. In many ways, improving productivity and effectiveness of the scientific enterprise, particularly life sciences, is the key to future societal progress, economic growth, and public health alike. Scientific research, technology innovation and effective production are the arsenal of democracy. The productive synergy between democracy and scientific research should not only be maintained but also strengthened in the interest of human progress and democratic societies.

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