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COMMENTARY

Team science and the physician–scientist in the age of grand health challenges

Clifford J. Steer,[1] Peter R. Jackson,[2] Hortencia Hornbeak,[2] Catherine K. McKay,[3] P. Sriramarao,[4] and Michael P. Murtaugh[4]

[1]Departments of Medicine and Genetics, Cell Biology, and Development, University of Minnesota Medical School, Minneapolis, Minnesota. [2]Division of Extramural Activities, National Institute for Allergy and Infectious Diseases, National Institutes of Health, Bethesda, Maryland. [3]The Humphrey School of Public Affairs, University of Minnesota, Minneapolis, Minnesota. [4]Department of Veterinary and Biomedical Sciences, College of Veterinary Medicine, University of Minnesota, Minneapolis, Minnesota

Addresses for correspondence: Clifford J. Steer, Departments of Medicine and Genetics, Cell Biology, and Development, University of Minnesota Medical School, MMC 36, VFW Cancer Research Center, 406 Harvard Street, S.E., Minneapolis, MN 55455. steer001@umn.edu; or Michael P. Murtaugh, Department of Veterinary and Biomedical Sciences, College of Veterinary Medicine, University of Minnesota, 1971 Commonwealth Avenue, St. Paul, MN 55108. murta001@umn.edu

Despite remarkable advances in medical research, clinicians face daunting challenges from new diseases, variations in patient responses to interventions, and increasing numbers of people with chronic health problems. The gap between biomedical research and unmet clinical needs can be addressed by highly talented interdisciplinary investigators focused on translational bench-to-bedside medicine. The training of talented physician–scientists comfortable with forming and participating in multidisciplinary teams that address complex health problems is a top national priority. Challenges, methods, and experiences associated with physician–scientist training and team building were explored at a workshop held at the Second International Conference on One Medicine One Science (iCOMOS 2016), April 24–27, 2016, in Minneapolis, Minnesota. A broad range of scientists, regulatory authorities, and health care experts determined that critical investments in interdisciplinary training are essential for the future of medicine and healthcare delivery. Physician–scientists trained in a broad, nonlinear, cross-disciplinary manner are and will be essential members of science teams in the new age of grand health challenges and the birth of precision medicine. Team science approaches have accomplished biomedical breakthroughs once considered impossible, and dedicated physician–scientists have been critical to these achievements. Together, they translate into the pillars of academic growth and success.

Keywords: academic medicine; one health; health policy; health research

Introduction

Human societies face complex global challenges to health. At the individual level, causes and cures of disease are influenced by genetic and epigenetic variation, diet, endogenous microbial communities, social status, external environment, and, perhaps, by factors not yet understood. Community and population health are influenced by air, water, and food quality, cultural histories, medical access, and additional factors. The discovery of interventions and the practice of medicine at all levels is daunting, because the causes of many biomedical problems are unknown.

Consensus exists that complex health problems are best addressed by teams of collaborative experts with complementary skills in different fields, including basic science, the medical and social sciences, engineering, and economics. The increased integration of diverse experts into research programs is an important shift from the traditional model of independent researchers pursuing single projects. Operationally, team science requires developing and then sustaining collaborative, cross-disciplinary

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researchers committed to specific programs. The challenge is to adapt the development and training of scientists and physicians so that expert teams are considered standard, and not the exception.

To address team science implementation in biomedical research, the International Conference on One Medicine One Science (iCOMOS www.icomos.umn.edu), under the direction of Dr. Clifford J. Steer of the University of Minnesota Medical School and Drs. Hortencia Hornbeak and Peter Jackson of the National Institute of Allergy and Infectious Diseases of the National Institutes of Health, coordinated a daylong workshop. Important points of the workshop were how to foster team science and the importance of physician–scientists to the success of science teams. Team science presentations featured components of successful collaborations, including models, practices, tools, and funding strategies. Experts from schools of medicine, veterinary medicine, nursing, dentistry, and biomedical engineering spoke about barriers to training physician–scientists within modern training structures and strategies for overcoming those barriers. Talks and a panel discussion addressed challenges to developing physician–scientists and how team science can meet the challenges.

Team science

Team science encompasses collaborative efforts to address challenges through leveraging of the strengths and expertise of professionals trained in different fields. Although traditional single investigator–driven approaches can be effective for many scientific endeavors, teams of investigators with diverse skills and knowledge may be best suited to capitalize on new opportunities arising from unforeseen advances in the biomedical sciences and to address complex health challenges due to aging populations, living in unhealthy environments, inadequate nutrition, and other adversities. It is important to distinguish team science from the science of team science (SciTS). Team science initiatives are designed to promote collaborative, and often cross-disciplinary (including multi-, inter-, and transdisciplinary) approaches to answering research questions about particular phenomena. The SciTS field encompasses conceptual and methodological strategies aimed at understanding and enhancing the processes and outcomes of collaborative, team-based research. SciTS experts are concerned with (1) understanding and managing circumstances that facilitate or hinder the effectiveness of collaborative science and (2) evaluating the outcomes of collaborative science.

There is growing knowledge about effective strategies for implementing and successfully managing science teams, as well as a rapidly expanding scholarly literature on the academic discipline of SciTS.[1] Most importantly, the SciTS field focuses on understanding and enhancing the antecedent conditions, collaborative processes, and outcomes associated with team science initiatives.[2] They include scientific discoveries, educational outcomes, and translation of research findings into new practices, patents, products, technical advances, and policies.

Organizing a team approach to problem solving presents investigators with difficult questions and choices. Some variables include the level of desire to contribute to complex problem solving; the need to protect one's own interests; the availability of a value system placing value on individual as well as team success; and other tangible and intangible factors. Other variables are that individual interests often vary widely across disciplines; roles within a group may require different skills and temperaments; and the expected contributions and benefits of joining the team need to be articulated early, clearly, and carefully. Gaetano Lotrecchiano, assistant professor of Clinical Research, Leadership, and Pediatrics at George Washington University, presented facilitation tools to help accomplish the task of team building. He emphasized that personal interests and motivations are important to uphold and must not be lost in assessing the interests of the team.[3,4] Collaborative leadership resources include the important welcome letters that orient team members to the project's components and frame the expectations of teamwork. Strategies for identifying potential team members were further explored by Griffin Weber, associate professor of Medicine at Harvard Medical School. Finding collaborators starts with investigating the faculty and researchers at one's own institution, often by talking to those with similar research interests but in different departments. Open-source academic professional networking programs and services provide access to more researchers in one or many fields.[5] Resources include general academic social networking websites, field-specific services, and institution-specific sites.

Initiating collaborations across fields is akin to breaking ice jams, in part because disciplinary expertise creates barriers against cross-communication and awareness. However, successful modern medical investigations into complex phenomena require diverse expertise. As an example, emergencies such as the Flint Water crisis or spikes in Legionnaires' disease required coordinated responses by experts in public health, policy, governance, engineering, justice, and medicine. The challenge is to successfully integrate experts with different values, priorities, core beliefs, and languages. This integration requires proactive approaches that facilitate a clear understanding, acceptance, and respect of differing points of view and perspectives while focusing on uniform, coherent goals among team members.

In addition to disciplinary expertise, effective science teams are diverse in employment sector (academic, government, and industry), location, culture, nationality, and involvement extent. Different strategies can be employed to facilitate the efficiency and effectiveness of integrating individuals into cohesive teams. Effective collaborations are often based on structured communication approaches by which experts become aware of cross-disciplinary ideas, approaches, and expectations. Michael O'Rourke, professor of philosophy and faculty in AgBioResearch at Michigan State University, presented strategies to break the ice and initiate critical information flow, including, for example, toolbox dialogue that builds collaborative capacity through the use of structured dialogue to identify implicit assumptions and values.[6,7] Concept mapping illustrates complex project elements, illuminates interdependency, and facilitates understanding of language, values, and beliefs in an effort to negotiate a common project framework. Lastly, sociotechnical integration research seeks to heighten reflexive awareness and enable effective communication among technical experts and humanists.[8]

In sum, a growing trend within team science is cross-disciplinary science in which team members with training and expertise in different fields work together to combine or integrate their perspectives in a single research endeavor. Cross-disciplinary team science facilitates expansive studies that address many complex, interacting variables and is a promising approach to accelerate scientific innovation and the translation of scientific findings into effective policies and practices. Team science success is influenced by contextual factors that affect each stage of a scientific initiative, with implications for efficiency, productivity, and overall effectiveness. They include (1) funding trends; (2) institutional infrastructure and resources for research, communications, and data sharing; (3) organizational policies—such as promotion and tenure policies—that affect team-based endeavors; (4) team processes, including the existence of agreements related to proprietary rights to data and discovery, as well as mechanisms for feedback and reflection; (5) team member interpersonal dynamics, and (6) team member collaborative skills and experiences. While challenges to team science success can be formidable, potentially enormous impacts can result from successes.

Physician–scientists

With respect to health, physician–scientist team members provide a veritable Swiss Army knife of expertise spanning discovery research to bedside interventions. The United States National Institutes of Health (NIH) defines the physician–scientist workforce (PSW) expansively to include MDs, MD–PhDs, nurse–scientists, dentist–scientists, and veterinarian–scientists who spend the majority of their time in biomedical research. While the definition includes many professionals, most NIH support of the PSW is directed to MDs and MD–PhDs. Physician–scientists are broadly trained in medicine and science, they understand the One Medicine One Science (OMOS) vision, and they incorporate multidisciplinary perspectives and knowledge when addressing complex issues. The PSW is active in translational medicine and clinical research and essential in transforming the results of biomedical research into clinical practice.

The struggle to increase the number of physician–scientists

A 2014 NIH report on the PSW included recommendations for improving MD–PhD training programs, increasing the diversity of students and investigators, restructuring the support of individuals, addressing barriers for new and independent investigators to access awards, and tracking the capacity and performance of the PSW.[9] The need for a multipronged approach was delineated by Brooks Jackson, vice-president for Health Sciences and dean of the University of Minnesota Medical School, who summarized difficulties associated with increasing the number of physician–scientists and keeping them engaged in research. The approximately 14,000 physician–scientists in the United States constitute only about 1.5% of U.S. MDs. About 7000 of these physician–scientists have an MD–PhD. The important concern is that the number of physician–scientist principal investigators (PIs) on NIH grants (8200) has been flat for 30 years, while the number of PIs with PhDs alone has increased. Currently, only about 30% of NIH-funded PIs have an MD degree. Thus, about 70% of NIH-funded PIs are PhDs without medical practice training.

Dean Jackson noted that the challenge facing the biomedical research community is not to produce more dual degree MD–PhDs. There are more physician–scientists and more MD–PhDs graduating than ever before and, over the past 30 years, the number of MD–PhDs as a proportion of all MD graduates has increased from 0.8% in 1985 to 3.3% in 2015. The critical challenge to the biomedical research community is retaining successful physician–scientists who face increasingly difficult career environments when compared with the lucrative career opportunities available to MDs providing direct clinical care. Physician–scientists face larger financial hardships, increased training burdens after graduation, and greater challenges to the work/home life balance. Private practice pays more than a career in research, and educational debt is higher than ever. To highlight the financial burden, at the University of Minnesota, the cost for MD–PhD training is $435,000, while the cost for MD training alone is $138,000. Students matriculating into medical school are older than in previous generations and the MD–PhD requires more years of training and additional time in postdoctoral positions. After research training, a physician faces the challenge of obtaining NIH funding; the age at first award averages 44 years for MD–PhDs and 45 years for MDs. These ages are 10 years later than the average ages at first NIH award in 1980. NIH also has a salary cap, which further discourages graduates who must manage a high debt load.

Additional burdens for physician–scientist graduates include decreasing reimbursement rates for clinical research and decreasing state and non-NIH federal funding. There also are requirements for maintaining board certification, increased regulations for clinical research, and stringent rules for licensing and professional accreditation.

The motivation to pursue research is further reduced by loan-forgiveness programs that provide incentives for physician–scientists to enter primary care and flexible training models that support direct clinical practice training, such as part-time programs. Medical schools now matriculate more diverse student cohorts, but students in these cohorts are not connecting to MD–PhD training. Their reasons range from debt burden to a desire to provide primary care to their communities, many of which are in rural areas. This disinterest in MD–PhD training is important, because female students and students of color can contribute greatly to research and can strengthen programs established to attract, train, and retain similar students.

Dean Jackson also spoke about the paradox that modern biomedical research requires interdisciplinary team science, yet many MD–PhD training programs remain centered on independent scientist models that lack appropriate team science development. In addition, academic departmental structures for promotion require the acquisition of individual research awards. The continued emphasis on training individuals who then acquire individual awards reinforces outmoded perceptions about the value of independent physician–scientists and impedes the acceptance of interdisciplinary team science.

While the specific influence of each challenge to physician–scientist training is not empirically known, MD–PhD retention is the most critical problem that demands innovative solutions. Training costs need to be addressed by developing more financing tools (scholarships, frozen tuition, and fellowships), and by piloting shorter, less expensive training models, such as designated research tracks and integrating medical and research training. In place of a formal PhD curriculum, some medical schools have shifted from traditional MD–PhD models to interprofessional training emphasizing team research or have created institutional physician–scientist career development programs for students and faculty in place of a formal PhD. The NIH is addressing retention by expanding loan-repayment programs for clinical research, training awards, grants for the transition from training to independent research, and awards for new investigators. Academic departments and faculty need to develop structures for promotion that more highly value and support team science and the participation of physician–scientists in collaborative research.

Physician–scientist training program: the Minnesota experience

The University of Minnesota Medical School training program for physician–scientists offers one example by which multitalented team science leaders can be developed, as well as the challenges that might be experienced. Erik Peterson, associate director of the Physician–scientist Training Program and associate professor of Medicine at the University of Minnesota, described this comprehensive post-graduate clinical residency and research-training program, which was established in 2002 and is based on the guidelines of the American Board of Internal Medicine Research Pathway. From 2002 to 2012, the program struggled with insufficient funds and administrative support and a low rate of program completion by candidates. A leadership change led to increased funding and a designated administrative coordinator. The additional resources supported new recruitment strategies on and off campus, social and recognition events, and development expenses for trainees. Recruitment strategies included combining residency and specialty fellowship interviews, group dinners with current trainees and directors, and meetings with investigators and potential mentors. In addition, accepted trainees could short-track residency and claim a guaranteed subspecialty fellowship slot. Trainee success has grown thanks to resource and strategic leadership improvements. From 2002 to 2012, the training program had seven graduates, of which three remain in academic research and four are in private medical practice. Since 2013, there have been three graduates, and all are in academia.

Other strategic program changes included coordinated training in partnership with the institutional review boards for human subjects and animal care and use, career development programs, and help in grant writing and manuscript preparation. Trainee projects are expected to seed cross-disciplinary teams and to engage with other professional schools and departments. A short-track residency with flexible scheduling weaves together research and residency time. The flexible scheduling quickens integration into research, resulting in earlier scholarly productivity and increased applications for NIH awards. The changes leading to a more successful training program required increased administrative efforts and strategic attention to funds allocation.

The Swiss Army knife, *sensu latu*, cuts a broad swath across the medicine–science spectrum to embrace nursing, dentistry, engineering, and animal medicine. In a panel discussion moderated by Gregory Vercellotti, professor of medicine, University of Minnesota, representatives across this spectrum shared their perspectives and experiences, revealing the kinds of challenges that are encountered in building diverse teams. Jaime Modiano, director of the Animal Cancer Care and Research Program and professor of veterinary medicine, showed how easily words can have multiple inferences. He noted that veterinarians serve several masters, most notably animals and owners. Thus, it is important to be aware of the implications of terms and language when discussing issues. For example, the phrase "the cost–benefit of cancer treatment" has different meanings when discussing human versus animal patients, and the topic is presented differently to the families of humans versus animals.

Mark Herzberg, professor of dental surgery and director of the Mucosal and Vaccine Research Center in the School of Dentistry, considered the word "team" as the important challenge to operating effectively together. "Team" implies that members are united to achieve common goals and objectives. However, team members with divergent backgrounds, perspectives, and expertise may be challenged to fully embrace projected objectives, problem solving approaches, or both. Because every team member needs to feel ownership of the question(s) under study and the approach(es), the likelihood of drift from a project or poor performance increases without consensus approval. For these reasons, the selection of team members is critical, requiring careful consideration of psychological factors in addition to technical and other merits.

For the nursing profession, teamwork is an essential part of the ethos. Connie Delaney, professor and dean of the School of Nursing, noted that nurse–scientists are key components of translational teams that transform scientific advances into better patient care. Nursing education and practice are based on interprofessional training that embraces team science ideals. Team approaches must be supported with appropriate infrastructures, including Big Data and data-sharing capabilities. The right infrastructure helps to realize the full potential of a team. As pointed out previously by Dean Brooks Jackson, one challenge in training nurse–scientists is developing a tenure process that values individual contributions to team success. Traditional tenure evaluations commonly consider only individual accomplishments rather than individual contributions to team accomplishments. Revision of tenure codes to increase the value of contributions to team successes is a primary issue for expanding willingness to participate in team science approaches to complex problems.

Engineering plays a key role in many team science programs, since the reduction of scientific findings to effective delivery of patient care is the end goal. Engineering is notably important for biomechanical aspects of patient treatment and is frequently essential in managing large-scale public health projects. Bin He, Distinguished McKnight University Professor of Biomedical Engineering in the College of Science and Engineering, expounded on collaborations among physicians and engineers to meet the demands of precision medicine for nanodevices, artificial structural and physiological replacements for damaged body parts, and other needs. Research funding is an important limitation to the rate at which bioengineering is fully incorporated into team science projects.

It is obvious that, in the future, team science will become indispensible for successful, collaborative translational research and for fulfilling the OMOS vision of bench to health for people and animals. As pointed out by Peter Igarashi, chair of the Department of Medicine, the traditional model of a clinical investigator who pursues mechanistic studies focused on a detail of a particular condition or disease while contributing equally to teaching and patient care is no longer viable given current time requirements for clinical practice, teaching, and research. The University of Minnesota Medical School is working to develop specialized faculty that collaborate effectively in properly assembled teams to advance medicine through science.

Physician–scientists and building a diverse team science workforce

Analysis of the Minnesota physician–scientist training experience reveals that time and structural priorities are major obstacles to training and integrating physician–scientists into high-functioning teams. Collaborations require more time and resources than independent projects and are fraught with greater uncertainty, since more unknowns are present at project initiation. For instance, coordinating schedules of participants with clinical practices can be stultifying. Medical culture changes in recent years appear to be placing more emphasis on clinical practice at the expense of scientific knowledge. Preprofessional and professional learning requires extensive memorization and practice, whereas physician–scientists must incorporate hands-on research and open-ended scientific inquiry. The shift from education focused on the scientific method to apprenticeship training is a threat to development of researchers. The focus on apprenticeships and the promotion of clinical practice are driven in part by economic pressures on medical schools. While cost recovery is a major challenge for academic teaching and research, the unintended consequence of doing the wrong thing for the wrong reason is that less attention is paid to the scientific training of physicians.

As mentioned, the American academic system, which favors individual accomplishments in research and teaching, is an obstacle to team science. Nevertheless, expansive programs to produce the Swiss Army knife physician–scientist in many manifestations (e.g., medical, veterinary, nursing, dental, engineer, social science, economics, and policy) are possible and should be favored in universities providing a full range of disciplinary knowledge. These institutions include the University of Minnesota, which has NIH-, U.S. Department of Agriculture–, and National Science Foundation–supported training programs that provide numerous opportunities for physician–scientist training in furtherance of OMOS. Collaborations and intellectual cross-fertilizations are promoted when potential team members are colocated and large public universities can institutionalize collaborations across academic units that share facilities and faculty in order to fully realize the vision of physician–scientists leading team science.

Because complex health problems pose multifactorial, plurisectoral challenges at the intersection of humans, animals, and the environment, an urgent need exists to provide all medical professionals with excellent scientific training and communication skills to develop, join, and lead teams that discover novel solutions to challenging problems. However, scientific teams that incorporate physician–scientists will never become routine if there is a failure of the developmental pipeline producing MD–PhDs. Development of physician–scientists and impactful problem solving can occur at multiple levels.

Physician–scientist development is well supported by NIH training programs, but these programs face significant issues, including fall-out due to the migration of highly trained experts to clinical medicine, gender disparities, and the lack of cultural diversity. Improved mentoring, institutional commitment, and funding agency dedication to team science can send powerful messages to new investigators about the value and significance of participating in expert groups committed to improving health. Gender balance is an evolving concern, and dedicated commitment to the integration of women into team science programs is essential. Such commitment is also common sense since, for more than a decade, women have constituted the large majority of incoming students in all medical disciplines. Strong institutional and sponsor support is essential to retain, mentor, and promote the career development of women and minorities committed to activities that advance multidisciplinary team building and problem solving.

The Minnesota experience demonstrates typical difficulties in training and successfully retaining skilled physician–scientists. Increased attention to effective recruitment and retention should be stressed. Successful training programs provide an environment that welcomes all students, including women and minorities. Students should see themselves as valued members of the institutions, programs, and research enterprises. The positive actions and behaviors of resident faculty are critical to trainee retention and the maintenance of the physician–scientist development pipeline. Institutional programs dominated historically by men must find ways to provide an academic environment comfortable and inviting to blacks, Latinos, women, and other highly intelligent individuals without prior benefit of advanced educational opportunities. Institutional commitments to mentoring and education are required to fully develop the latent skills and abilities of all students.

Physician–scientists, be they MD–PhD, DVM–PhD, DDS–PhD, or RN–PhD, are essential to the full realization of team science problem solving and advancement of human, animal, and environmental health. Lauren Trepanier, professor of medicine at the University of Wisconsin School of Veterinary Medicine, presented workforce models for collaboration across health professions that specifically engaged MDs with veterinary scientists. She observed that the term *clinician–scientist* rather than *physician–scientist* might be a more accurate and inclusive term, since it presents an all-encompassing idea of expertise in medicine. Veterinary medicine and science are paramount to advancing medical science and practice, and are critical when addressing epidemiological crises. Veterinary clinicians have experience with spontaneous animal models of metabolic, genetic, and infectious diseases that also occur in humans. These diseases are similar in phenotype to human diseases, compressed in time to onset, and occur in environments shared with humans. Veterinarians also have experience with and access to breeds and herds of known pedigrees and environmental backgrounds. These animals offer natural clusters of genetically and socially similar populations.

It has been noted that only 3% of NIH funding is awarded to investigators with veterinary degrees. There are NIH funding instruments for translational research, but they are specific and require programs to be explicit about the translational aspects of their research projects. Of 62 consortium sites, 10 are affiliated with veterinary schools. The veterinary clinical scientist training pipeline is limited. Two-thirds of the 35 North American members of the American Association of Veterinary Medical Colleges are in universities without medical schools, and only about 10 offer dual DVM–PhD programs. Pipeline failures for developing clinician–scientists in veterinary medicine include access (exposure, education, and interdisciplinary networking), time to complete education and training, funding and debt, mentoring, and demands for clinical practice. This paucity is exacerbated when DVM–PhDs choose to enter private practice. Focused initiatives to address these pipeline failures are necessary. Some proposed responses include more training on grant writing and translational science conferences, as well as grants for veterinary scientists.

In the School of Nursing at the University of Minnesota, students are incorporated into teams during practice and research training. Progress has been made in addressing multisite institutional review boards and data sharing. However, these advancements are not easily disseminated across schools and departments, and research teams often start from the beginning in navigating the bureaucracy. The challenge to creating and maintaining a robust team science and physician–scientist pipeline might be attributed to the previous success of the medical education establishment in creating a robust pipeline for developing skilled clinicians, while the scientific community established an independent pipeline to develop and reward purpose-driven independent investigators. Grafting of dual-degree programs onto these entrenched systems showed recognition of a need, but was not a long-term solution, since the training programs were and are maintained in the separate worlds of medicine and science. Fundamental changes in policies and practices may be needed to overcome established bureaucratic and cultural norms.

Proposals for improving the clinician or physician–scientist pipeline include tuition remission programs, establishing a culture of team science in training programs, and pairing trainees with mentors in team science settings. Institutional actions that increase networking opportunities, such as aligning health professional schools within the same university and developing translational research summits on similar diseases, may serve to increase retention and broaden the team science base.

Tools and funding for physician–scientist training

The NIH has worked to improve the biomedical workforce through new funding configurations and new initiatives for physician–scientist training and research. Peter Jackson, cochair of the workshop and chief of the AIDS Research Review Branch at the National Institute of Allergy and Infectious Diseases (NIAID) at the NIH, urged applicants to learn the application process and to interact often with NIH staff. He provided a range of resources and websites for NIH research funding opportunities, as well as team science crowdsourcing tools (Table 1).

Navigating the application process successfully is difficult, and the NIH provides training through electronic resources, presentations by staff, and regional meetings in order to improve applicants' success rates. Funding opportunities suitable for physician–scientists include institutional training grants (T32 and T35), individual fellowships (F30–F31), Mentored Clinical Scientist Research Career Development Awards (K08), Mentored Patient-Oriented Research Career Development Awards (K23), and NIH Pathway to Independence Awards, which support transition from a mentored postdoctoral fellowship to an independent faculty position. These award mechanisms are shown in Figure 1.

Nontraditional funding opportunities for physician–scientists are also emerging. Hortencia Hornbeak, associate director for scientific review and policy at the NIAID, NIH, discussed the changing research funding landscape that emphasizes awards to support creative, flexible, productive people rather than specific projects; funds from multiple external sources; and multidisciplinary team science. Specific award examples include NIH Pioneer Awards and Outstanding Investigator Awards, as well as similar instruments from the Howard Hughes Medical Institute and the Wellcome Trust.

In this new landscape, it is important for physician–scientists to work in a strategic manner to sustain their research support. They must align their research goals with those of several funding agencies/sources, including sponsors that support complementary research, establish collaborative relationships with investigators in other disciplines, and use unique resources, such as publicly available data repositories.

A unique opportunity available to physician–scientists for support of competitive but unfunded NIH applications by private biomedical foundations and private industry is through a matching program—the Online Partnership to Accelerate Research (OnPar) operated by Leidos Life Sciences. Benefits of the OnPar program include providing foundations access to peer-reviewed research proposals that directly relate to their funding priorities, providing businesses access to a rich pipeline of early-stage and translational research proposals that align with their priorities, and providing applicants with strong research proposals another opportunity to secure funding (additional information is available at https://nexus.od.nih.gov/all/2016/03/23/a-pilot-partnership-to-find-private-support-for-unfunded-applications/).

The internet provides new entrepreneurial opportunities for physician–scientists to access career-enhancing resources through crowdsourcing

Table 1. **Websites and resources for team science and the physician–scientist**

URL	Website title	Website description	Date visited
NIH funding			
https://www.niaid.nih.gov/grants-contracts/new-investigators	Information for New Investigators	Site designed by the NIH to help new investigators explore new opportunities and funding approaches through NIH and NIAID to meet research goals	June 5, 2017
https://www.niaid.nih.gov/research/career-development-grants	Career Development Grants SOP	Site designed to provide researchers with continuing biomedical research training	June 5, 2017
https://www.niaid.nih.gov/grants-contracts/find-funding-opportunity	Finding a Funding Opportunity	NIH site for giving researchers up-to-date information on research opportunities, policy, funding opportunities, and award opportunities	June 5, 2017
https://www.niaid.nih.gov/grants-contracts/apply-grant	Apply for a Grant	Site contains examples of grant applications and summary statements, data sharing and model organism sharing plans	June 5, 2017
https://www.niaid.nih.gov/grants-contracts/funding-news-notices	Opportunities and Announcements	Site that lists all NIAID-related grant funding opportunities	June 5, 2017
https://commonfund.nih.gov/	Office of Strategic Coordination—The Common Fund	NIH common fund homepage giving general information for what common fund entails	June 5, 2017
https://www.nih.gov/research-training/medical-research-initiatives	Medical Research Initiatives	Site listing links to various current initiative topics in biomedical research	June 5, 2017
https://commonfund.nih.gov/highrisk	High Risk, High Reward Research Programs	Site listing four unique NIH directive awards under the common fund program	June 5, 2017
https://www.nigms.nih.gov/training/dpc/Pages/default.aspx	Enhancing the Diversity of the NIH Funded Work Force	NIH site for explaining how the NIH wants to expand diversity and the initiatives for implementing the changes toward diversity in research	June 5, 2017
Crowdsource funding			June 5, 2017
http://www.nextscientist.com/3-examples-crowdsourcing-science/	3 Examples of Crowdsourcing Science	Site explaining what crowdsourcing is and how science can use it to achieve results with scientific problems, collecting funds, and advertising job opportunities	June 5, 2017
https://www.thebalance.com/a-guide-what-is-crowdfunding-985100	What is Crowdfunding? The main categories of crowd funding and how you can get involved	A second site explaining what crowdsourcing is and how science can use it to expand ideas, increase collaboration, and collect funds	June 5, 2017
https://www.thebalance.com/what-to-do-before-you-begin-crowdfunding-985188	Essential Things You Need to Do Before You Begin Crowdsourcing	Site explaining dos and don'ts of crowdsourcing and giving examples of how to start up with crowdsourcing	June 5, 2017

Continued

Table 1. *Continued*

URL	Website title	Website description	Date visited
https://chroniclevitae.com/news/1307-can-%20crowdfunding-fill-%20the-science-%20funding-gap	Can Crowdsourcing Fill the Science Funding Gap?	Article discussing how crowdsourcing can be used to collect funds and potential future outlook for crowdsourcing science	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/26601600	On the nature of cross-disciplinary integration: A philosophical framework	An article describing the development of a framework that integrates challenging insights—integration as a generic combination process, the details of which are determined by the specific contexts in which particular integrations occur	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/26636555	Building Interdisciplinary Research Models Through Interactive Education	A study designed to develop and evaluate an interactive toolbox workshop approach within an interprofessional graduate-level course to enhance student learning and skill in interdisciplinary research	June 5, 2017
http://exchanges.wiley.com/blog/2015/03/10/crowdfunding-science-what-are-the-options-and-opportunities/	Wiley Exchange	Site with news and resources for scientists, librarians, and societies	June 5, 2017
Team science			June 5, 2017
https://acd.od.nih.gov/documents/reports/PSW_Report_ACD_06042014.pdf	Physician–scientist Workforce Working Group Report	Report explaining the NIH study concerning the current status of physician–scientists in the workforce and their views on the future of funding for these individuals	June 5, 2017
https://www.teamsciencetoolkit.cancer.gov/Public/KeyArticles.aspx	Team Science Toolkit	Site listing a series of articles that discuss team science and the current status of team science	June 5, 2017
http://www.scienceofteamscience.org/	The Science of Team Science 2017 Conference	Site highlighting the 2017 SciTS conference, opportunities at the conference, and what will be reviewed there	June 5, 2017
https://www.nap.edu/catalog/19007/enhancing-the-effectiveness-of-team-science	Enhancing the Effectiveness of Team Science	The National Academies Press website to access the book *Enhancing the Effectiveness of Team Science*	June 5, 2017
https://ccrod.cancer.gov/confluence/display/NIHOMBUD/Home;jsessionid=508AE1F7455DFE12C3F90CE6E80D7963	Collaboration and Team Science	NIH site discussing the benefits of team science and field guides for further readings on team science collaboration	June 5, 2017
http://teamscience.net/	TEAMSCIENCE	Site for promoting team science and giving modules that promote and help with team science ideas	June 5, 2017

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Table 1. ***Continued***

URL	Website title	Website description	Date visited
http://www.ajpmonline.org/article/S0749-3797(08)00412-1/abstract	The Collaboration Readiness of Transdisciplinary Research Teams and Centers	Site with a PDF link to an article that discusses cross-disciplinary team science collaboration between government and scientific establishments	June 5, 2017
http://toolbox-project.org/toolbox-team/	The Toolbox Project	Site that contains workshops that promote structure dialogue among collaborators	June 5, 2017
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4936491/	Individual motivation and threat indicators of collaboration readiness in scientific knowledge–producing teams: a scoping review and domain analysis	An article reviewing the status of the collaboration readiness of a knowledge-producing team	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/27388617	Pilot analysis of the Motivation Assessment for Team Readiness, Integration, and Collaboration (MATRICx) using Rasch analysis	A study evaluating the preliminary psychometric properties of the Motivation Assessment for Team Readiness, Integration, and Collaboration	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/23919361	A dynamical approach toward understanding mechanisms of team science: change, kinship, tension, and heritage in a transdisciplinary team	A study exploring a social constructionist-grounded multilevel mixed-methods approach to identify social dynamics and mechanisms within a transdisciplinary team	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/24073147	How to talk to strangers: facilitating knowledge sharing within translational health teams with the Toolbox dialogue method	An article describing a method—-the toolbox dialogue method—-for addressing these challenges by means of a structured dialogue among team members concerning their respective approaches to complex problems	June 5, 2017
Physician–scientist			June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/26173540	Faculty Promotion and Attrition: The Importance of Coauthor Network Reach at an Academic Medical Center	A study designed to examine predictors of intraorganizational connections, as measured by network reach (the number of first- and second-degree coauthors), and their association with probability of promotion and attrition	June 5, 2017
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4078286/pdf/amiajnl-2014-002727.pdf	Scalable Collaborative Infrastructure for a Learning Healthcare System (SCILHS): Architecture	A review detailing the informatics approaches taken by SCILHS to identify large cohorts of patients and engage them for research	June 5, 2017

Continued

Table 1. *Continued*

URL	Website title	Website description	Date visited
https://www.ncbi.nlm.nih.gov/pubmed/24509520	The use and significance of a research networking system	A study designed to provide the first description of the usage of an institutional research "social networking" system or research networking system (RNS)	June 5, 2017
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3666890/	Identifying translational science within the triangle of biomedicine	A study designed to create a method to track the relevance of research when it is applied to bedside medicine	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/23533569	SHRINE: enabling nationally scalable multi-site disease studies	A study designed to create a patient research system that could aggregate as many patient observations as possible from a large number of hospitals in a uniform way	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/22686207	Current state of information technologies for the clinical research enterprise across academic medical centers	A study designed to track the adoption rate and practical implementation of medical strategies within the field of clinical research	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/22037890	Direct2Experts: a pilot national network to demonstrate interoperability among research-networking platforms	A case study exploring an initiative, which, in only 6 months, achieved interoperability among seven major research-networking products at 28 universities by taking an approach that focused on addressing institutional concerns and encouraging their participation	June 5, 2017
https://www.ncbi.nlm.nih.gov/pubmed/20190053	Serving the enterprise and beyond with informatics for integrating biology and the bedside (i2b2)	An article describing how i2b2 software may be used by an enterprise's research community to find sets of interesting patients from electronic patient medical record data, while preserving patient privacy through a query tool interface	June 5, 2017

and crowdfunding. Crowdsourcing is the nontraditional approach to securing services or supplies and refining research projects from a larger community of interested parties. Crowdsourcing allows many people to work on a project, increasing the potential to improve the pace, quality, and variety of results. Crowdfunding similarly canvasses the online community for financial support that, in aggregate, supports specific projects. Many websites provide crowdsourcing and crowdfunding tools and examples of successful transactions (Table 1).

Additional challenges confronting the physician–scientist workforce

Several challenges confront the physician or clinician who elects to pursue a research career. Increases in medical education costs can burden students with large amounts of debt, especially those who were not enrolled in an integrated MD–PhD program. The training required to obtain competency in clinical and scientific research continues to increase, thus resulting in a marked prolongation of the training

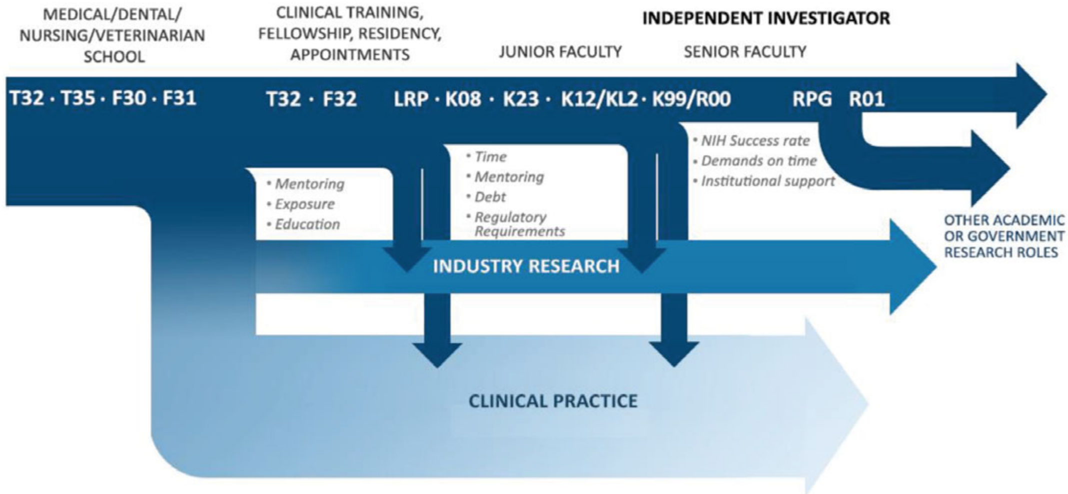

Figure 1. NIH support for the physician–scientist training pipeline. The figure is not drawn to scale, as more physician–scientists enter clinical practice than academic or industry research. The figure is adapted from Ref. 9.

process. The transition between finishing a clinical or postdoctoral fellowship and initiating an independent research position is a vulnerable period in the career path of any physician investigator. Funding pressures have mounted with the decrease in NIH funding, and physician–scientists are increasingly being asked to support a higher percentage of their income by seeing patients. Financial opportunities in clinical practice offer attractive options for clinically trained physician–scientists who are also valuable to academic medical centers as clinicians. Financial opportunities thus pull talented researchers away from investigative work and create conflicting demands on time and energy. Other challenges confronting newer physician–scientists are finding ways to balance work/life demands, finding supportive mentors to guide early career investigators, and the increasingly time-consuming and demanding requirements to maintain clinical credentials.

Physician–scientists across all domains face similar challenges, although the extent of the challenges varies from discipline to discipline. The non-MD segments of the PSW have lacked a critical mass of scientific researchers, because the veterinary, dental, and nursing training programs strongly focus on producing clinical practitioners. A resulting major challenge among these segments of the PSW is a shortage of faculty members with scientific research programs who can serve as role models and mentors to students in training.

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Competing interests

The authors declare no competing interests.

References

1. Little, M.M., C.A. St. Hill, K.B. Ware, *et al.* 2017. Team science as interprofessional collaborative research practice: a systematic review of the science of team science literature. *J. Investig. Med.* **65:** 15–22.
2. Winter, S.J. & N. Berente. 2012. A commentary on the pluralistic goals, logics of action, and institutional contexts of translational team science. *Transl. Behav. Med.* **2:** 441–445.
3. Lotrecchiano, G.R., T.R. Mallinson, T. Leblanc-Beaudoin, *et al.* 2016. Individual motivation and threat indicators of collaboration readiness in scientific knowledge producing teams: a scoping review and domain analysis. *Heliyon* **2:** e00105.
4. Mallinson, T., G.R. Lotrecchiano, L.S. Schwartz, *et al.* 2016. Pilot analysis of the Motivation Assessment for Team Readiness, Integration, and Collaboration (MATRICx) using Rasch analysis. *J. Investig. Med.* **64:** 1186–1193.
5. Murphy, S.N., A. Dubey, P.J. Embi, *et al.* 2012. Current state of information technologies for the clinical research enterprise across academic medical centers. *Clin. Transl. Sci.* **5:** 281–284.

6. Schnapp, L.M., L. Rotschy, T.E. Hall, *et al.* 2012. How to talk to strangers: facilitating knowledge sharing within translational health teams with the Toolbox dialogue method. *Transl. Behav. Med.* **2:** 469–479.
7. Hessels, A.J., B. Robinson, M. O'Rourke, *et al.* 2015. Building interdisciplinary research models through interactive education. *Clin. Transl. Sci.* **8:** 793–799.
8. Fisher, A., M. O'Rourke, R. Evans, *et al.* 2015. Mapping the integrative field: taking stock of socio-technical collaborations. *J. Responsible Innov.* **2:** 39–61.
9. National Institutes of Health. 2014. Physician–scientist Workforce Working Group report. Bethesda, MD: National Institutes of Health.

