Catalyzing Interdisciplinary Research and Training: Initial Outcomes and Evolution of the Affinity Research Collaboratives Model

Katya Ravid, DSc, Francesca Seta, PhD, David Center, MD, Gloria Waters, PhD, and David Coleman, MD

Abstract

Team science has been recognized as critical to solving increasingly complex biomedical problems and advancing discoveries in the prevention, diagnosis, and treatment of human disease. In 2009, the Evans Center for Interdisciplinary Biomedical Research (ECIBR) was established in the Department of Medicine at Boston University School of Medicine as a new organizational paradigm to promote interdisciplinary team science. The ECIBR is made up of affinity research collaboratives (ARCs), consisting of investigators from different departments and disciplines who come together to study biomedical problems that are relevant to human disease and not under interdisciplinary investigation at the university. Importantly, research areas are identified by investigators according to their shared interests. ARC proposals are evaluated by a peer review process, and collaboratives are funded annually for up to three years.

Initial outcomes of the first 12 ARCs show the value of this model in fostering successful biomedical collaborations that lead to publications, extramural grants, research networking, and training. The most successful ARCs have been developed into more sustainable organizational entities, including centers, research cores, translational research projects, and training programs.

To further expand team science at Boston University, the Interdisciplinary Biomedical Research Office was established in 2015 to more fully engage the entire university, not just the medical campus, in interdisciplinary research using the ARC mechanism. This approach to promoting team science may be useful to other academic organizations seeking to expand interdisciplinary research at their institutions.

Addressing complex biomedical research questions increasingly requires the development of new infrastructure and approaches to facilitate innovation.[1,2] Traditional structures may exclude overlapping or complementary expertise from across disciplines, potentially limiting the ability of academic medical centers to conduct high-impact research. To test a more nimble structure for interdisciplinary research, we established the Evans Center for Interdisciplinary Biomedical Research (ECIBR) in 2009. It is based in the Department of Medicine at Boston University School of Medicine but is open to faculty from across the university. As we have reported, the ECIBR is made up of affinity research collaboratives (ARCs), consisting of investigators affiliated with different departments and disciplines who come together to study a biomedical problem that is not currently under investigation at the university.[3] ARCs are funded yearly by the ECIBR for up to three years, pending peer review by a panel of experts. Now that six years have passed since its inception, we describe the initial research outcomes of the ARCs and their evolution beyond the three-year funding period into more sustainable organizational entities.

Please see the end of this article for information about the authors.

Correspondence should be addressed to Katya Ravid, Boston University School of Medicine, 700 Albany St., CVI, W-601, Boston, MA 02118; telephone: (617) 638-5053; e-mail: kravid@bu.edu.

Acad Med. XXXX;XX:00–00.
First published online
doi: 10.1097/ACM.0000000000001716

Catalyzing Interdisciplinary Research: Others' Work and the ECIBR's Approach

Background

In the last decade, interdisciplinary collaborations, often referred to as team science, have become critical to solving increasingly complex biomedical problems and advancing therapeutic discoveries at a more rapid pace than traditional approaches. Wuchty and colleagues[4] analyzed nearly 20 million papers over five years and in 2007 concluded that "teams increasingly dominate solo authors in the production of knowledge." In 2015, members of the Committee on the Science of Team Science at the National Research Council published a report entitled "Enhancing the Effectiveness of Team Science," in which they made recommendations on how to improve the effectiveness of inter- and multidisciplinary collaborations in the biomedical enterprise at both the individual and institutional levels.[5]

The work of Clinical and Translational Science Award programs

Clinical and Translational Science Award programs have served as platforms for fostering collaborative research across disciplines mainly through pilot funding and interactive seminars and workshops to formally teach collaborative science. For instance, Northwestern University's Clinical and Translational Sciences Institute (https://nucats.northwestern.edu/) developed an interdisciplinary program involving three tiers of seed funds (ideas, innovative initiatives, and innovative initiatives incubator) awarded to investigators for collaborations within the university. In addition to funding for each tier, the institute provides assistance in project management and team science. Similarly, the Michigan Institute for Clinical and Health Research (https://www.michr.umich.edu/) organizes three-part interactive seminars based on three

central topics—frameworks for forming a science team, developing language and values, and strategies for effective meetings. The South Carolina Clinical and Translational Research Institute (http://academicdepartments.musc.edu/sctr/index.htm) developed a one-credit/15-week course covering topics such as personality assessment, research team construction with case examples, and team authorship, taught by seasoned faculty members involved in team science and translational research. The Robert Wood Johnson Foundation provides seed funds for a transdisciplinary training program in public health based on intensive group and individual mentoring and scholar-directed research projects aimed at developing interdisciplinary projects and networking. Alternatively, the University of Texas System developed initiatives to foster collaborations within its network of universities and hospitals, such as a free online tool (http://influuent.utsystem.edu/) and a platform (http://www.texasfreshair.org/) to connect investigators with each other and with local industries.

The ECIBR's approach

In addition to the seminars, workshops, and educational approaches provided by our university's Clinical and Translational Science Institute (CTSI) (https://www.bu.edu/ctsi/) and the Department of Medicine (http://www.bumc.bu.edu/facdev-medicine/seminars/), we developed new approaches to empower groups of faculty to pursue interdisciplinary, collaborative research projects to address topics or problems that were not being addressed by existing organizational structures. Because the CTSI had a strong interdisciplinary translational focus, we sought a new organizational approach that would catalyze interdisciplinary basic research related to human disease. Accordingly, we established the ECIBR in 2009 as a virtual center with the goal of fostering interdisciplinary team science via an ARC mechanism.[3]

As we have described elsewhere, each ARC includes the following six features[3,6]: (1) Each ARC includes at least five faculty from at least two disciplines, led by one to two ARC directors, of whom at least one is from the Department of Medicine. ARCs are encouraged to include investigators from across the university and industry. (2) The ARC mechanism is based mostly on a "bottoms-up" approach. Namely, an ARC consists of a self-assembled group of investigators who propose studying a novel interdisciplinary research area that is not being studied by an existing center or program. The ARC research areas are not necessarily tied to institutional strategic plans, although some have evolved into institutional goals, as described below. Specifically, the ECIBR does not exclude any areas of research as long as they are sufficiently interdisciplinary. (3) ARCs enjoy institutional support in the form of mentorship from the ECIBR director; peer review of ARC applications by a group of 11 to 14 faculty representatives from different disciplines across the university (following a National Institutes of Health [NIH] study section format); and peer mentorship among the ARC directors and members, who meet quarterly and for an annual retreat. (4) Pilot funding (usually in the range of $50,000–$75,000) is awarded to support research supplies, trainees, and seminars/workshops (typically allocated at a ratio of 0.4:0.4:0.1) and may be renewed annually for up to three years, pending yearly review. (5) Faculty participants are strongly encouraged to retain their departmental affiliation throughout the collaborative period. (6) ARCs receive administrative support for thematic seminars and workshops. The Department of Medicine has provided these funds for the ARCs as well as for part-time administration of the ECIBR.

Impact of the ECIBR and ARC Mechanism

The research focus and initial outcomes of the 12 ARCs that were supported during the first six years of the program are summarized in Table 1. The reasons that the ECIBR limited funding in some cases are also listed in Table 1. These reasons include securing substantial extramural support, such as an NIH-funded program project or Proteomics Center, or merging with another ARC focused on what became a similar and/or complementary topic.

Investigators who participated in these ARCs represent three or more disciplines from different departments and schools (Boston University School of Medicine, School of Dentistry, School of Bioengineering, and School of Public Health).[3] The initial scientific output of these ARCs is shown in Table 2. Overall, 123 grants were awarded by external agencies (222 grant applications; success rate of 55%) with at least two ARC investigators serving as co–principal investigators or coinvestigators.

In addition, ARC investigators coauthored 421 scientific publications. Importantly, these publications were highly cited. Depending on the ARC, 5% to 25% of publications were in the top 1% of most cited articles in their respective research areas (according to a Citation Metrics and InCites analysis; data not shown). However, as noted in Table 2, the range and standard deviation in each category (publications, grants, core participants, and trainees) are large, partly because of the variability in the duration of funding (see Table 1). For instance, the two ARCs that were funded for only one year engaged only one pre- or postdoctoral trainee as an active participant (hence, the range of 0–39 or 0–15 in Table 2). Although inferences are difficult with our small sample size, the four fully funded ARCs with the greatest number of pre- or postdoctoral trainees and core faculty participants have the greatest number of grants and publications (see Table 2).

As we have described elsewhere, we evaluated several ARCs using a social network analysis, which monitors the frequency of interactions.[7] This analysis is based on the notion that social relations are critical conduits for the transmission of knowledge, attitudes, and skills.[8] Using methods we have described previously,[3] we evaluated the frequency of information exchanges and collaborative activities using a faculty survey conducted at year three of each ARC and compared our findings to the pre-ARC period. Shown in Figure 1 is a recent social network analysis of the "Nanotheranostics" ARC, which demonstrates more information exchanges and collaborative activities (e.g., coauthorships on publications or on grant applications) during the ARC period than before. These results are similar to those we reported for the first four ARCs.[3]

The outcomes described above demonstrate that the ARC mechanism represents an effective model for catalyzing new interdisciplinary research. Key factors in promoting the success

Table 1

Characteristics of the 12 Affinity Research Collaboratives (ARCs) at the Boston University School of Medicine, 2009–2015

Title	Departments/Centers involved	Disciplines involved	Years of activity	Evolution
Biomarkers of disease	Biochemistry Bioengineering Medicine Proteomics Center	Biochemistry Cardiology Diabetes and metabolism Chemistry Engineering Epidemiology Neurology Rheumatology Vascular biology	2009–2010	National Institutes of Health–funded National Proteomics Center (2010–present)
Cardiovascular consequences of metabolic disease	Biochemistry Medicine Cardiology Biophysics	Biochemistry Cardiology Diabetes and metabolism Vascular biology	2009–2010	National Institutes of Health–funded program project grant (4/01/2011–2/29/2016)
Mitochondria in health and disease	Bioengineering Industry (Novartis, Pfizer, Seahorse Bioscience) Medicine Public health Biochemistry	Endocrinology Vascular biology Cardiology Biochemistry Chemistry Bioengineering Cancer biology Epidemiology	2009–2012	ARC program and research core facility (bioenergetics)
Protein trafficking and neurodegenerative disease	Biochemistry Medicine Neurology Pharmacology Genetics Bioinformatics	Biology Biochemistry Biostatistics Neurology	2009–2012	New program in personalized medicine and Alzheimer's disease
Sex differences in adipose tissue biology and related metabolic disease	Cancer center Biochemistry Computational biomedicine Cell and molecular biology Medicine	Biochemistry Bioinformatics Cell and molecular biology Endocrinology Immunology Microbiology	2009–2012	ARC program in collaboration with the Boston Nutrition Obesity Research Center
Induced pluripotent stem cell (iPSC) bank	Bioengineering Medicine Sickle cell center Systems biology	Bioengineering Hematology Oncology Microbiology Pathology	2009–2012	Boston University Center for Regenerative Medicine
Molecular, biomechanical, and genetic determinants of arterial stiffness	Bioengineering Medicine Industry (cardiovascular engineering) Physiology	Biochemistry Epidemiology Genetics Vascular biology	2010–2013	ARC program and research core facility (arterial stiffness)
Obesity, cancer, and inflammation	Biochemistry Cancer center Nutrition center Public health Medicine Microbiology	Biochemistry Epidemiology Immunology Obesity, nutrition, and metabolism Social and behavioral sciences	2010–2011	In 2012, this ARC merged with another ARC on metabolic disease
Calcium homeostasis in health and disease	Bioengineering Chemistry Cellular imaging core Health sciences Medicine Physiology and biophysics	Calcium signaling Cardiology Genetics Hematology Imaging Obesity Vascular biology	2010–2013	New pre-ARC on personalized medicine and Parkinson's disease
Nanotheranostics	Chemistry Biomedical engineering Medicine Surgery Nanotechnology innovation center	Chemistry Engineering Cell biology Biochemistry Cardiology Cancer biology	2011–2014	ARC program merged with the Boston University Nanotechnology Innovation Center

(*Table continues*)

Table 1
(Continued)

Title	Departments/Centers involved	Disciplines involved	Years of activity	Evolution
Metabolic diseases and insulin resistance: Studies in patients undergoing bariatric surgery	Biochemistry Medicine Surgery Pharmacology Pediatrics Public health	Bioinformatics Microbiology Nutrition Obesity Physiology Endocrinology Clinical studies	2012–2014	Members joined the Metabolic Clinical Research Collaborative initiative
Computational genomic models of environmental and chemical carcinogenicity	Molecular and cell biology Medicine Public health Computational biomedicine	Biostatistics Cell biology Computational biomedicine	2013–2015	ARC program within the Cancer Center

of the program were (1) a core of enthusiastic faculty and an inclusive approach to membership; (2) an exciting and promising new scientific pathway that did not exist within the organizational structures of the departments, schools, or university; (3) an inclusive and open approach to advice from within and outside the core group of faculty; (4) encouragement of industry participation; (5) active participation by graduate and postdoctoral students in establishing interdisciplinary networks among their peers; (6) rigorous internal peer review that maintained high scientific standards during initial review and the annual renewal; (7) funding over a three-year period that was sufficient to generate preliminary data; (8) ongoing seminars and research-in-progress meetings; and (9) willingness of the ECIBR director to serve as scientific advisor to each ARC and to join faculty in envisioning new focus areas for ARC research.

The two primary barriers to the success of the ECIBR were (1) geography—the departments are distributed over two Boston University campuses, and (2) language—ensuring that the lexicon across disciplines was understood and shared. These barriers have since been addressed through virtual conferences and shared workshops and with thematic seminars focused on interdisciplinary content.

Table 2
Initial Outcomes of the 12 Affinity Research Collaboratives (ARCs) at the Boston University School of Medicine, 2009–2015

Metric	Publications[a]	Grants[a]		Core participants[b]	Trainees	
		Applications	Funded		Pre-ARC	ARC
All ARCs						
No.	421	222	123	100	97	50
Average ± SD	35±33	19±23	11±13	8±4	8±11	4±5
Range	1–91	1–87	1–44	4–15	0–39	0–15
Four ARCs with the most participants[c]						
No.	258	161	98	49	69	35
Average ± SD	64±24	40±31	24±13	12±4	17±15	9±5
Range	41–91	18–87	17–44	7–15	5–39	6–15

[a]These publications and grants included at least two authors, co–principal investigators, or coinvestigators who were ARC members, and focused on studies directly related to ARC research.
[b]Core participants were individual ARC members who received funding from the Evans Center for Interdisciplinary Biomedical Research. The total number of ARC members from across the two university campuses during this period was more than twice as many as the number of core participants. Thus, the incentive for joining an ARC was not just monetary but also access to novel technology, ideas, workshops, and thematic interdisciplinary seminars.
[c]These three-year ARCs had the greatest numbers of trainees and core participants compared with the total pool. These standard deviations were also narrower compared with the total pool.

Despite the success of the ECIBR after six years, important questions remain about the continued development of interdisciplinary research. Those questions include (1) Should successful ARCs be disbanded at the end of the ECIBR funding period? If not, who should continue to support them? (2) Could ARCs serve as springboards to new research infrastructure and translational research? (3) How could we further expand the impact of interdisciplinary research by maximizing involvement by the broadest range of disciplines within the university?

The Evolution of the ARCs

Many of the first ARCs have evolved in different directions and into a number of entities with the goal of sustaining the momentum generated by these new interdisciplinary research pathways (see Figure 2).

From an ARC to an ARC program

A number of successful ARCs (see Table 2) have developed into ARC programs. These ARC programs were provided $8,000 to $10,000/year to organize monthly meetings, workshops, and seminars. In addition, the ECIBR continued to provide administrative support. These programs also were encouraged to continue adding new participants to facilitate the growth of ongoing studies and to develop new lines of interdisciplinary investigation that might be eligible for new ARC funding. For instance, members of the "Protein Trafficking and Neurodegenerative Disease" ARC program formed a new program focused on personalized medicine in the context of Alzheimer's disease.

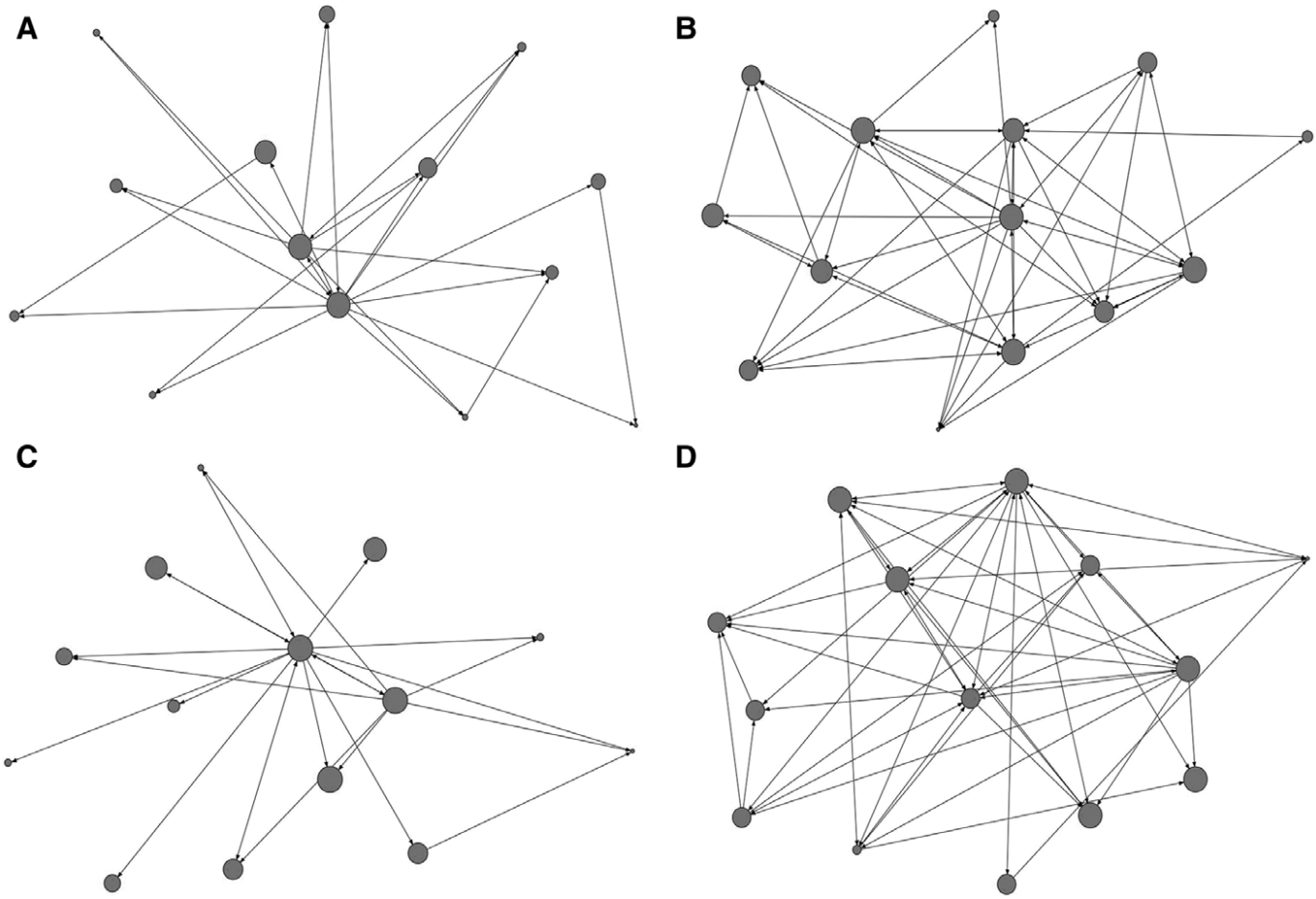

Figure 1 Results of a social network analysis of the "Nanotheranostics" affinity research collaborative (ARC) at the Boston University School of Medicine. Panel A depicts the sociogram expressing the structure of the information exchanges in the 2007–2010 pre-ARC period. Panel B depicts the sociogram expressing the structure of the information exchanges in the 2010–2013 ARC period. Panel C depicts the sociogram expressing the structure of the collaborative activities in the 2007–2010 pre-ARC period. Panel D depicts the sociogram expressing the structure of the collaborative activities in the 2010–2013 ARC period. In all panels, the nodes are sized according to their out-degree centrality, and the lines express the frequency of exchanges, with shorter lines showing more frequent exchanges and longer lines less frequent ones. The absence of a connection indicates a rare or nonexistent information exchange. Arrows indicate the directionality of the tie. The centrality of any given investigator is determined by identifying the number of connections that person claims and evaluating the strength of those connections. An increase in both the centrality values for individual ARC investigators and the density of the corresponding networks is a strong indicator that collaboration has increased. The pre-ARC and ARC periods both included 13 investigators who participated in the survey.

From an ARC to a center or university program

Often together with the ECIBR, ARC investigators envisioned new formal research entities that extended from the work of the ARC. For example, the "Induced Pluripotent Stem Cell (iPSC) Bank" ARC leveraged its success to form the Boston University Medical Campus Center for Regenerative Medicine. The "Cardiovascular Consequences of Metabolic Disease" ARC transitioned to an NIH-funded program project. Similarly, the "Biomarkers of Disease" ARC contributed substantially to the successful renewal of the specialized Cardiovascular Proteomics Center, which was supported by the National Heart, Lung, and Blood Institute from 2010 to 2015. The "Sex Differences in Adipose Tissue Biology and Related Metabolic Disease" ARC was considered a particular strength in the successfully renewed NIH-funded Boston Nutrition Obesity Research Center. The "Nanotheranostics" ARC helped to create a new research branch in nanomedicine within the Boston University Nanotechnology Innovation Center. Of importance, this initiative was instrumental in establishing an NIH-funded training program, the Cross-

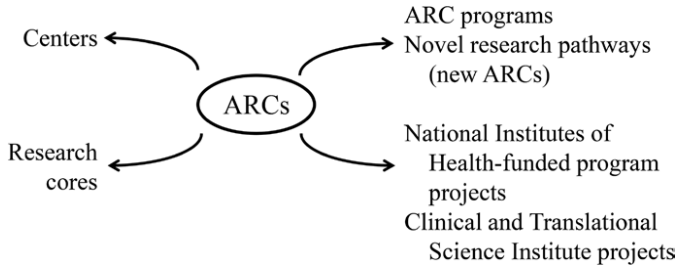

Figure 2 Evolution of the affinity research collaboratives (ARCs) at the Boston University School of Medicine, 2009–2015.

disciplinary Training in Nanotechnology for Cancer, which has trained numerous pre- and postdoctoral fellows in the area of nanomedicine in the past five years.

From an ARC to a research core

In some cases, the technical expertise developed within the ARCs has been transferred to existing or newly formed university research cores. For example, the expertise of the "iPSC Bank" ARC has been shared with the school's Transgenic Center in testing iPSC in vivo in mouse models. Tools for measuring arterial stiffness in mice, derived from the "Molecular, Biomechanical, and Genetic Determinants of Arterial Stiffness" ARC, have been centralized and made available to all investigators on campus. Similarly, methods for measuring thrombosis in vivo, as developed by the new "Thrombosis to Hemostasis in Health and Disease" ARC, have been made available to all investigators on campus. Thus, the ARC mechanism has had a sustained impact on our university through the development of unique core research resources.

From an ARC to a translational study

An important goal of the ARC mechanism has been to develop new basic science approaches that can create opportunities for translational research in collaboration with the university's CTSI. A notable example involves the "iPSC Bank" ARC which, with mentoring and support from the CTSI and extramural funding, developed a highly curated iPSC bank that was made available through an open access program to investigators around the world. To further enhance translational research, the iPSC bank faculty provided iPSC training for investigators across the country by offering an annual, weeklong "hands-on" course at Boston University and a "do-it-yourself" video, and by providing access to all university-derived iPSCs from subjects with heart and lung disease phenotypes.

Another example of an ARC fostering translational research is the work of the "Computational Genomic Models of Environmental and Chemical Carcinogenicity" ARC, which developed a computational approach to genetic signatures induced by specific carcinogens being tested in patients with lung cancer. The "Thrombosis to Hemostasis in Health and Disease" ARC, in collaboration with the university's CTSI, developed a protocol for identifying and studying cohorts with thrombotic microangiopathic hemolytic anemia (TMA). This multifaceted TMA program provides a robust educational platform for staff and trainees to improve the care of ethnic minorities at Boston Medical Center who are potentially at higher risk for TMA. It also includes a clinical database and a biobank leveraged by other investigators within and outside the university.

From the ECIBR to the Boston University Interdisciplinary Biomedical Research Office

While the Department of Medicine–supported ARC mechanism has been available to all investigators, it has tended to attract the attention of investigators from the Boston University Medical Campus. Therefore, the university opened the Interdisciplinary Biomedical Research Office (IBRO) to facilitate more robust and impactful interdisciplinary biomedical research across the engineering, physical, computational, biological, and biomedical departments. The IBRO is a joint initiative of the Department of Medicine and the Office of the University Vice President and Associate Provost for Research that was established in the 2015–2016 academic year.

Discoveries made by research teams supported by the IBRO will continue to go through the CTSI to be developed into translational research and for guidance related to technology developments. For example, a new IBRO initiative involves developing skills in software and hardware application combined with biomedical expertise with the goal of creating a university program in electronic health. Similarly, another IBRO initiative on "Computational and Systems Biology Approaches to the Study of the Microbiome" leverages expertise from across the university. The IBRO uses the same ARC mechanism as the ECIBR but with university-wide support and greater outreach.

Conclusion

In this article, we have described an approach to creating new faculty-driven, interdisciplinary research initiatives that have resulted in numerous publications, new research grants, and training opportunities. While this mechanism encourages investigators to develop unique resources and innovative research pathways, several of the ARCs have become aligned with the strategic goals of the university. Essential to the continued development of the ARC mechanism has been the "bottoms-up" approach and the resources provided by the Department of Medicine, the CTSI, and the Office of the Associate Provost for Research. The ARC mechanism has led to the development of important research centers, cores, and translational research initiatives that provide sustained support for high-impact interdisciplinary research (see Figure 2). The ARC structure is nimble, peer-reviewed, modest in cost, and has a substantial return on investment. Potential barriers have been differences in the scientific terminology used among investigators from different disciplines and the geographic distribution of the ARCs across two campuses. Our experience emphasizes the importance of fostering flexible, faculty-initiated, and creative opportunities for investigators to convene new research paradigms. As such, we believe that ARCs are an effective and efficient institutional approach to catalyzing interdisciplinary team science that is exciting for faculty and leads to new approaches in the study of human disease.

Acknowledgments: The authors offer their gratitude to the outstanding, enthusiastic faculty of Boston University, who are central to the development of affinity research collaboratives and to research progress. They also acknowledge Dr. Barbara Corkey for her support and encouragement; Dr. Karen Antman, Boston University School of Medicine dean and Boston Medical Center provost, for supporting new concepts; and Dr. Jean Morrison, Boston University provost, for supporting the Interdisciplinary Biomedical Research Office. They thank Dr. Bennett Goldberg for his insights and Russ Faux with Davis Square Research Associates for valuable expertise in social network analysis. Finally, they thank Ms. Robin MacDonald, the administrative manager of the Evans Center for Interdisciplinary Biomedical Research and the Interdisciplinary Biomedical Research Office, for her devoted efforts and skillful help and the Evans Medical Foundation for support. The authors apologize to the schools whose work they did not highlight in this article owing to space limitations and contextual focus.

Funding/Support: The affinity research collaboratives are funded by the Evans Medical Foundation at Boston University School of Medicine and by the Clinical and Translational Science Institute, and the Interdisciplinary Biomedical Research Office by the Office of the Associate Provost for Research.

Other disclosures: None reported.

Ethical approval: Reported as not applicable.

K. Ravid is professor of medicine and biochemistry and founding director, Evans Center for Interdisciplinary Biomedical Research and Boston University Interdisciplinary Biomedical Research Office, Boston University School of Medicine, Boston, Massachusetts.

F. Seta is assistant professor of medicine, Department of Medicine, Boston University School of Medicine, Boston, Massachusetts.

D. Center is professor of medicine and vice provost for translational research, Department of Medicine, Boston University School of Medicine, Boston, Massachusetts.

G. Waters is professor of speech, language, and hearing sciences and vice president and associate provost for research, Boston University, Boston, Massachusetts.

D. Coleman is professor of medicine and chair, Department of Medicine, Boston University School of Medicine, Boston, Massachusetts.

References

1 Alberts B, Kirschner MW, Tilghman S, Varmus H. Rescuing US biomedical research from its systemic flaws. Proc Natl Acad Sci U S A. 2014;111:5773–5777.
2 Dzau VJ, Yoediono Z, Ellaissi WF, Cho AH. Fostering innovation in medicine and health care: What must academic health centers do? Acad Med. 2013;88:1424–1429.
3 Ravid K, Faux R, Corkey B, Coleman D. Building interdisciplinary biomedical research using novel collaboratives. Acad Med. 2013;88:179–184.
4 Wuchty S, Jones BF, Uzzi B. The increasing dominance of teams in production of knowledge. Science. 2007;316:1036–1039.
5 Cooke NJ, Hilton ML, eds. Enhancing the Effectiveness of Team Science. Washington, DC: National Academies Press; 2015.
6 Coleman DL, Spira A, Ravid K. Promoting interdisciplinary research in departments of medicine: Results from two models at Boston University School of Medicine. Trans Am Clin Climatol Assoc. 2013;124:275–282.
7 Wasserman SF, Faust K. Social Network Analysis: Methods and Applications. New York, NY: Cambridge University Press; 1994.
8 Freeman LC. Centrality in social networks conceptual clarification. Soc Networks. 1979;1:215–239.