

Science at the Interstices: An Evolution in the Academy

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Abstract

Biomedical science is at an evolutionary turning point. Many of the rate-limiting steps to realizing the next generation of personalized, highly targeted diagnostics and therapeutics rest at the interstices between biomedical science and the classic, university-based disciplines, such as physics, mathematics, computational science, engineering, social sciences, business, and law. Institutes, centers, or other entities created to foster interdisciplinary science are rapidly forming to tackle these formidable challenges, but they are plagued with substantive barriers, born of traditions, processes, and culture, which impede

scientific progress and endanger success. Without a more seamless interdisciplinary framework, academic health centers will struggle to move transformative advances in technology into the foundation of biomedical science, and the equally challenging advancement of models that effectively integrate new molecular diagnostics and therapies into the business and social fabric of our population will be similarly hampered. At the same time, excess attention on rankings tied to competition for National Institutes of Health and other federal funds adversely encourages academic medical centers (AMCs) and universities

to hoard, rather than share, resources effectively and efficiently. To fully realize their discovery potential, AMCs must consider a substantive realignment relative to one another, as well as with their associated universities, as the academy looks toward innovative approaches to provide a more supportive foundation for the emergent biomedical research enterprise. The authors discuss potential models that could serve to lower barriers to interdisciplinary science, promoting a new synergy between AMCs and their parent universities.

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Throughout the history of science, investigators have crossed disciplines or have come together from different disciplines to solve “big science” problems. Recent historical examples include the Manhattan project and the sequencing of the human genome. Indeed, new scientific disciplines, such as neuroscience and biomedical informatics, have evolved at these interstices between scientific disciplines and will continue to do so. A complex mixture of the growth and maturation of science itself with the invention and development of technology molds the fabric of science and its evolution. Concurrently, the social, political, and historical environment in which scientists do their work inescapably creates a contextual framework that impacts how investigators approach vexing questions in the life sciences.

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Science Evolving

In the 21st century, the “century of biology,¹” and particularly in biomedicine, academic medicine is at a turning point. With the advent of the turn of this century, academicians witnessed a renewed recognition that many of the most important scientific problems (e.g., understanding the underpinnings of disease processes, developing pest-resistant and more nutritional crops) cross disciplinary boundaries.² In their 2004 editorial, Kafatos and Eisner³ discuss the unification of knowledge driving current progress in the life sciences. Indeed, the increasing numbers of authors on scientific publications through the last two decades of the 20th century demonstrate, in part, the importance of collaboration and team science.⁴

In biomedicine, discoveries at the subcellular, cellular, and systems levels, in nanoscience and nanoengineering, in mathematical and computational modeling, and in informatics are converging to lay the foundation for transformative knowledge of disease processes and preventive and therapeutic interventions. The outer envelope of discovery will continue to oscillate to and fro across the boundaries of existing

disciplines to achieve transformative advances.

The Academy Evolving

Academic health centers (AHCs) have evolved from medical schools with hospital affiliations to multibillion-dollar organizations that often incorporate schools of medicine, nursing, dentistry, and public health that are affiliated with large hospital systems that, in turn, incorporate outpatient networks. It is within and surrounding these complex AHCs, and in parallel to the evolution of science toward interdisciplinary boundaries, that academicians have witnessed, and will continue to witness, alchemy that reshapes disciplines—and the operations of the academy itself—shifting the foundation on which much of the biomedical research enterprise rests. This reformation has spawned the establishment of research centers and institutes which not only step out of the bounds of traditional academic departments but also cross the boundaries between academic medical centers (AMCs) and their home universities. The history and evolution of interdisciplinary research, both within and outside of academia, have been described,^{5,6} as have the philosophy, epistemology, and methodology of interdisciplinarity.^{7–13}

To respond to the confluence of scientific disciplines, universities and AMCs, in some cases with the help of philanthropists, are creating and building entities that colocate groups of scientists—physician–scientists, biologists, engineers, mathematicians, informaticians, social scientists—to enable them to tackle biomedical problems in new ways. For example, in many institutions across the country, bioinformaticians, radiologists, and engineers have come together in centers for imaging science that support both clinical research incorporating advanced imaging and scientific advances in imaging science and technology in the same venue. These organizational entities, operating at the interstices between academic disciplines, are at once capable of attacking some of the most formidable questions in science, but they are also plagued with formidable barriers, operational as well as cultural, oftentimes related to time-honored traditions within the academy (Figure 1). Discussions of some of these hurdles, including conflict between centers and departments, complicated financial models, and the effort of adapting to the culture of interdisciplinary research, are ongoing.^{14–20} The literature includes additional reports discussing interdisciplinary research, notably the National Academy of Sciences’ recent review of interdisciplinary research and education, which put forth 28 recommendations to better facilitate

interdisciplinary research.²¹ Also, reports on the vast array of interdisciplinary centers formed during the last two decades to address the confluence of scientific disciplines give an account of a mix of models that cross boundaries between AMCs and their home universities, between multiple academic institutions, and between academic institutions and private research institutes.^{22–24} We focus the remainder of this article on overcoming barriers that still exist between AMCs and their home universities, and between AMCs and entities outside themselves and their home universities, that slow the pace of both the evolution of science and the evolution of the academy.

Barriers to Evolution Within the Academy

Identifying barriers to science within the university

As noted, likely the most formidable challenges in the evolution of biomedical research, such as nanoscale cellular sampling or high-throughput molecular analysis, require expertise from disciplines that fall at the boundaries of most AMCs and their parent universities. These include disciplines that encompass the applied and theoretical physical sciences, including engineering, as well as the social sciences, law, and business. To address questions at these boundaries, institutions typically create entities named “centers” or “institutes,” legitimizing them as organized

entities, with variable degrees of academic status. For example, some universities have formed a number of centers of systems biology, mixing biology and technology to grapple with the complexity of biological systems, and, in other cases, AHCs have created new interdisciplinary science departments with full academic status in their own right.²⁵ Nonetheless, as intellectual campfires of interdisciplinary research and learning form, significant barriers born from entrenched institutional practices and culture surface, and, if unchecked, these barriers may drown the flames of discovery.

As is true outside the academy, the matter of money often arises as an important issue in efforts to bridge domains within a university. In cases where the bridge connects an AMC and its home university, the manner in which funds flow to support research at each may differ rather dramatically. Most medical center faculty, particularly at research-intensive private universities, rely on federal National Institutes of Health (NIH) support from grants to cover most, if not all, of their time devoted to research—the so-called “soft-money model”. In contrast, outside the AMC, “hard money” supports a large portion of faculty research time, through operating funds provided by tuition and/or endowment revenues. The dichotomies of the two models are manifest in the hiring practices of the medical center and the university. Expansion of faculty in the soft-money model has fewer constraints, yet it is riskier. Medical centers are usually willing to go at risk and leverage health care revenues to hire faculty who are intended to obtain the majority of their support from NIH. This has allowed AMCs to expand faculty numbers quite rapidly, particularly during the period from 1997 to 2003 when the administration doubled the federal NIH budget. On the other hand, expanding university faculty on the basis of a hard-money model carries less financial risk, but it is also more difficult, because financial leverage to grow faculty numbers on the basis of tuition or philanthropy is more confining than clinical revenue and, in the latter case, unpredictable. Hence, when a center is formed across the medical center and the university through an investment of seed funds (regardless of the source), as these resources are consumed, the center leadership may find it difficult or impossible to grow in a strategic manner

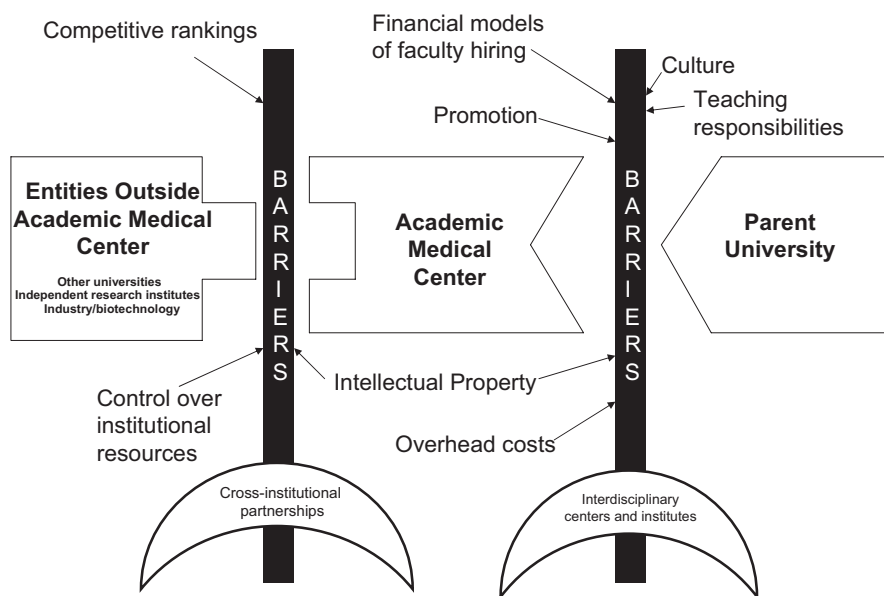


Figure 1 The barriers (black vertical bars) that impede transdisciplinary research both between academic medical centers (AMCs) and their parent universities and between AMCs and outside entities.

that supports programmatic imperatives, particularly if the expansion requires the addition of faculty based in disciplines outside the AMC. Many times, centers begin to experience disproportionate growth of medical center faculty at the expense of faculty who represent disciplines that adhere to hard-money financial models at most universities, such as physics and mathematics at most universities.

Moreover, medical and nonmedical center faculty can experience discord as it becomes clear that faculty within a transdisciplinary center experience widely varying expectations from their primary departments or schools surrounding expected teaching load (medical centers typically require lighter loads), promotion criteria (medical centers typically expect more extramural support for research), or support for administrative activities (medical centers typically support a wider range of support staff). Even the rates of allowable expense by faculty from their start-up packages may differ between camps. When provided by medical centers, start-up packages are typically budgeted annually, and expense reimbursement depends, to some degree, on the operating margin of the school or home department; outside the medical center, on the other hand, faculty start-up packages are often available in their full amount, at any time, as cash reserves. Finally, efforts to launch a multiinvestigator grant proposal with support from the NIH (or a comparable agency) for faculty residing in multiple departments and schools can be thwarted by varying understandings and expectations within those operating units surrounding the assignment of overhead costs, and these efforts can be frustrated by misaligned incentives around receiving credit relative to published rankings that track grant support dollars.

Overcoming barriers to science within the university

Managing multiple faculty who work in a kaleidoscope of economic models within interdisciplinary centers requires leadership to be flexible and engaged so that barriers, such as those described in the previous section, can be addressed responsively. Even so, particularly as transuniversity institutes become large and comprehensive in scope, the number of case-by-case difficulties and conflicts that require the time and effort of senior management may become unwieldy.

In most institutions, center and institute directors report directly to the dean of a school, such as a dean of medicine or engineering. Nonetheless, over time, the faculty, space, and financial resources of the institute or center may evolve to include several schools within the university, making oversight by a single dean awkward. In these cases, overarching administrative models that allow the center or institute to operate more flexibly and efficiently can greatly streamline administrative processes as well as academic and financial oversight. There are a number of approaches to streamlining the administration of centers and institutes that bridge institutional silos. These include allowing the institute to make its own academic appointments and manage its own promotion processes, or allowing it to homogenize, to whatever degree desirable, the approach to supporting and advancing faculty within the institute or center; for example, incorporating new evaluation criteria specific to the center's scholarship. In some cases, to avoid putting deans of schools in conflict or forcing them to manage budgetary challenges that stretch their resource base, it may be practical for the reporting structure and budgetary oversight of a center director to flow outside the typical academic hierarchy and directly to a vice chancellor or provost for research affairs. Clearly, moves of this nature create a visible precedent in the university, and administrators must carefully weigh and manage the operational and political ramifications. Nonetheless, providing the leader of a transinstitutional center or institute nationalized space and financial resources can greatly facilitate the director's ability to ensure balance in faculty recruiting, administrative support, advancement, and teaching commitments.

Increasingly, universities and medical centers are exploring greater centralization of the infrastructure required by transinstitutional centers and programs, such as accounting processes or submission review for grants. Among other advantages, such as economies of scale, a more centralized approach facilitates the development of a common set of financial and administrative understandings or standards for all operating units within the university, and it can reduce the need for a principal investigator to navigate a complicated set of administrative hurdles with each distinct operating unit when submitting or managing a grant involving faculty from across the university.

Centralization of operational processes, such as grants and contracts management, postaward grants accounting, animal care, or human subjects protection, to name a few, particularly if highly standardized, also facilitates implementation of state-of-the-art information systems, which, in turn, can provide just-in-time information and services for all faculty while easing their administrative burdens. Also, centralization of shared core resources (e.g., imaging facilities or DNA-sequencing cores), typically highly heterogeneous and spread across AHCs, can provide better access for more scientists, supply more advanced technology at lower cost, and improve the quality of service provided. This trend of centralization, although supportive of transinstitutional science, also facilitates institutional efforts to meet the escalating demands of financial reporting and federal compliance oversight.

Resource Sharing Among Institutions

The ranking wars: Barriers to resource sharing among institutions

As science has become increasingly broad, unique foci of scientific depth have emerged in AHCs, through both opportunity and intention. The adage, "If you've seen one academic health center, you've seen one academic health center," has never been truer. With the ease of transporting information across the Internet, the technical barriers to cross-institutional collaboration are fading. Although leveraging the distinctive strengths of AHCs toward advancing interdisciplinary science makes inescapable sense, large-scale collaborations among peer institutions remain atypical, with the possible exception of NIH- or National Science Foundation-funded networks focused on particular research questions (e.g., the NIH Pharmacogenetics Research Network or the network of Clinical and Translational Science Awards [CTSA]). In addition, the pattern of growth of major resources required by investigators in AHCs has, and continues to be, largely duplicative, as individual centers continue to build comprehensive arrays of research service cores, ranging from DNA sequencing to mass spectrometry, to meet the technical needs of their own investigators.

During the last two decades, NIH funding aggregated within individual

AHCs has been held up as an indicator of research excellence and used as a factor in popular rankings of medical schools and universities. As all other sectors in health care bring focus to publicly reported quality measures, the question posed to AHCs in the future is unlikely to be how much funding does the institution hold; rather, the focus is likely to turn to how productive are faculty at the institution in their use of NIH funding. Given that NIH funding totals are, in essence, input measures, a gradual shift toward output measures that reflect (albeit never perfectly) research productivity, such as publication impact, citations, investigational new drug applications, patents, initiation of first-in-human studies, or national research awards, is foreseeable. Although the most popular rankings of medical schools do not yet include measures of research productivity, objective measures that heavily weigh numbers of citations by NIH-funded faculty, and other output measures, are becoming readily available and publicized.²⁶

The shift in emphasis to output measures will be a process, not an event, as a cultural evolution of AHCs will be challenged by the current political realities imposed by an economic model for research that is heavily dependent on NIH grant funding. NIH funding for investigators working in AHCs is, by far, the largest component of the financial portfolio supporting most research-intensive AHCs; hence, in the foreseeable future, NIH funding will be essential to the stability of AHCs and their faculty. For these reasons, as well as the fact that NIH funding is garnered through a rigorous peer-review process, it will continue to be used as a surrogate of faculty productivity in measures that rank institutions and their faculty through the promotions process. Nonetheless, adding measures of assessment that broaden the view of productivity, such as weighing the citations from collaborative (multilab, multiprincipal investigator) works equal to those primarily led by a single principal investigator, in both *U.S. News and World Report* rankings for institutions as well as the promotion criteria for individual faculty, will be essential to changing the research climate to one more supportive of interdisciplinary and interinstitutional science.

Overcoming barriers to resource sharing among institutions

How might a more public focus on research productivity encourage transinstitutional collaboration? As described above, the most challenging questions in science increasingly require a broad range of expertise and technologies, and it is both expensive and inefficient for all institutions to develop substantial depth in every resource domain their investigators may require. An optimistic view is that when institutions are less subject to public rankings that emphasize the size of their NIH portfolios, a renewed sense of priority on cross-institutional resource sharing could emerge. Further, as the federal budget deficit grows, AHCs will see ever more pressure to achieve their research objectives with fewer federal dollars, and they will be called on to work cooperatively, as opposed to competitively.²⁷

The recent NIH CTSA, available to AMCs and their research partners (other medical centers, universities, and industry), has the potential to address this issue at a significant scale because, ultimately, 60 institutions will be joined in a national network. Could AMCs effectively combine resources in support of distinctive translational techniques in regional hubs, with accompanying obligations to provide exportable technology and services to an array of other centers and research partners in the network? This approach, although atypical in biomedical science, has long been in place in other disciplines; for instance, the Department of Energy (DOE) network of laboratories commonly allocates research resources using a hub/center philosophy (see, for example, the DOE SciDAC and INCITE advanced computing programs which provide centralized supercomputer facilities to the research community for computational-intense projects^{28,29}). Would this kind of approach jeopardize research quality? The biomedical science literature is replete with data that are difficult to replicate across centers because of variations in methodology or technology.^{30–32} Hence, aggregation of biomedical research resources into service hubs could not only achieve cost savings and more efficient use of increasingly scarce dollars, but, as in clinical services and other industries, it could also improve the quality of science through reducing variation. Focused investments could allow AHCs to build

standardized technical resource hubs at scale, with the critical mass of people and capital equipment necessary to operate the most advanced technology in a reliable and reproducible manner. Although it will always be necessary to innovate and incubate new methods within individual research groups, once procedures and methods are standard, faculty at many AHCs could use shared facilities. Similar to data-coordinating centers that provide biostatistical services for clinical research networks, hubs could also provide services ranging from bioinformatics to transgenic cell lines, from DNA sequencing to flow cytometry, and more. Help with creating these types of services hubs is already coming from the NIH, where the National Cancer Institute and National Center for Research Resources are recommending sharing of research cores both interinstitutionally and intrainstitutionally between cancer centers and CTSA investigators. Continued national support for this hub philosophy will help AMCs and their research partners build a more efficient research network.

As AMCs reach beyond their walls for purposes of leveraging resources to accelerate discovery, workable models for intellectual property sharing that encourage joint discovery are essential. AMCs have historically underemphasized, relative to industry, their opportunity to capitalize and market the intellectual property developed by faculty. Systematic sharing of intellectual property across academic institutions to strengthen patent portfolios is also uncommon, in contrast to the portfolio practices of the biotechnology industry. Better cooperation among institutions toward sharing intellectual property could lead to an expansion of license and royalty revenues for AMCs and, thereby, reduce the reliance of the academy on the fluctuating tide of federal agency budgets, such as NIH. Recent issue briefs from The Association of Academic Health Centers on the bundling of intellectual property from AMCs and consolidating tech-transfer information discuss how this sharing of the products of collaborative, interdisciplinary research can benefit AMCs and provide a one-stop shop for entities interested in licensing products and technologies.^{33,34}

As the academy becomes increasingly focused on working through these and other systemic barriers to cooperation, the culture of discovery within our medical centers and their companion

universities will be invigorated. Ultimately, implementing administrative models that set higher standards for synergy and aligned incentives may be the key to unleashing the true potential of our research enterprises, even in an atmosphere of constrained national resources for biomedical science.

In Sum

Amidst the many perfect-storm scenarios described for AMCs, perhaps one deserving of greater attention rests in the fundamental architecture of its scholarship. The federal budget in support of AHC missions has flattened as the costs of discovery and education continue to rise. At the same time, many of the key roadblocks to progress in biomedical science do not lie within traditional walls but rest in domains within the academy, where economic and scholarship traditions are far different from their own. Moreover, the publicly reported measures of excellence for most AMCs reward competition between institutions, when collaboration would be far more efficient and productive. Thus, the academy must look to innovative, far-reaching changes in how it conducts the business of scientific discovery. To provide support for the evolving biomedical enterprise, the academy must explore new models that realign operational processes as well as incentives while bridging the disciplinary interstices within and between institutions.

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