The University as an Open Laboratory

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Abstract: *Colleges and universities are two of the most formidable resources a country has to reinvent and grow its economy. This is the second of two papers that outlines a process of building and strengthening research universities that enhances regional technology development and facilitates flexible networks of collaboration and resource sharing. In the first paper, research clusters were highlighted. In this paper, the concentration is on the implementation of research clusters to unlock the potential of the universities as open laboratories. The focus of the open laboratory is on swift translation to practice, leveraging and diversifying limited funding resources, integration across disciplines, and facilitating community partnerships to build global competitive advantage in research and development. The strategies described were undertaken at large public universities and in a smaller college environment which are representative of many colleges and universities. The analysis of the factors influencing research and development in today's competitive environment, alongside key research management interventions, provides a framework for adapting the concepts to fit the needs of a full range of educational institutions and environments.*

Keywords: *open laboratory, research clusters, university research strategy, interdisciplinary research, innovation, competitiveness, regional development, technology transfer*

Introduction

The greatest challenges facing the education and research community today revolve around the issues of a quality education, funding, relevance, and return on investment. National concerns are often focused on how to unlock the potential of universities and the investments being made to effectively put research into practice, while creating an entrepreneurial workforce that can lead an economic renaissance. In the previous paper, we explored the implications and potential of organizing a university's research processes around challenge-based, interdisciplinary teams or research clusters. Research clusters were defined as flexible and inclusive, team-based, interdisciplinary research structures that encompass faculty members, centers and departments, and community partners (including other universities); they are focused on common themes or broad focus areas inspired by major 21st century challenges.

In this paper, the emphasis is on the implementation of those ideas to catalyze and orient a university or college to become a partnered open laboratory across divergent disciplines (from the arts to engineering and humanities to medicine).

The open-laboratory concept, as detailed here, is the actualization of research clusters in the creation of an integrative learning and research environment. In an open laboratory, the processes of education and research come together in a seamless path, from discovery to implementation. Every effort is made to reduce barriers between research and practice, industry and academia, and learning and doing. The open laboratory's focus is on solving a set of pressing challenges in a way that furthers the creation of basic knowledge, develops a community of entrepreneurial knowledge builders and users, and drives regional economic development. Open laboratories are made of research clusters that incorporate students (undergraduate and graduate), faculty members, industry researchers, and potentially consultants, federal laboratories, and others working together as a synergistic team with multiple sources of funding and themed objectives.

Research colleges and universities, in collaboration with industry and government, are tackling some of the most challenging issues of society. The open-laboratory provides research administrators with a framework to address and discuss some of the greatest challenges that universities and industry are facing. Many universities have implemented elements of the open-laboratory approach very successfully, but as simple as it sounds, significant barriers to implementation (on and off the university campus) of open-laboratory concepts occur, due to traditional university and industry frameworks. Often these undertakings are core facility-based and are relegated to facilities that are outside of the traditional educational process (at least for undergraduates, e.g., science centers, institutes, applied research laboratories and experiment stations, etc.). In the context of this paper, an open laboratory integrates community partnerships and the entire educational process in a way that enhances both basic and applied research.

The university as an open laboratory begins with the roots of both the land-grant ideal and university-based applied research laboratories. Land-grant institutions were created through the Morrill Act in 1862 and founded on the concepts of hands-on research and a timely application methodology. The faculty, students, and scientists worked together to solve problems, with no separation between basic and applied research. As Pasteur proclaimed, "there is not pure science and applied science but only science and the applications of science" (Stokes, p. 2). The university as an open laboratory concept extends and broadens the land-grant concepts (university-wide) to the 21st century challenges of transforming the economies in which universities are situated, and creating a more relevant educational environment for students.

Land-grant institutions have had a tremendous impact on the agricultural productivity of the United States. Founded in 1862, when the population was growing and farm productivity was stagnant or decreasing, these institutions were key elements in transforming the agricultural landscape (and the industrial economy) around the world (Renne, 1960). In 1860, agriculture required approximately 55% of the workforce (Gallman & Weiss, 1969). As of 2010, just 2-3% of the U.S. workforce was employed in farming. With regard to industrial development, the United States went from exporting slightly more than 20% of the finished goods it imported

(1860), to exporting 7.5 times what it imported (1945), and back to exporting less than 50% of what it is importing (2010) (U.S. Census Bureau, 2012; Carteret al., 2006).

Touring the historical archives of any of the land-grant institutions, one often runs across pictures of students and faculty members working alongside farmers in the field to solve the problems of disease, blight, and productivity. This problem-solving practice was hands-on training at its best. The mechanics curriculum of the new economy was created by the students and faculty members who were solving the challenges of the use and development of new machinery that powered the industrial and agricultural economy. The concept of agricultural and engineering extension is a potent element of the open-laboratory concept detailed in this paper extended to include the entire university academic community. It should be noted that these ideas were not confined to the United States. Internationally, the University of Twente, founded in the Netherlands in a dying textile region during the 1960s, was based on similar concepts and brought about a remarkable economic transformation of the region, while building a strong cadre of entrepreneurs in nano- and micro-materials and devices (Eijkel, n.d.).

Historically, universities have played a pivotal role in bringing new ideas and research into practice, while training students that could carry on the process of discovery, innovation, and invention in society at large. This has not been a uniform process. At times, boundaries between basic and applied research have been blurred (particularly during times of crisis or national challenge), and universities, government, and industry came together to form synergistic and entrepreneurial teams with astonishing results. At other times, the efforts seem to flounder, compartmentalize, and become tangled in ownership issues and bureaucratic processes, while the challenges grew ever more complex.

Background

Environment and Rationale for an Open-Laboratory Approach to Research

After World War II and the stunning success of science and technology evolution, President Franklin D. Roosevelt and Vannevar Bush sought to sustain the momentum of discovery and technology development during peacetime (Stokes, 1997). The result of their efforts was the implementation of a doctrine that espoused the separation of basic and applied research and a linear process from discovery to implementation. While this linear process was not the typical practice during wartime, nor the approach most responsible for the success of those wartime efforts, Vannevar Bush asserted that "applied research invariably drives out pure" (Bush, 1945).

The authors suggest that the separation between basic and applied research is a false dichotomy that has weakened the pursuit of basic research as well as applications to practice over time. One has to look no further than the collapse of basic research centers at large corporations in the 1980s and 1990s. Decades earlier, an effort was made to prevent applied research from driving out pure; leading corporations, government agencies, and laboratories separated basic research from applied research. Basic research was to be conducted without regard to how it could be applied. Arguably, some of the corporate basic research infrastructure collapsed, because researchers became starved for funding that would have been provided by the results of applied research.

In 2013, this is occurring on an international scale, as limited resources from stagnant economies are leading to questions about the value of a university education and constraints on basic research funding. Increasing pressure is placed on universities and national laboratories, two of the last refuges of basic research, to show applications of basic research. The authors suggest that this worldwide phenomenon might have occurred because too little research had gone into practice to fund the growing investment in basic research. The global economies that are growing in the developing world are those that have been successful at translating the basic and applied research of developed countries into useful technologies. There is a growing awareness that, as the catch-up process is completed, a way must be found to orchestrate the innovation of new technology development in concert with basic research discoveries.

There was a time when the United States was known for Yankee ingenuity and possessed the bravado to think that that every project attempted would eventually be successful eventually (NASA History, 1962). A president could state that the country was going to send someone to the moon and back within a decade, – and it happened; when Detroit, Michigan, represented the pinnacle, not the nadir of U.S. industrial inventiveness; when almost half of the U.S. populace worked on creating and making things, and finished products outnumbered U.S. imports seven to one (U.S. Census Bureau, 2012; & Carter, Gartner, Haines, Olmstead, Sutch, & Wright et al., 2006); when we cured disease, not just sustained perpetual patients, and it appeared as if pharmaceutical growth to treat disease would be exponential, not flat. Policy-driven bureaucracies were not so risk adverse; growth seemed limitless, as did educational opportunities and a secure job for everyone after college. It has been estimated that half of 2012 college graduates are under or unemployed (Vedder, Denhart, and & Robe, 2013).

Travelling to the moon now seems more implausible than it did a half a century ago. On the first author's 2009 tour of NASA, an astronaut described the impending mission to the moon with language that suggested it represented a step back from the thirty-year-old shuttle and looked more like the Apollo program. In later conversations, another representative wondered aloud if NASA had not simply been lucky the first time in getting a man to the moon. In 2009, the Human Space Flight Plans Committee reviewed the Constellation Human Space Flight Program and found the plan to be far behind schedule and too underfunded to meet most of its goals (NASA). It was cancelled in 2010.

The manned space program, like the bankruptcy of Detroit, is only emblematic of something that seems to have been lost, and cannot be relegated solely to the complexity of the issues we now face. Perhaps, at its core, what has been lost is the timely translation of basic research concepts and ideas into practice, including 1) creating a feedback loop that strengthens and energizes the basic science, 2) developing the right environment and networked structure that can coordinate complex challenge-directed programs, and 3) creating an entrepreneurial workforce that works synergistically across both worlds. No better place exists for this evolution to occur than in our universities; however, researchers and administrators need a better model if they are to strengthen an economy that can continue to fund the growth of basic research.

Successful Initiatives and the Clues to the Tenets of Their Success

To gain insights into the paradigm shift that would be required to build a new model, the authors examined successful examples (and a few failures) over the last century in which everything seemed to come together. These events and projects yield clues to the characteristics necessary for the successful reintegration of basic and applied research and the role of universities in this process. Mindell (2009) described a striking paradigm shift which began prior to the start of WWII, in which professors, who had doubled as scientists, ran labs with students and few financial resources and did not put much effort into the applicability of their basic research. However, during the war, he describes how “science became mobilized on a grand scale” and “[t]he massive ‘research and development’ (R&D) laboratory emerged in its modern form (p. 1). Thousands of physicists from the government, military, universities, and industry worked together to create laboratories that focused on war-time innovations, including the atomic bomb, medical research, psychological testing, electronics, radar and more.

Mobilization and collaboration were not confined to wartime efforts alone, as there were similar endeavors over the following decades. Among those examples are the successful creation of the hydrogen bomb and commercial atomic reactors, the development and deployment of the space shuttle, the decoding of the human genome, and a vaccine for polio—Roosevelt made a plea in 1944, and the vaccine was available in 1951 (Woolley & Peters, 2013). These highly successful, game-changing initiatives contrast with the quest for commercial fusion power (always seemingly 50 years away); the space plane (multiple failures); cures for diseases such as cancer and diabetes (despite President Nixon declaring a war on cancer in 1972); and the solving of social issues such as poverty, inner city and rural employment, and developing nations’ basic human resource needs (Easterly, 2006).

In 2013, the challenges of the disease and fusion power research are far more complex, both scientifically and organizationally, and the basic science is often not thoroughly understood. Perhaps, our approach is not matching the challenge; part of the difficulty we face is effectively bringing to bear and integrating interdisciplinary, basic, and applied research capability to solve these challenges through networked teams of community partners, industry, and academia. In a time of funding constraints and slow progress, might it make sense to reexamine the discovery paradigm that has been taken for granted? Networked, flexible, and entrepreneurial research clusters and open-laboratory environments together are a set of nonthreatening mechanisms that have the potential to shift the research paradigm at universities and create a more facilitative environment for discovery that leads more swiftly to implementation. It is a model based in part on the reintegration of basic and applied research espoused by Stokes (1997) in Pasteur’s Quadrant: “Breakthroughs achieved by use-inspired basic research can lead to further pure research, just as breakthroughs in pure research can lead to further use-inspired research” (p. 2). This is summarized well by Judy (2010) as characteristics that lead to successful major technology breakthroughs. The success of major technology breakthroughs required the following:

- tight cycles of rapid innovation and continuous improvements

- advances in scientific knowledge about materials, systems, and the laws of the physical universe
- an experimental environment that anticipates and rewards failure
- synthesis of information and ideas from many inputs
- management and coordination of hundreds or thousands of individual efforts, often across geopolitical boundaries
- break-neck speed of execution from research to development to mass production to implementation
- appropriate levels of information security and secrecy, or openness and sharing to enhance collaboration (p. 1)

Building on this analysis, the authors examined exemplary research translation at national laboratories and universities, as well as successful regional efforts in economic development. These comparisons yield clues as to how a successful open-laboratory approach might work, resulting in a set of salient features for successful translation to practice. While others may see it differently, the authors derived the observations detailed in Table 1. Successful projects exhibited most of these characteristics in one form or another. If one characteristic was weaker, another made up for it by being more dominant. At times, the goals are less specific, such as regional economic development, but many of the characteristics observed above were still exhibited.

In establishing research clusters and an open-laboratory environment, universities can incorporate many of the characteristics present in already successful programs. For example, the University of California, Berkeley is limiting bureaucracy, encouraging entrepreneurship, diversifying its funding, and rewarding collaboration and risk-taking. It was recently recognized by the Obama administration for "spearhead[ing] an intellectual property management strategy that stimulates support of the University's research and maximizes societal impact of the discoveries from the University's research" (Socially responsible licensing & IP management: IPIRA-Intellectual Property and Industry Research, 2012). They have "institutionalized this strategy as UC Berkeley's Socially Responsible Licensing Program (SRLP)" (Socially responsible licensing & IP management: IPIRA-Intellectual Property and Industry Research, 2012). One of its highly successful initiatives, co-sponsored by the Gates Foundation, enabled basic gene cloning research on campus (in collaboration with a private Berkeley-founded start-up company), while the Institute for One World Health (iOWH) oversaw the regulatory and distribution aspects of the project.

> Simultaneous funding from the Foundation enabled parallel performance of basic, translational, and regulatory work, cutting years off the typical bench-to-bedside timeline. The product development partnership involved a three-way collaboration agreement and two royalty-free licenses from IPIRA [Intellectual Property and Industrial Alliances]. In 2004, the partners de-risked the project by advancing it along the value chain, and in 2008 sanofiavent sub licensed the rights from iOWH and Amyris (Socially responsible licensing & IP management, 2012).

Berkeley is not alone. The State University of New York (SUNY) Albany, Texas A&M, Twente, MIT, Boston University, North Carolina, Stanford, and Cornell (to name only a few) host

Table 1. Successful Project and Open Laboratory Characteristics

Flexible Networks and Seamless Collaboration: Universities, government, and industry work seamlessly, and the potential of universities is unlocked. Teams consist of faculty, industry members, economic development entities, and students.

Shared Goal: Everyone (faculty, industry members, economic development entities, and students) works toward the same goal. Basic and applied research are valued equally and enable and reinforce each other.

Clear Timeframe: The timeframe in which to accomplish the challenge (generally a decade or less) is specific and well-understood – but not necessarily the means.

Funding and Facilities: Funding is appropriate to the task, and facilities and equipment are state-of-the-art. Resources are focused and leveraged for larger ultimate returns.

Atmosphere of Innovation: An entrepreneurially-driven environment fosters innovative concepts, ideas, and processes.

Multidisciplinary Expertise: Expertise from all relevant fields is concentrated in well-coordinated, focused teams with engaged administrators (at all levels) who have field-specific knowledge and are backed by skilled managers.

Education Integral: Universities are integral to the success of basic and applied research endeavors. A seamless path exists for progressing from student to research colleague.

Limited Bureaucracy: Bureaucracy is kept to a minimum to support the mission and the team. Barriers to collaboration are minimized, including overregulation, IP ownership issues, and promotion and tenure guidelines.

Risk-Taking Rewarded: Calculated risk-taking is encouraged and recognized as a necessity, and safety is rightly valued but not overly controlling. Risk is viewed as a critical part of learning.

Failure Not an Option: Project failure is not an option. Multiple networked pathways (many of which will fail) assure success. Failure is part of the quest, but perseverance assures primary goals are met.

Global Competition: Global competition is recognized and encouraged as a critical element in success, as is global collaboration.

Appropriate Incentives: Faculty incentives are aligned with project outcomes and objectives with appropriate rewards for entrepreneurial activity.

Unified Leadership: Leadership is unified with support across the political, academic, and industry landscape and is able to coordinate highly complex endeavors for societal benefit, not only financial gain.

hundreds of centers and laboratories that cross disciplines and span industries (See Appendix). On their own, the centers and laboratories perform specialized functions. Bound together in research clusters, they can turn the university (and the region itself) into an open laboratory. Of course, not all open laboratories are launched by colleges and universities. Oakridge and Sandia National laboratories, affiliated with the U.S. Department of Energy, are examples of a highly successful, industry-government-university laboratory collaboration. Both were created in World War II to work closely with the military to work on the Manhattan Project (atomic bomb) and subsequently other national security projects. Sandia National Laboratories, a Lockheed Martin Company, "invested $31.5 million in 474 research projects with 93 universities" in 2012 (Sandia National Laboratories, 2013). Oak Ridge National Laboratory, managed for the U.S. Department of Energy by UT-Battelle, boasts the sponsorship of over 3,000 private, public, and university scientists, and hundreds of patents and technology licenses (See Appendix) (Oak Ridge National Laboratories, 2013).

Internationally, the University of Twente, in the Netherlands created an open laboratory based on many of the concepts described in this paper. In the 1970s, the region was an economically depressed dying textile center, and the university was simultaneously struggling with enrollment and finding its mission. After a strategic decision to become "the entrepreneurial university" and work with regional leaders in an open-lab model, it is now an electric place where businesses are constantly created, with 800 startups to its credit (de Boer & Drukker, 2011). The community has also been transformed into a hub for nano and micro technology, where application parallels discovery. Most research administrators must work within existing university structures; however, Twente has a matrix organization where research needs are above the departments, and faculty hiring is driven, in part, by university-wide research goals.

Clearly, best practices exist within each of these programs. Is it possible to move even further in applying the concepts of a) creating a flexible network of co-evolutionary paths for basic science and technology development including flexible intellectual property (IP) and licensing; b) securing multi-source funding to ensure that the facilities and projects are appropriate to the task; c) encouraging entrepreneurship; d) and welcoming the best minds from all relevant fields to work in well-coordinated, interdisciplinary and focused teams with engaged administrators at all levels? The following examples detail the authors' experiences in answering this question and building or reestablishing effective open laboratory environments.

Examples of Implementations at New Mexico State University, The University of Houston, and Penn State Behrend

To demonstrate how open laboratories can be applied in practice, the authors' experiences implementing open laboratories in two universities, New Mexico State University, (NMSU) and the University of Houston (UH), are detailed below. Furthermore, previously established and on-going transitions to open laboratory environments at Penn State Behrend expand on processes utilized in the other institutions.

New Mexico State University

The Physical Science Laboratory (PSL) of New Mexico State University emerged as an early form of the open laboratory in 1947 through a contract with White Sands Missile Range. It grew from the physics department and integrated students (primarily undergraduate), faculty members, and White Sands researchers to develop the early rockets and technology for the nascent U.S. space program. The laboratory drew students from multiple disciplines across the university, and blended basic science with application and hands-on training with departmental lectures. It was an unqualified success, with thousands of graduates earning leadership positions in the space and computer industry. The open laboratory provided relevant training easily transitioned to industry; paid students' (thereby enabling them to afford university tuition and expenses); made breakthroughs in space communication, rocketry and telemetry; and provided the faculty with a strong base of research funding.

Over time, the laboratory became a victim of its own success, drifting to ever-larger applied research applications to employ its growing cadre of non-faculty members with a focus on applied research. Like many applied research laboratories, it became disjointed from the educational and research process within the university, and faculty members and students drifted away. As a result, the laboratory went into a state of decline (as did research funding for the Physics department), that was only reversed only when research clustering was introduced, and PSL returned to its roots as an open laboratory for basic and applied research. The interdisciplinary open laboratory teams again began working closely with White Sands tenant organizations and industry on projects such as adapting research on improvised explosive devices to jammer technology to protect soldiers (creating a prototype in four months); and researching ways to integrate robotics with human teams, while probing a deeper understanding of human behavior.

During that time, the first author visited the Mathematics department to reintegrate basic and applied research and get the faculty re-involved with the laboratory. After viewing a presentation on how basic research in combinatorial mathematics could be enriched by solving some critical challenges in experiments the laboratory was conducting, one of the senior faculty members questioned aloud why they should do such a thing. The answer came sometime later when a math faculty member, having accepted the challenge, joined the laboratory. In discussions with his math colleagues, the faculty member described how his research was being applied and enriched. Not long after he joined the laboratory, so many faculty members became interested and engaged that too few were available to teach (as a consequence of buying out their time). The PSL staff was then able to reengage in the teaching mission, creating a win-win environment for basic and applied research that benefited the students, the department, and the laboratory. This process was repeated in various ways with departments from arts (creative media), history (intelligence studies), and engineering (intelligence and remotely power vehicles). The laboratory doubled its expenditures, while enlivening the teaching and research opportunities across campus.

The University of Houston TcSUH Applied Research Hub

High-temperature superconductivity was discovered at the University of Houston (UH) in the 1980s. At the time, there was considerable excitement about the applications and future discoveries that might lead to lossless transfer of power, perhaps even up to room temperature. A major center was established (the Texas Center for Superconductivity at University of Houston (TcSUH) under an expert leadership team, headed by one of the founders of high-temperature superconductivity. Unfortunately, twenty years later, significant advances in utilizing the technology and moving to ever-higher temperature superconductivity were still largely unrealized (in spite of the great research being done), and funding was becoming more limited. Over those twenty years, however, the technology had advanced to the point that the brittle ceramic cuprate compound could be deposited as a thin film on a nickel alloy substrate, providing a potential application medium. UH could play a key role in the development, if a way could be found to bridge the basic science capabilities of TcSUH with a leading industry partner (establish a cluster), and develop an IP agreement that allowed the flexibility for everyone to benefit.

The director of the center, along with a recently hired industry colleague, developed a concept called the Applied Research Hub that would bring together industry and academic researchers and engineers in a team on site at UH. The research group worked with the College of Engineering's Mechanical Engineering Department, the center director and, later, the Executive Vice President to develop a proposal for a Texas Emerging Technology Fund (ETF) grant to hire a team of researchers that would be drawn from both industry and academia and placed in the recently acquired Energy Research Park adjacent to campus. Texas ETF grants were a somewhat unique funding approach established by the governor that required a matching commitment from both the university and industry. Universities could contribute faculty lines, make a key strategic or cluster hire, and provide space, while each partner would contribute funding and industry could contribute equipment. The basic concept of the ETF was contribution of a third (or more) of the resources by each party to focus on commercialization of emerging technology and spinouts within roughly five years (Emerging Technology Fund, 2005).

Key to pulling together this proposal was development of a flexible IP agreement that gave UH a portion of the revenue from the science and technology that was developed, along with commitment from the industry partner to move equipment to Houston to establish laboratories for fabricating high-temperature superconducting wire. Experiments would be performed in these laboratories and then tested in the adjacent pilot manufacturing facility, resulting in a coevolution of the science and technology necessary to speed product development and enhance basic research opportunities.

The successful proposal resulted in the creation of TcSUH's Applied Research Hub through a Texas ETF grant for $3.5 million. The university invested $3.8 million, and SuperPower Inc., a leading developer and producer of high-temperature superconducting wire, invested $8.8 million. The Applied Research Hub focused its work on the development of high-performance, high-temperature superconducting wire for devices being developed in energy, medical, and transportation applications as well as future applications in many fields. Recent large awards have been ARPA-E grants (totaling more than $5 million) and a Texas Higher Education Coordinating Board grant ($1.5 million) to purchase a reel-to-reel metal organic chemical vapor deposition system for the research hub.

To date, significant advances have been made in the current carrying capacity of the superconducting wire, bringing it into the range for commercial applications. This could be a boon for long distance power transfer, particularly from renewable sources, for high-efficiency generators and motors, and magnetic energy storage. Moreover, the thin film, roll-to-roll manufacturing techniques developed along the way, are now being directed to production of more efficient solar panels, flexible electronics, etc. Within three years, the university established an advanced materials processing center on campus that became integrated with elements of a wind initiative (for power transfer and light-weight generator design), a solar initiative (thin-film technology application), and smart grid (power systems control) endeavors. Although it is too early to label it an unqualified success, the open laboratory is enlivening the basic and applied research environment and leading to commercial applications that will provide feedback to support the basic and applied research.

The University of Houston Science and Engineering Research Center.

Concomitant with the creation of the open laboratory for materials, a similar effort was undertaken in biological research with the development of the University of Houston Science and Engineering Research Center. Configured with key core facilities, ranging from a Nuclear Magnetic Resonance system to a large clean room with wet lab space, it brings together faculty clusters from medicinal chemistry, synthetic biology, and cell signaling to potentially build from molecular structures to test device and drug delivery. Clusters and core facilities have been successfully established and research revenue has grown significantly, as has the reputation of UH and its links with the Texas Medical Center. Whether it will evolve into a set of teams that can work successfully together across larger multidimensional challenges with industry is still an open question, as each faculty leader has his/her own areas of interest; however, some faculty members have commented that participation in the clusters has created opportunities to rethink the boundaries and applications of their own research.

Translating Cluster-Based Research Swiftly into Applications at the UH: Industry Relations and the Center for Industrial Partnerships (IP-Related Revenue).

To fulfill the potential of research clusters and the open-laboratory concept, IP licensing approaches must evolve concurrently, as in the case of the applied research hub at UH. Prior to this agreement, IP licensing at UH had followed a traditional approach (in basic research environments) in which translation to practice was not often an integral part of the research process. If a patent resulted from research, then the university might find a company interested in the discovery (to keep it off the market or expand its existing patent protection) or the researchers themselves might opt to develop the application (often a dicey proposition fraught with conflict of interest as well as issues related to time, resources, and management). Either way, the majority of technology did not result in substantive applications or funding. It is the author's experience that universities struggle to break even on IP licensing operations when all the costs were accounted for. Additionally, UH licensing processes were often challenging, due in part to ownership issues mandated by the Bayh-Dole Act (for federally funded research but often carried over to industry-funded projects) and IRS regulations (e.g. tax free bonding for research buildings). UH's evolution of its IP policies in response to this, along with the development of supporting space, also became a driver of the open-lab concept.

In decisions on the potential of research for application and licensing, some universities have taken the approach that outside business experts and venture capitalists can do a better job than internal personnel, as was recently pursued by UCLA (Basken, 2013). There is reason to question that this is a complete solution to technology transfer operations for universities. The authors' experience with this approach at NMSU and the Physical Science Institute suggest that this, while this is a positive and necessary step in successful technology translation, it may be too late in the development process. During the 1990s, the U.S. federal government undertook an initiative to facilitate the transfer of discoveries made in research and development laboratories, often for military or DOE applications in the commercial sector. The Defense Advanced Research Projects Agency (DARPA) was even renamed ARPA at one point, thinking that the successful Defense R&D process could somehow be broadened to commercial industry. Significant investments were also made in national laboratories to translate technology developed for military and energy applications into commercial products and processes. Despite the success of these endeavors, translation to practice (after the fact) is often found to be a costly and time-consuming challenge if no thought is given to commercial applications or drivers during the discovery phase.

What if the process of discovery was pursued hand-in-hand with knowledge of the commercial drivers, manufacturing processes, and potential applications, as a parallel—not a sequential process, and not to drive basic research, but to function symbiotically with it? This question was the genesis of the idea for UH's Center for Industrial Partnerships and the "open-laboratory" concept—a natural evolution of the cluster-based approach to research. The key idea, to develop relationships before and during the discovery process with application partners, would enable the distribution of the benefits of discovery and implementation. This is similar to the successful approach employed by the Wisconsin Alumni Research Foundation (WARF). WARF uses a continuous cycle of technology transfer which leads to royalty, licensing, and investment income, that in turn is reinvested into new research. (WARF Mission & Vision, 2013).

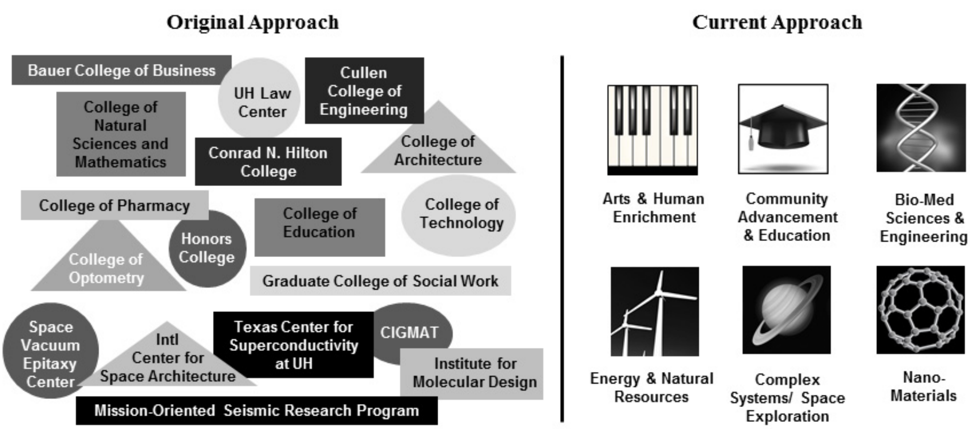

Figure 1. Research Approach – Front Porch: University of Houston

Source: Boyko, B., Birx, D. (2009), modified by Gonda, W. (2013), Presentation to the UH Board of Regents

Open laboratories provide the entrepreneurial space and flexible IP arrangements for truly collaborative research and development, and with research clusters, became a way to build critical mass and focus interdisciplinary and collaborative strengths in key strategic areas. They also formed a "front porch" for a potentially interested community, commercial/industrial, national, and international partners who organized research around key themes (See Figure 1). However, once themes were established, one of the most frequent questions received in the research office from industry was, "How do we learn what research faculty members are doing in the areas most relevant to our interests?" and "What IP exists that might be adapted to our needs?" To address these questions, the research group established the Center for Industrial Partnerships (CIP). It became the "front door" for the university's interface with industry. To make this process effective and to create a bridge to industry, UH initially established its CIP within the Office of Intellectual Property Management (OIPM) to oversee technology development and transfer by actively seeking partners in the private sector to fund research that could then be commercialized (See Figure 2). The CIP supports faculty member entrepreneurship by developing partnerships with commercial and non-profit organizations, trade organizations, business acceleration programs, and economic development groups to foster cross-sector collaboration, create new business opportunities for UH faculty, and fast-track the commercialization of inventions. In this endeavor, UH had considerable support from the governor's office, the legislature, and congressional representatives, as well as the community, the chancellor, and the Board of Regents.

In cluster hires, UH would look for leaders who could bridge industry and academic environments, and could build teams and establish centers that spanned basic and applied research. Faculty members could agree to give up traditional IP ownership claims in return for research support, corporate involvement, and financial incentives (always at the faculty members' option). A more flexible IP licensing process focused as much on the joint development and application of future discoveries as on generating income from existing IP. Initially, the idea of increasing IP ownership flexibility was primarily to increase investment in joint research between academia and industry. Revenue from licensing was considered secondary.

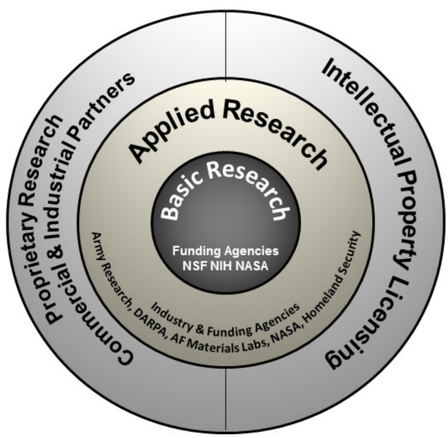

Figure 2. University of Houston Center for Industrial Partnerships

Source: Boyko, B., Birx, D. (2008), modified by Gonda, W. (2013), Presentation to the UH Board of Regents

However, the results were striking in two ways. First, the funding opportunities for research increased markedly. Second, the licensing from IP increased significantly from approximately $752,000 in 2006 to $4.4 million in 2010. Under the direction of a new Vice President of Research, revenues continued to accelerate. In 2013, revenues stood at over $16 million and were projected to grow to $40-50 million by 2020. Figure 3 shows the IP-related numbers from FY2006-FY2010.

	FY2007	FY2008	FY2009	FY2010
For-Profit Awards	$9.6M	$8.6M	$12.2M	$5.7M
For-Profit Expenditures	$6.2M	$7.1M	$9.0M	$4.9M
Licenses to Commercialize IP Created/Owned by UH	2	1	6	6
Total Revenues from Royalties	$348K	$1.1M	$1.9M	$2.6M

UPDATE: FY2013 Actuals: $16.5M / FY2020 Target: $40-50M

Figure 3. Industrial Partnerships: University of Houston
Source: Fletcher, E., Birx, D. (2010), modified by Gonda, W. (2013), Presentation to the UH Board of Regents
Note: $348K based on 2002 data

The Open Laboratory Concept at Penn State Behrend

Regions throughout the Great Lakes portion of the United States once dominated the world of manufacturing. Those days are gone; nevertheless, significant remnants of the manufacturing industry remain in the region "accounting for 34% of the nation's manufactured products and 71% of its exports" (Nikolishen, 2013), Also remaining is an orientation toward engineering and technology that comes from living in a region where manufacturing was once so dominant. Some of those manufacturing companies have retained or grown their position of dominance in IP through the distinct products they manufacture. Others own little formal IP, but possess the know-how of manufacturing processes that enables them to be competitive in their industry by implementing lean manufacturing techniques and providing lower wages. For the latter companies, this situation does not always provide stability, but is often a battle for survival.

Penn State Behrend resides in the middle of one such region in northwest Pennsylvania. It is ideally positioned to work with local industry to turn the latest research advances into new products, bring in outside partners by increasing development of IP, foster an environment where new companies are created, and develop an entrepreneurial workforce. The college began its implementation of a precursor to the open-laboratory concept in the 1990s, with a focus on plastics manufacturing, after a group of industry leaders approached the college to apply science and technology principles to improve their competitiveness. The creation of an academic plastics program and a NIST-funded Plastics Technical Development Center provided engineering and technical talent to help companies develop and adopt new technologies and increase their capabilities (See Figure 4). The engineering talent pool made of students, faculty members, and industry partners became capable of developing new technologies and products. For example, the development of cross-linked polyethylene piping and the associated manufacturing enabled plastic pipe to compete with copper in residential water piping.

This open laboratory spawned curriculum advancements, including a significant industry-based capstone program across all engineering disciplines. The capstone project experience enabled many organizations to develop and manufacture new products, and now supports over 40 different organizations each year. Furthermore, the open laboratory led to the creation of the Knowledge Park, a technology and business park adjacent to campus. Knowledge Park was the home to GE Transportation's IT service development team in the 1990s, which used teams of GE employees and Penn State Behrend faculty and staff members to create the disruptive reverse-auction software technology that GE has employed widely throughout the corporation (Colvin, 2008).

Figure 4. Penn State Behrend Plastics and Polymer Processing Open Laboratory

Note: This 10,000-square-foot manufacturing and test facility integrates manufacturing, undergraduate education and industry research. Areas of research are in polymer processing, materials development and medical device design.

In 2010, the second phase of the development of the open laboratory began with a decision to further parallel basic and applied research partnerships with industry. After examining the region's industrial base, a decision was made to emphasize advanced manufacturing, medical devices, soft materials, and nano-manufacturing. The four pillars of the second phase of the open laboratory concept are a) a focus on translational research; b) a new approach to IP that facilities cooperation with industry; c) interdisciplinary teams of students and faculty embedded and working side-by-side with research partners, and d) open facilities, shared between industry and the university.

First, in terms of research focus, faculty members and administration collectively made the decision to extend principles of science and technology research into applications in which they could be commercialized, particularly with industrial partners. This represented a shift from engaging in projects that are solely basic research to include the domain of proof-of-concept, prototyping, and pilot production through commercialization. The faculty promotion and tenure reward system was revamped to reward faculty members for patents, industry funding, and technical transfer to commercial application, on an equal basis to traditional rewards for publication and federal funding.

Second, in 2011, Penn State University adopted and broadly publicized to industry, a new, flexible approach to IP ownership that allows shared or even full ownership of IP to companies that sponsor research as long as there is no federal flow through funding (Foley, 2012). The focus shifted from IP ownership (which was not providing significant long-term financial benefit) to a long-term research relationship with industrial partners. This shift enabled Penn State Behrend to implement the open-laboratory concept. Interest was immediate; within a matter of months, a large international company placed an innovation center in the college's research park. In this effort, implementation was challenging given a considerable learning curve within the contracts office and risk-management offices, but after several months, success was achieved.

Third, as a primarily undergraduate college in a large public research university, Penn State Behrend was in a unique position to integrate research and education, while supporting regional economic development. A significant challenge, how to conduct meaningful research with undergraduate students as a primary source of talent, led to the Intern Mashup concept in which interdisciplinary teams of undergraduate students led by faculty members, research associates, and industry partners form to address applied research challenges. The mashup provided flexible and timely responses to needs of industry partners. Penn State Behrend was able to secure external funding by building credibility of research outcomes and IP development through the senior project experience that was then translated into larger faculty-led projects. Furthermore, faculty and staff members leveraged the Intern Mashup Concept, which has provided for faster turnaround in funding and executing research projects.

Fourth, Penn State Behrend adopted a philosophy of shared facilities and co-location of partners. Knowledge Park has become a key part of the strategy for marketing and identifying new open laboratory partners. The strategy shifted from a focus on real estate development (necessitated by economic reasons) to recruiting industry partners who want to work in an open-laboratory environment and engage with students and faculty in applied research at shared facilities. Industry partners are provided access to state-of-the-art equipment, incorporating reasonable charge-out rates and required training. Industry partners consign equipment on campus for joint projects, bringing advanced technical capability. Like many university parks, Knowledge Park was undersubscribed, not well-connected to the campus, and struggling financially. However, pursuing the open laboratory strategy has brought significant change. The occupancy in the park has increased to the point where it has reached capacity (employing 500 employees in 18 companies), and is profitable for the first time in its history. Furthermore, industry funding for research has increased by 300%, and internships in campus innovation centers has increased by 400%.

Knowledge Park staff, the college's leadership, and the School of Engineering are developing a new Advanced Manufacturing and Innovation Center to house both academic spaces and spaces for industrial partners who engage extensively through the open-laboratory model. This novel approach, housing both academic and industry partners in one facility, has already been a significant catalyst in attracting business partners, and is enabled through the joint management of the park with the Economic Development Corporation of Erie County (Pennsylvania). Scheduled to open in 2015, the Advanced Manufacturing and Innovation Center will encompass the open laboratory ideals to become a fertile environment for collaboration and cross-pollination of ideas. Although the Advanced Manufacturing and Innovation Center, which will bridge the academic center of the campus and Knowledge Park has not yet been built, interest by companies who want to be located there is substantial, as is the success of retention efforts.

While the second phase of open-laboratory initiative is only two years old, the results are promising. 1) A Medical Plastics Center, with support from The Commonwealth of Pennsylvania and a number of significant industry partners (including Harmac Medical, Bayer Medrad, and Philips Respironics) was created to support manufacturers in the development of new medical devices. The open laboratory facility is used in educational programs and by industry partners to conduct research. 2) FMC Technologies, a global energy company, created an FMC-Penn State Behrend Design Center in Erie around the concept of Intern Mashup, where teams of students work with FMC engineers on applied problems that are supplied from FMC locations worldwide. 3) Encouraged by the open laboratory progress, Autodesk Corporation, an industry leader in CAD, engineering analysis, and entertainment software, created a one-of-a-kind, five-year partnership to supply their entire software library to the college. 4) After a period of introduction and negotiation, SKF, a global technology provider, created the SKF North America Innovation Center in Knowledge Park. The location of this innovation center was driven by the flexible IP policy, the integration of the open-lab approach with Knowledge Park, and the Intern Mashup model. Teams of student researchers are being led by faculty and industry researchers, and the team innovations have already been integrated into SKF's manufacturing operations.

Digital Arts, Media, and Technology and Penn State Behrend future directions.

One of the advantages of research clusters and open-laboratories is that they foment collaboration among universities, colleges, and departments that typically do not work together; they can involve the liberal arts as well as the larger non-profit and for-profit communities. Faced with issues of relevance in research and declining enrollments in the arts, humanities, and social sciences, as well as somewhat challenging job prospects for students after graduation, the Penn State Behrend faculty and administrators looked closely at community needs, strengths, and opportunities. An open laboratory, built from a research cluster of computer science, engineering, arts, humanities, and the social sciences, could integrate and develop a unique and fundable, collective research strength. Furthermore, it can create a bright future for a large segment of the region's population by providing graduates with a strong education in the liberal arts with applied technical skills across a range of fields.

Penn State Behrend's strong engineering and business programs, combined with its strength in the liberal arts, creates an opportunity for a set of research clusters, that could range from the digital humanities to cyber security, and from interactive media and entertainment to modeling and simulation (creating virtual environments for everything from product design to advanced manufacturing and workforce training). To provide a home for these endeavors, the college is designing an open laboratory called the Digital Media, Arts, and Technology Center with the same philosophy of providing an integrative environment for the disciplines and the communities being brought together as with the Advanced Manufacturing and Innovation Center. These activities could occur on any campus without research clusters and open laboratories; however, they are greatly facilitated by providing a flexible mechanism for cluster creation and inculcating a culture of collaboration and problem solving that touches each component and mission of a university or college community. The virtual environment is active in anticipation of the building. With the recent gift from Autodesk, the hiring of a cluster of faculty members across the disciplines, and building of the component programs, virtual "construction" of this piece of open laboratory is well under way and is influencing the entire campus.

Lessons Learned

For more than a century, the practice of separating applied and basic research and discipline-based education has increased the success of universities in the advancement of knowledge. However, something critical has been lost along the way; that loss is being felt acutely by the students and society at large, and in the translation of research to practice that is critical for collective progress. Unintended barriers have arisen and bureaucracy has proliferated. Communities that can transcend these barriers will reap the benefits.

Research clusters and open laboratories can be thought of as parallel to the constructs of industry clusters and the open innovation movement (as shown in Figure 5). Industry clusters are ecosystems of similar industries that grow due to efficiencies of supply, labor, and cross-fertilization. University research clusters are analogous to industry clusters in the university, and are ecosystems of research capabilities aligned to meet and achieve research impact based on efficiencies of cross-fertilization. The university open laboratory is a paradigm that is analogous to the open innovation movement. In open innovation, organizations innovate by going outside of their boundaries to form mutually beneficial partnerships that allow companies to take advantage of innovations outside of their scope of influence (Chesbrough, 2003). As an open laboratory, universities should not only be able to freely flow ideas, knowledge, and inventions outward, but also be open and able to integrate innovation from outside the boundaries of the university from industry—a pathway that is often difficult to find and navigate.

In the authors' experiences, research clusters enabled each of the universities, with which the authors were engaged, to function as an open laboratory. In each case, it was found that without a critical mass of expertise and diverse skills from a research cluster, an open laboratory was not able to impact the community or the funding profile of a campus. Companies have traditionally sought university research partners to enhance their research, but universities have not traditionally looked to industry in the same way, and unintentional barriers have arisen. There were ingrained cultural and developmental barriers to overcome. Industry partners were often surprised that progress slowed on projects when academic semesters and student researchers changed, confused as to where to go to get the expertise they sought, and dissatisfied with university treatment of IP on projects they funded. A sense of advocacy, knowledge of domain expertise, and flexibility in developing IP relationships is important to achieving success, as is bringing in faculty with expertise in industry to bridge the cultural gaps. The development of research clusters is essential to the growth of open laboratories. The cluster provides a critical mass of expertise necessary to attract partners.

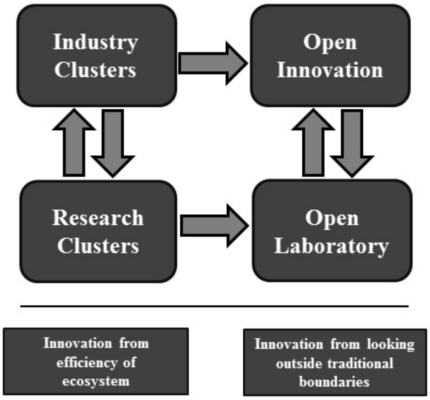

Figure 5. Relationship of the Open Lab Paradigm to Clusters and Open Innovation

Historically, industries actively sought partners for innovation and research, but developed a skeptical view of academia's ability to deliver over time. The ability to provide examples of past successes of bringing technology to commercialization (whether through capstone or funded research projects) is vital in demonstrating credibility. Moreover, the team approach between the university and economic development agencies lets each group play to their strengths. In each university though, promotion and tenure incentives for research cluster and open laboratory participation remains a challenge, particularly for new faculty who are often the most open to these approaches.

Changing the approach to IP, from blanket university ownership to a flexible model in order to adapt to business and industry needs, will alter the IP landscape remarkably. While IP policy changes yield significant results, as with any change, they will meet resistance. Once new centers and funding sources are in place, there is typically greater acceptance and swifter implementation of these policies.

At the core of changing the traditional research environment are flexibility, a broad sense of direction, and the alignment of incentives with objectives. Promotion and tenure processes and faculty evaluations are difficult to change. This is because application to practice is often tinged with a dim view that is associated with workforce training, and the perspective that the knowledge resulting from applying new ideas to practice is somehow less worthy or valuable than knowledge pursued for knowledge sake. Moreover, interdisciplinary research is often viewed as lacking intellectual rigor and depth, allowing individuals to piggyback on the work of others without exerting the intellectual stamina necessary for individual discovery. However, such change is possible and can be faculty led. Administrative support for faculty and the belief in the intrinsic value of the research paradigm shift are critical to move forward. Adding highly respected faculty members with strong basic research credentials (experience in industry or applied settings) and have seen the value in working across disciplines to solve research challenges helps immeasurably.

Senior faculty members need to work together to modify and align faculty rewards through promotion and tenure guidelines to begin to break the taboo of interdisciplinary and applied research. Acceptance will be slow, but by making these changes, it increases the opportunity for the faculty and student body to engage in meaningful research in a way that promotes knowledge in practice, feeds the creation of basic knowledge, enlivens the interaction between disciplines, and reinvigorates research overall. Even when it is too difficult to modify promotion, tenure, and evaluation guidelines, the concepts can become inculcated with newly changed perceptions of the faculty and students. While faculty members will benefit from a more holistic view of the research scholarship and new funding sources, the biggest beneficiaries are often undergraduate students, as internships and increasing opportunities are created to work with faculty and staff on exciting industry projects.

The involvement of business faculty members in the research process can be an important part in both the evolution of many research clusters and the open laboratory concept. For example, at NMSU, the business faculty members mentored the Physical Science Laboratory in its successful effort of rebirth. At UH, a key business faculty member was brought in as the Associate Vice President for Research, and was instrumental in using business concepts to improving and streamlining the research process. At Penn State, business and engineering faculty members were placed together in a new research and engineering design center that fomented collaboration in entrepreneurial research and education. The authors found that having an organization and contract in place that can match researchers with industry makes universities more accessible and ameliorates early industry concerns about not knowing which researchers to contact. Hiring faculty with industry experience, where the term industry is used in the broadest context and includes those with national laboratory and applied research and medical degrees, can often overcome cultural issues related to working within interdisciplinary, challenge-based teams and the valuing of everyone's contribution to a greater whole. This model borrows from modern physics research in which experimentalist and theorist work together across areas of expertise to build the tools that advance the study of science.

Many colleges and universities have created research and technology parks to attract industry and develop regional economies. The record of such parks is mixed, with many struggling to meet their financial obligations. This struggle typically leads the research park to attempt to attract tenants without a connection to their mission, and ultimately become real-estate ventures. This real-estate challenge can be overcome by the adoption of the open laboratory approach, where the research park has a clear connection to the campus.

Open laboratories are works in progress. Although there are glimpses of success, the full potential remains to be seen. The steps taken along the way have born considerable fruit wherever they have been attempted, whether in an established research environment or a largely undergraduate institution. Some aspects of the lessons learned from successful historical endeavors have yet to be tried in significant ways, and will require assistance from a broader collaboration among industry, government, and academia. Although bureaucracy in partnerships with industry has been reduced at each of the universities (by using templates, different contracting paths, informal clustering, space, flexibility, etc.) it has grown considerably in the federal-contracting arena. While risk taking has been encouraged in some settings by faculty incentives and promotion and tenures changes, it is far from widely accepted in a typical tenured environment. Additionally the concept of parallel and co-evolutionary basic and applied research has yet to find its full expression. Furthermore, the concepts of urgency, failure is not an option, and a clear timeframe to meet coordinated complex multi-organizational, interdisciplinary goals are largely foreign outside of big physics (large collider and accelerator) and biology (human genome) projects. It is hoped that the ideas presented here evolve. The framework for the evolution can be built on the foundation of research clusters and open laboratories.

In some of the universities in which first author was employed, as many as 50 percent of the students worked part-time, many in jobs completely unrelated to their studies. This distracted from the education (in and outside of the classroom), decreased learning opportunities, and resulted in lower graduation rates (within a 4-6 year time frame). One of the primary motivations of the open laboratory and related internship opportunities is to get students, particularly at the undergraduate level, more broadly involved in hands-on learning that links with their academic programs and provides funding for their education. Certainly, the opportunity to engage with faculty members in research activities increases interest in the subject matter, develops teamwork, in many cases supports financially students' education, and perhaps not surprisingly, vastly increases graduation rates. In 2009, the UH Honors College demonstrated that graduation rate for students who participated in honors program and research-like activities was 92 percent (double that for the traditional student).

What remains on the horizon is the vision of managing the complexity of numerous small startups and larger established companies, research centers, and individual faculty members to swiftly translate research into practice in coordinated ways that address major 21st century challenges and enrich both basic and applied research. Research clusters and open laboratories are two tools that might make it possible to realize this vision. The successful transformation of higher education and our communities will be an ancillary outcome.

Conclusion

The pressures on universities and colleges to become more efficient, more relevant, and less costly are ubiquitous, and research is among the costliest elements. Agency funding is stagnant, application to practice is slow, and a lack of economic robustness prevails. If the value of research to solve immediate educational and societal challenges cannot be demonstrated as the venerable science centers of major corporations, research will suffer, and so will our society. It has been posited in these two papers that research clusters and open laboratory concepts can impact both the research and economic challenges a university community faces, and on a broader scale, the general educational landscape in remarkable and synergistic ways.

Compartmentalization of research, practice, and education; ownership and application; incentives and organizational objectives and structures; and government, industry, and academia viewpoints have resulted in a less vibrant and robust research and development process than is possible. Research clusters and open-laboratory concepts attempt to break down those barriers and create a fertile environment that enriches discovery, research, and the educational process, while stimulating economic development and job creation. To the extent possible, these papers have sought to describe the challenge, postulate a set of solutions based on lessons learned, and demonstrate their application by example.

Through these examples, the authors hope that the concepts of open laboratories can be understood as a process to build on centers and institutes, departments, applied research laboratories, and "open laboratory" core equipment facilities. They reintegrate and enliven basic and applied research, undergraduate and graduate education, and industry and academic partnerships to speed research into practice and increase funding from a more diverse set of sources, while solving ever larger and more complex interdisciplinary challenges. Far from being the domain of international research universities alone, it has been shown that these concepts are applicable to both research and emerging universities alike, and suggests a hopeful future where universities are seen as the nexus of the next great economic revolution in their communities and across the globe.

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Appendix

Successful Open-Lab Strategies of Research Institutions

Not meant to be all-inclusive, examples only of partnerships and methods

University of California, Berkeley	
Research Centers & Labs	100+ centers and labs in the College of Engineering and Computer Sciences alone combine to form an open-lab environment that includes a wireless research center, quantum architecture lab, collaborative telerobotics, and biomimetic millisystems lab
Sampling of Partners	National Instruments, Intel, Nokia, Panasonic, DARPA, NSF, California Energy Commission, ARL, Semi-Conductor Research Corporation, Angel Investors, Goldman Sachs, JP Morgan
Characteristics, Strengths & Activities	Environment: flexible IP and licensing policies, promotes entrepreneurism, best minds, diversified funding, international competition (and collaboration), education integral, numerous multi-faceted projects within specific fields. Sponsorship diversified on many projects including world funding agencies, U.S. government agencies, private companies, and foundations. "Research and discovery at the highest level, informed teaching, and the creative desire to excel." Diverse, award-winning faculty. "Highest numbers of elected National Academy of Engineering members (87) in an electrical engineering and computer science department in the country." National outreach programs for underrepresented groups.
Impact	Faculty and alumni have founded 118+ start-ups, resulting in 11 successful IPOs, and over 195.35B in market capitalization
Cornell	
Sampling of Centers and Open Labs	Over 100 centers ranging from nanoscale technology and medicine, to humanities and social sciences. Notable: Center for Materials Research, which houses the pay-to-participate Industrial Collaboration program
Sampling of Partners	Department of Health and Human Services, National Science Foundation, Department of Defense, Department of Agriculture, Cotton Incorporated, Hyosung, Procter & Gamble, GM, Kraft
Strategies & Activities	Adequate funding and facilities, education integral Funding portfolio: majority from federal sources. Focus on infrastructure: facilities and researchers. Most research dollars spent are in medical, biology, and interdisciplinary research. Research distinctions include energy recovery LINAC (ERL), nanotech/nanoscience, astronomy/space sciences, and biophysics, genetics/genomics
Impact	2010 Portfolio: 12 new companies formed; 114 Cornell licenses negotiated (highest annual number ever); 140 patents issued; 338 new technologies disclosed; 420 patents filed; Nobel Prize faculty or alumni: 4
SUNY Albany	
Notable Open-Lab	First established college of nano-technology in the U.S.
Sampling of Partners	Local, state and federal economic development partners, Motorola, Intel, Air Products, IBM, SEMATECH, and many more.
Strategies and Activities	Built interdisciplinary research clusters, focus on entrepreneurial activity and economic development, state-of-the art facilities/Research HUB.
Impact	Research HUB : 3,000+ employees; $17 billion in public and private investment (source: Democrat and Chronicle web site)
North Carolina Research Triangle	
Centers & Open Labs	Research Triangle Park
Partners	Twelve college and universities work with over 200 companies and government partners
Strategies & Activities	Technology transfer, clusters, seamless collaboration, fluid pathways, education integral Top cluster for R&D, tech, life sciences, and agriculture/bio
Impact	Patented discoveries ranging from a potential HIV cure to cochlear implants. Native patents: Over 3,500
University of Twente	
Notable Centers/Labs	MESA+
Sampling of Partners	Kennispark
Strategies & Activities	University research centers, entrepreneurship; "co-exploitation of specialized laboratory facilities by the university and private businesses"; developed to focus limited resources ; faculty working in a unique matrix structure. Research needs are factored into faculty hiring decisions.
Impact	800 startup companies; 20-30 spin-offs each year; jobs in park: 330 companies employing 5,100 (excluding university)

* Primary sources: Web sites of laboratories, universities, and research parks

Sandia National Labs	
Sampling of Partners	U.S. Department of Energy; Lockheed Martin; numerous universities, government entities, and companies, including GE, Parker Hannifin, Caterpillar, Federal Aviation Administration, University of New Mexico, Technology Venture Corporation
Strategies & Activities	Created in World War II to work closely with the military on the Manhattan Project (atomic bomb) and subsequently other national security projects. Performs research for government/military/industry with university, government, and industry researchers.
Impact	"invested $31.5 million in 474 research projects with 93 universities" in 2012. In 2005, started Entrepreneur in Residence initiative to stimulate spin-off companies.
Oak Ridge National Laboratory	
Sampling of Partners	Managed for the U.S. Department of Energy by UT-Battelle, partners with the state of Tennessee and numerous universities and industry partners.
Strategies & Activities	Created in World War II to work closely with the military on the Manhattan Project (atomic bomb) and subsequently other national security projects.
Impact	Sponsorship of over 3,000 private, public, and university scientists and hundreds of patents and technology licenses

* Primary sources: Web sites of laboratories, universities, and research parks