RESEARCH NEXT:

A Landscape Analysis for the Future of University Research

Co-Chairs:

Tim Lieuwen
Wen Masters

Section Leads:

John Avery
Jarrett Ellis
Stefan France
Clayton Kerce
Margaret Loper
Gage Ramos
Devesh Ranjan
Valerie Sitterle

Georgia Tech

researchnext.gatech.edu

Preface to Phase 1 Report

Georgia Tech is committed to developing leaders who advance technology and improve the human condition, and is poised to take a leading role in the global research landscape. I am proud to present the Phase 1 report of the Commission on Research Next (CRN). The commission launched in early 2020 with the goal of catalyzing research that matters. In alignment with the Institute's strategic plan, the work of CRN strives to position the Institute to respond to the challenges of the future with innovation, expertise, creativity, and a dedication to improving human lives and the world at large.

The commission benefited from the work of more than 50 contributors from across Georgia Tech, led by co-chairs Tim Lieuwen, Regents Professor, David S. Lewis Jr. Chair in the Daniel Guggenheim School of Aerospace Engineering, and executive director of the Strategic Energy Institute; and Wen Masters, deputy director, Information and Cyber Sciences, Georgia Tech Research Institute (GTRI). The report is based on literature reviews, interviews with critical stakeholders, and information gleaned from institutional databases, national databases, and government reports. With Phase 1, the commission sought to identify and understand the internal and external forces, challenges, and networks that shape the university research ecosystem, examining how research universities engage with society, industry partners, government organizations, and other universities.

As we envision the research enterprise at Georgia Tech over the next 10 years and beyond, its central tenets must be service and connectedness if we are to truly realize the Institute as a leading global engine of innovation, entrepreneurship, and opportunity. We will help create knowledge as well as jobs and enable economic development, and we will be a crucial partner to industry and government as they solve problems and create policy to address complex challenges. We envision a future in which we continue to strive for inclusive excellence and truth, and leverage our scale and resources to address the most urgent challenges of our time.

The Commission on Research Next was created to develop the plan that will take us there. Our plan will be people-centered, value-based, and data-informed. Like our Institute's strategic plan, this belongs to all of us, and it will be up to us to make it a reality.

We welcome and look forward to your feedback.

Sincerely,

Chaouki T. Abdallah
Executive Vice President for Research
Georgia Institute of Technology

researchnext.gatech.edu

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CHAPTER ONE:

FRAMING THE RESEARCH LANDSCAPE


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1.1 Introduction

Research Next started with one question:

If we were to develop the university research enterprise from scratch, what would it look like?

This question arises from the growing complexity and interconnectedness of modern research universities. Rather than being insulated places where scientists in white jackets sit in their labs, universities contribute thought leadership in framing and addressing complex challenges; they create jobs and enable economic development; they are integral partners to government, industry, non-governmental organizations, and community engagement ecosystems; they are epicenters of innovation clusters.

Other questions immediately follow from this one, including:

- What are the global megatrends that will influence the future state of the university research ecosystem?
- What are the key problems that research universities must be prepared to address? As an institute historically focused on engineering and technology, how does the Georgia Institute of Technology (Georgia Tech) address techno-social challenges such as sustainability, global security, and equity?
- What research agenda and partnerships will have broad impact?
- How should research ecosystems organize themselves to best enable a group of creative people to do great things? How do we best create and support links between research, education, economic development, and research support?

The underlying premise of these questions — service and interconnectedness — is reflected in the Institute's core values. Georgia Tech's strategic plan, released in 2020 [GIT 2020] emphasizes that “Students are our top priority,” recognizing that universities are educators first and foremost. The mission is to make a positive impact on people's lives and improve the human condition, by educating students, developing leaders, creating knowledge, and advancing technologies. Universities are but one actor in the broader implementation of solutions to societal challenges, and so we must become deeply integrated as trusted partners within the broader ecosystem of governments, companies, and local communities. We must serve as physical “anchor tenants” in innovation clusters where students, researchers, startups, companies, venture capital, and community engagement organizations collaborate and engage.

The objective of this report is to frame these key questions — not to provide prescriptive solutions, but rather to identify the internal and external forces and factors that shape the research ecosystem. This chapter sets the stage by examining the societal engagement dimensions of research universities, the U.S. research university ecosystem, funding mechanisms, and innovation models. Subsequent chapters look at questions around internal organization, external drivers, research content, and partnerships.

1.2 Broader Societal Engagement

The infusion of expertise into broader societal conversations has never been more necessary. The collective challenges we face involve the complex interplay of policy, politics, finance, human behavior, historical context, and technology. Moreover, knowledge and science are easily politicized, and knowledge communities within research universities engage society in a multitude of ways.

As universities work toward a mission of meeting grand challenges and positively affecting humanity, it is important to recognize their cultural attributes — entrepreneurial, competitive, meritocratic, and decentralized — and how they intersect with other organizational cultures in the wider sphere of community advocates, corporations, and government.

Research universities are a subset of a larger group of expert communities, and careful consideration must be given to how they use their expertise as a resource for facilitating complex decisions. Pielke [Pielke 2007] has developed a useful framework, identifying four poles of engagement: pure scientist, issue advocate, science arbiter, and honest broker.

This framework is constructed around two questions shaping research university engagement:

(1) Is there high or low societal consensus around fundamental values? One example of an issue with high values consensus is the desire to minimize loss of life associated with a hurricane landfall, while low values consensus include such issues as fetal stem cell research or nuclear weapons.

(2) What is the uncertainty — either technical or political — around a decision? To illustrate, consider the role of expert knowledge in providing input to policy responses to the following low and high uncertainty events: an imminent hurricane landfall and a catastrophic meteorite impact that could occur sometime in the next 100 years.

With issues of high values consensus and low uncertainty, a particular set of knowledge clarifies what the next steps should be to address the issue. Increased knowledge or reduced uncertainty also reduces decision or political uncertainty — for example, a better calculation of the hurricane landfall location improves decision making around evacuations or contingency planning. Experts who are disengaged from the political/policy process can provide this helpful knowledge. Pielke identifies “pure scientists” as those who do their discovery and development divorced from the broader society. They develop knowledge but do not engage with decision makers or those seeking to apply its results. The “science arbiter” seeks to engage society by serving as an expert resource — not explicitly advocating for a given policy decision, but making themselves available to answer specific expert questions.

On the other hand, engagement of expert knowledge is quite different around issues with significant societal disagreement on values or where there is high uncertainty. In these cases, improved expert knowledge often does not clarify the path that rational people should take on a complex topic. As noted by Sarewitz [Pielke 2007a], in a broad range of areas such as climate change, endangered species, air pollution, or biotechnology, the growth of scientific knowledge has not reduced political controversy.

The “issue advocate” and “honest broker” both engage with broader society around decision making. The issue advocate explicitly advocates for policies, supported by their credentials as experts. On the other hand, the honest broker engages in societal discourse but does not advocate for a given policy decision. Even so, the honest broker does deeply integrate within this process and work with other stakeholders to understand the larger policy landscape. For example, in a policy discussion of regulating power plant emissions, the honest broker does seek to understand the interactions of their subject expertise with such issues as jobs, the cost of energy, energy equity, and so forth, all with the goal of expanding the scope of policy options. For the honest broker, the role of experts is to “clarify the implications of their knowledge for action, and to provide such implications in the form of policy alternatives to decision-makers who can then decide among different possible courses of action." [Pielke 2007]

Pielke also defines a fifth category, the “stealth issue advocate,” as those who present themselves as pure scientists or science arbiters but who are actually advocates for a particular position, seeking to leverage the legitimacy associated with their expertise — for example, an expert who approaches a problem with low societal values consensus and casts it in terms of one with high values consensus.

It is helpful to understand what role research universities are playing as they interject their expertise into wider social, political, and economic discussions. Today, one can easily find examples where universities and experts play any of these roles in different settings, depending upon the issue and the university culture. Moreover, because many of today's most critical issues are in areas with lower values consensus, there is an opportunity to integrate the honest broker role into the culture of the university. Or, as Pielke writes, “In situations of gridlock, policymakers frequently need new options, and not more science."

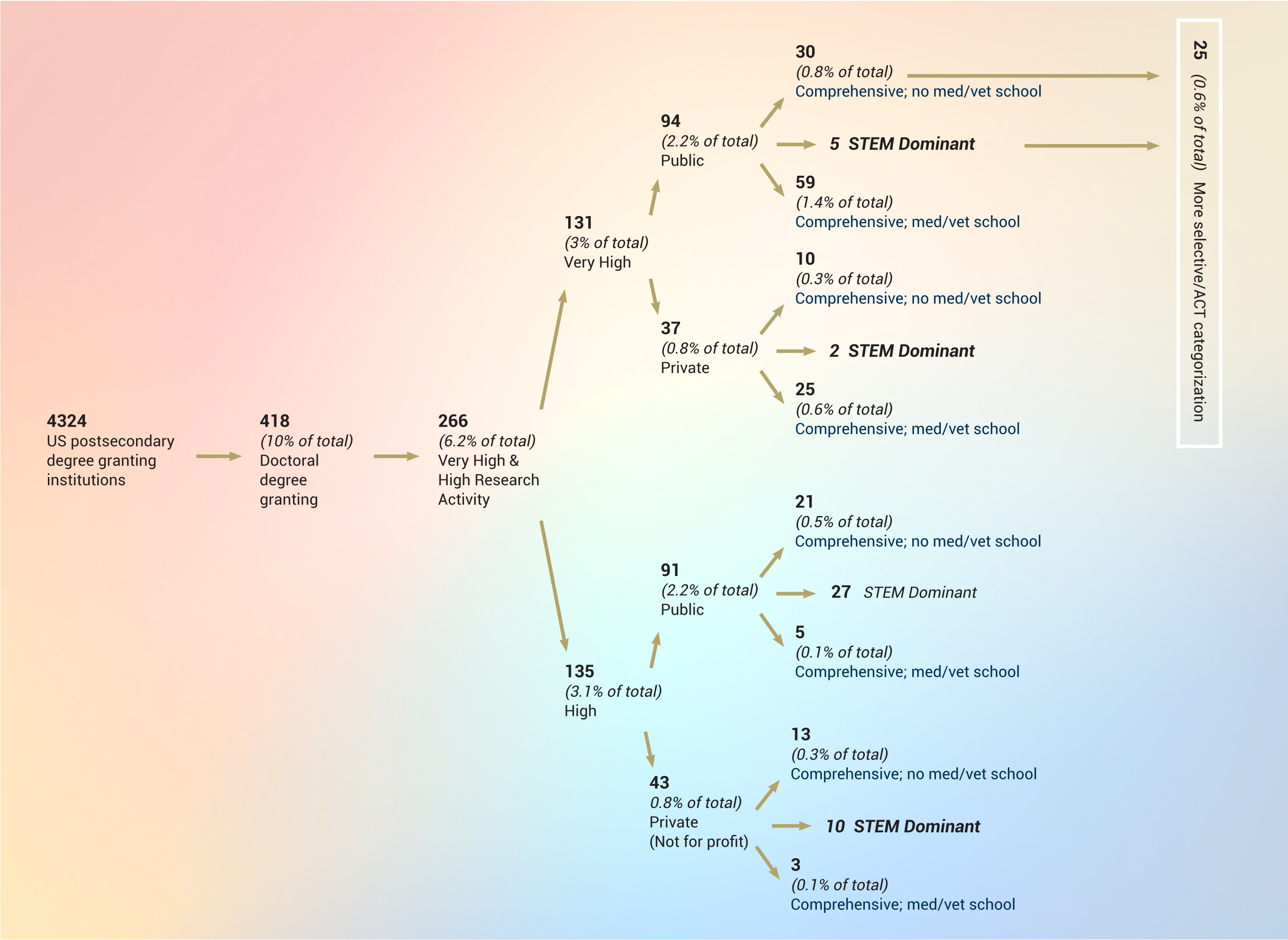
1.3 Research University Taxonomy

Research universities differ widely in subject expertise, size, and mission — and in terms of public versus private; volume of research activity; range of degrees and specializations, including science, technology, arts and humanities, law, and medicine; integration of applied and service functions such as field stations, hospitals, and applied R&D organizations; and degree of admission selectivity. Each of these attributes has a significant influence on the range of activities performed by the universities, their partners, the rules and laws they must work within, the students they educate, and the types of research they conduct.

Given these different categories, it is helpful to understand where Georgia Tech resides within the full group of postsecondary institutions [Indiana 2018].

- Doctoral degree granting institutions represent approximately 10% of all postsecondary degree granting institutions (418 out of 4,324 in 2018) and enroll about 36% of all students in these institutions.
- Of these, 266 are classified as having "very high" or "high" research activity, defined as awarding at least 20 research or scholarship doctoral degrees, with at least $5 million in total research expenditures.
- Of the 266 doctoral universities at very high or high research activity, 74 have "comprehensive" programs without a medical or veterinary school. For the Carnegie classification, "comprehensive" denotes institutions that award research doctoral degrees in the humanities, social sciences, and STEM fields. They may also offer master's or professional degrees in fields other than medicine, dentistry, or veterinary medicine.
- Of these 74 schools, 25 institutions are classified as public and considered more selective based on ACT categorization, as shown in Figure 1.1. That equates to 0.6% of the starting total.

Figure 1.1 *Classification breakdown of 2018 Carnegie data showing research university organization*



Further, of the 10 institutions of higher education that are institutes of technology or polytechnic institutes and classified as very high research activity (including Carnegie Mellon University and Case Western Reserve University), only three are public universities at the state level: Georgia Tech, Virginia Tech, and the New Jersey Institute of Technology.

1.4 Financial Environment

Financial support is one of the key enablers of research. Where and how is research funded in the United States? Where do research universities derive their support? Major categories of funding sources for research and development (R&D), as defined by the National Center for Science and Engineering Statistics (NCSES), are: federal government, state and local government, business, higher education, and other nonprofit organizations. Table 1.1 is a summary of NCSES data that shows all R&D expenditures in the U.S. by these five major funding sources from 2011 to 2018.

Table 1.1 U.S. R&D Expenditures, by source of funds: 2011 - 2018

(Millions of current dollars)

Fiscal Year	All Expenditures	Federal Government	State & Local Government	Business	Higher Education	Nonprofit Organizations
2011	426,160	127,014	4,386	266,422	13,103	15,235
2012	433,619	123,837	4,158	275,718	14,300	15,607
2013	453,966	120,130	4,244	297,168	15,378	17,046
2014	475,425	118,365	4,214	318,383	16,210	18,254
2015	493,684	119,524	4,267	333,208	17,299	19,386
2016	515,641	116,492	4,481	355,545	18,484	20,640
2017	547,886	120,961	4,582	381,137	19,723	21,482
2018	579,985	127,246	4,726	404,231	21,120	22,662

Source:
National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series)

As shown in Table 1.1, business has been the single largest source for R&D expenditures over this time period, and it has grown significantly. The business sector's R&D expenditure in 2018 was 1.5 times of that in 2011. In contrast, the federal government, while the second largest source, has remained flat, actually decreasing from 2011 to 2016. The other sectors have seen stable and gradually increasing R&D expenditures.

University research and development has been supported by all five major funding sources. The R&D expenditures in universities between 2011 and 2018 by source of funding are shown in Table 1.2 below.

Table 1.2 U.S. Higher Education R&D Expenditures, by source of funds: 2011 - 2018

(Millions of current dollars)

Year	All R&D Expenditures		Federal		State/Local Govt		Business		Higher Ed.	Other Nonprofit	
	Total	Higher Ed. Total	Total	Higher Ed.	Total	Higher Ed.	Total	Higher Ed.	Higher Ed.	Total	Higher Ed.
2011	426,160	60,089	127,014	35,742	4,386	3,615	266,422	2,999	13,103	15,235	4,630
2012	433,620	60,896	123,837	34,967	4,158	3,560	275,718	3,170	14,300	15,607	4,899
2013	453,966	61,549	120,130	33,839	4,244	3,643	297,168	3,376	15,387	17,046	5,313
2014	475,426	62,350	118,365	33,122	4,214	3,714	318,383	3,602	16,210	18,254	5,702
2015	493,684	64,624	119,524	33,555	4,267	3,773	333,208	3,843	17,299	19,386	6,154
2016	515,642	67,801	116,492	34,674	4,481	3,919	355,545	4,042	18,484	20,640	6,682
2017	547,885	71,252	120,961	36,034	4,582	4,064	381,137	4,276	19,723	21,482	7,173
2018	579,985	74,722	127,246	37,202	4,726	4,159	404,231	4,551	21,120	22,662	7,690

Source:
National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series)

The federal government has been the largest funding source for university research. The second largest source has been the universities' funds, while other nonprofit organizations, business, and state and local government have been distant runners-up. Business funded 6% of all R&D expenditures in universities in 2018, but that amount only accounted for 1.1% of total business R&D expenditures.

Federal funding of university research has a rich history. A framework for government support of university research was envisaged by Vannevar Bush in his report, *Science — The Endless Frontier*. It was produced at the close of World War II in response to President Franklin D. Roosevelt's request for recommendations on how wartime scientific research and technological gains and innovations can be "profitably employed in times of peace" for the "improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living."

This framework engendered a new responsibility of the federal government: technology and innovation. It also engendered a new government-university partnership supporting scientific research in universities. Within five years, a number of major federal agencies were established, including the Office of Naval Research (ONR) in 1946 and the National Science Foundation (NSF) in 1950. In addition, the National Institutes of Health (NIH) was significantly expanded and reformulated. ONR, NSF, and NIH soon became the mainstays of federal support for university-based research. Today, support for research and development is a permanent focus of the federal government.

Federal agencies supporting university research include the Department of Defense (DoD), Department of Energy (DOE), Department of Health and Human Services (HHS), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and Department of Agriculture (USDA). In 2018, the top three federal agencies with the largest R&D expenditures at universities were HHS, DoD, and NSF, with shares of total federal R&D funding at 55%, 14%, and 13% respectively [NCSES 2018].

The history of corporate funding for university research predates federal funding. In recent decades, particularly since the Bayh-Dole Act in 1980, the share of industry funding of university research has increased gradually and reached a steady rate of about 7% [NAP 2009] in the last decade. As shown in Tables 1.1 and 1.2, industry funding in 2018 amounted to 6% while total industry R&D expenditures was 69% of all R&D expenditures in the U.S. Although industry funding of university R&D is a relatively small portion, it has been an important component in spurring knowledge-intensive activities in collaborations between academia and industry that have contributed to rapid advancement in industrial innovation and economic development in many fields.

A recent study [Atkinson 2018] found that strong industry funding of a state's university research pays off in economic benefits to the state, and that positive correlations exist between the share of a state's university research supported by industry and its strength in key innovation variables such as high-tech startups, venture capital, high-tech jobs, and scientists and engineers. Industry funding is also associated with stronger university technology output. Another study, on the experiences and outcomes of graduate students in STEM fields [Schneider 2007] found that students who collaborated and interacted with industry were nearly five times more likely to produce intellectual property than those who did not.

Finally, nonprofit organizations play an important role in supporting university research and development, spurring innovation, and addressing societal challenges. As shown in Table 1.2, nonprofit organizations sourced 10.3% of the total R&D expenditures in universities in 2018.

1.5 Research and Development Classifications and Innovation Models

University research covers a broad spectrum of disciplines and R&D, from knowledge discovery through systems development. Research and development activities can be classified into three categories [NSF 2018]: basic research, applied research, and experimental development, which includes advanced technology development and systems development. R&D activities must satisfy five criteria: being novel, creative, uncertain, systematic, and transferable and/or reproducible. Another widely used classification is defined by DoD Financial Management Regulation, which classifies R&D into six budget activities (BA): BA1 (code 6.1) - basic research, BA2 (code 6.2) - applied research, BA3 (code 6.3) - advanced technology development, BA4 (code 6.4) - advanced component development and prototyping, BA5 (code 6.5) - system development and demonstration, and BA6 (code 6.6) - research, development, test, and evaluation (RDT&E) management support. DoD BA1 and BA2 correspond directly to NSF's basic research and applied research classifications, respectively. DoD BAs 3-6 correspond to the NSF experimental development classification. A detailed description of DoD's RDT&E taxonomy and its mapping to the NSF taxonomy can be found in Sargent [Sargent 2020].

Universities have been the primary R&D performing organizations conducting basic research with major funding from federal agencies. Bush's *Science — The Endless Frontier* was a formative influence. Indeed, the Office of Scientific Research and Development that Bush led during World War II had succeeded in bringing scientific knowledge to wartime applications. Breakthroughs in basic science drove the development of products to benefit society, and funding research came to be viewed as the surest path to innovation. It espoused a "linear model," which started with basic research, followed by applied research, and then experimental development to reach production and commercialization. The model, also known as "technology push," would soon be augmented with another linear model that used product/capability needs as the source of ideas driving R&D and innovation. This model is sometimes referred to as "market pull."

The ensuing decades witnessed a continuous evolution of innovation processes and models. In the late 1960s and early 1970s, a number of wide-ranging and systematic studies of successful innovation emerged, including Myers and Marquis [Myers 1969], which was sponsored by the NSF "to provide empirical knowledge about the factors which stimulate or advance the application in the civilian economy of scientific and technological findings," and Rothwell [Rothwell 1994] (and the citations therein). These studies indicated that technology push and market pull models were extreme examples of innovation, and that the more general innovation process was characterized by interactions, which led to the interactive model with feedback loops.

In the 1990s, an innovation process characterized by integration and parallel development was introduced by the Japanese automobile industry for rapid and efficient new product development. U.S. federal R&D agencies and industry quickly adopted this integrated innovation model. For example, ONR has expanded its mission from sponsoring basic research to vertically integrated basic research, applied research, and advanced technology development. A number of successful technological innovations for national security and civilian benefits by ONR and other agencies have been attributed to their use of the integrated innovation model.

As models of innovation evolve, the government's policy for R&D has evolved and so has the role of university research, the partnerships between government, industry, and university research, as well as the R&D partnership between universities and industry. Increasingly, universities are engaged in research in all R&D categories and have formed close partnerships with industry, which, via knowledge and collaborations, have contributed to the rapid growth of our technology-based economy. As invention, knowledge transfer, and innovation continue to generate new and improved products and technologies, universities will continue to play an integral part in the evolving innovation process. They will continue to be the engine of knowledge creation, while partnering with government and industry in knowledge transfer and innovation.

1.6 Organization

Research Next is organized into four main sections:

"The World Beyond" analyzes the external global factors that are beyond the control of individual research universities, but which affect how they function. The discussion centers around four areas: values, challenges, innovation, and policy.

"Research That Matters" identifies the grand challenges, topics, and methods for conducting research at technology focused research universities that are likely to emerge between now and 2050.

"Working With Others" focuses on partnerships. It considers the range of partners and approaches toward mutually beneficial collaborations, with particular attention on identifying and leveraging the potentially different missions of different partners.

Finally, "The World Within" examines the explicit and implicit structures and functions by which the research ecosystem carries out its mission. How is the work actually done? How can research organizations tackle complex societal challenges and create new research directions; empower and support all researchers; combine research, technology transfer, entrepreneurship, corporate engagement, and economic development; and ensure compliance, research security, and research integrity?

CHAPTER TWO:

THE WORLD BEYOND


CHALLENGES
PANDEMICS
NATIONALISM
CLIMATE CHANGE
SOCIAL TRENDS
INNOVATION
ONLINE COLLABORATION
ARTIFICIAL INTELLIGENCE
SOCIAL IMPACTS OF TECHNOLOGY
DATA SCIENCE
POLICY
POLITICS
SPONSORED RESEARCH
CAPITAL RESOURCES
GLOBAL TENSIONS
VALUES
EQUITY
SOCIETAL CHALLENGES
SUSTAINABILITY
SOCIAL JUSTICE

2.1 Introduction

Research universities reside within a broader environment and are influenced by a host of external global factors that are beyond our control. These factors shape the topics, methods, funding, partnerships, and other resources important to conducting research. The objective of this chapter is to identify these issues and how they might influence what we work on, how we work on it, and who we partner with. While these external forces may lie outside our control, by identifying these trends and potential future scenarios, we can proactively plan how we will engage, respond, and influence "The World Beyond."

This chapter organizes these external forces through the following four forces and trends:

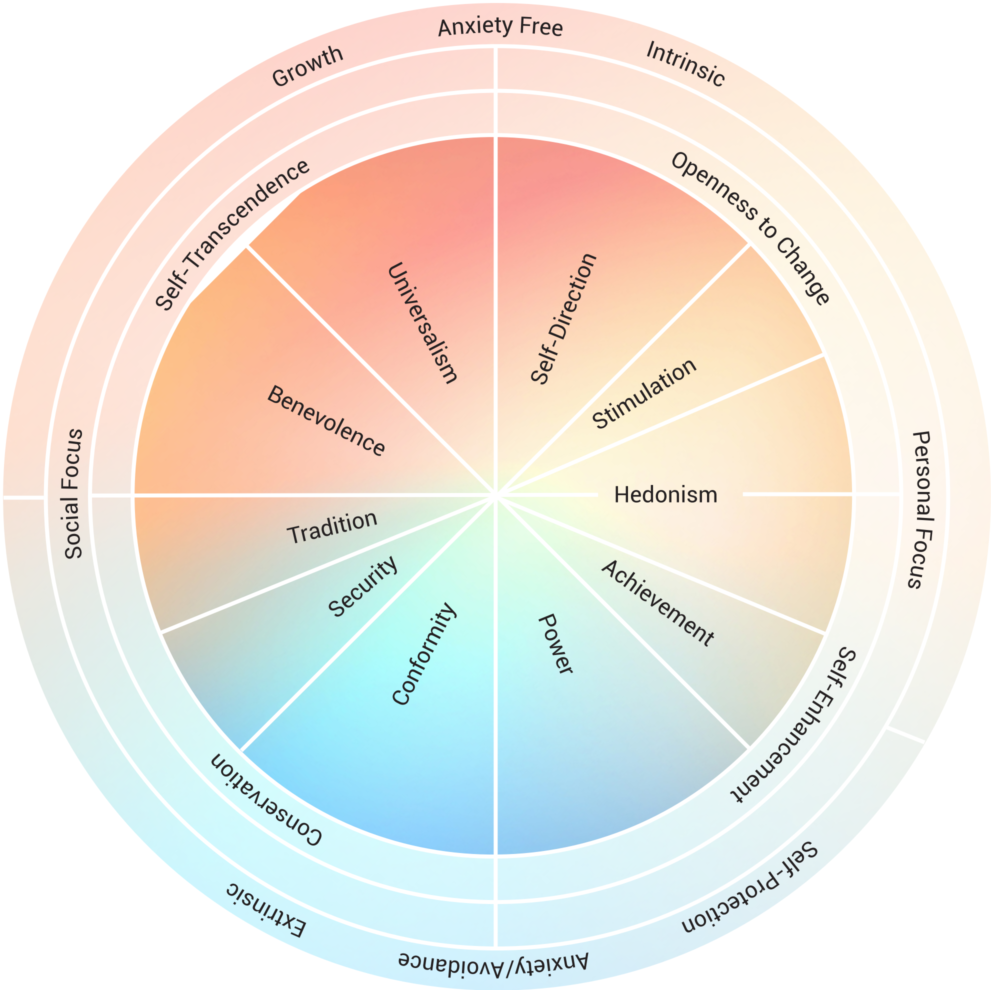
- Values: Normative sociopolitical factors that influence who we are and how we conduct research.
- Challenges: Systemic stressors that motivate responsive, real-world research.
- Innovation: Pivotal technologies that allow us to communicate and create new ways of doing research.
- Policy: Factors that influence the resource availability required for collective action.

This chapter also includes several "View From 2045" vignettes. These vignettes envisage future scenarios driven by the convergence or realization of these forces and trends.

2.2 Values

Value systems provide standards for evaluating actions, justifying opinions and conduct, planning behavior, selecting alternatives, engaging in social influence, and shaping how an individual or organization portrays itself to the world [Hebel 1998]. They vary across groups, from individuals to entire cultures, and present in hierarchies that may be dynamic in time. Such hierarchies arise from aspects of the human condition that are in natural tension, as indicated in Figure 2.1. This figure depicts both a cluster analysis of different value categories from a values survey across 20 countries [Schwartz 1992], and these value categories are more compactly organized in a structure of hierarchies of competing tensions [Schwartz 2016]. For example, different societies and groups prioritize personal fulfillment and social unity differently, or have different propensities to accepting new ideas relative to conservatism.

Figure 2.1



Structural similarity scores and clustering from a survey of values across 20 countries, organized in oppositional categories and hierarchies

These values become fundamental drivers in how research is prioritized, resourced, conducted, and evaluated. Values shape the economic and policy environment researchers compete within for funding, for example favoring near-term applications versus forward thinking discovery, or winner-take-all grand challenges versus broadly distributing resources. National security priorities are equally value driven, whether defensive in nature or for the projection of power.

Tension around these questions is inevitable. Nonetheless, organizations typically develop a set of shared core values, which summarize these normative, foundational beliefs. For example, core values shared across university research enterprises include “we tackle complex societal challenges” and “we empower and support all researchers.” At Georgia Tech, these core values are further expanded to include “students are our top priority,” “we strive for excellence,” “we thrive on diversity,” “we celebrate collaboration,” “we champion innovation,” “we safeguard freedom of inquiry and expression,” and “we act ethically.” The rest of this section provides several examples of how values drive research trends.

Tackling Complex Societal Challenges

Universities are at the core of innovation, both through their generation of new knowledge and unique role in developing and deploying minds that can solve the complex issues facing the world today [NRC 2014]. Government and industry rely on the activities of universities as the emerging "innovation hubs" of science and technology in the U.S. [NASEM 2019]. This perception registers at every level of society, as citizens overwhelmingly see universities as the engines of discovery for strategies to solve the world's most pressing concerns [UCA 2020].

Perhaps most saliently, universities exhibit reflexive interests in research that has a high positive impact on local, regional, and global communities. As seen recently, numerous universities mobilized research around the containment and mitigation of the coronavirus pandemic [GIT 2020]. Students themselves are demanding interdisciplinary training in support of "Public Interest Technology," defined as technology that "adopts best practices in human-centered design, product development, process re-engineering, and data science to solve public problems in an inclusive, iterative manner — continuously learning, improving, and aiming to deliver better outcomes to the public." [Doran 2020] In all, university values reflect accelerating momentum toward research that positively influences an increasingly interconnected world.

Sustainability

A broad concept of sustainability for global development is outlined in the United Nations Sustainable Development Goals [SDG]. Research driven by sustainable development includes an analytical framework to understand our planetary challenges, as well as frameworks to translate values into action. As Jeffrey Sachs argues: "Sustainable development is a way to understand the world as a complex interaction of economic, social, environmental, and political systems. Yet it is also a normative or ethical view of the world, a way to define the objectives of a well-functioning society, one that delivers well-being for its citizens today and for future generations." [Sachs 2015]

The fundamental role of normative values in driving approaches for sustainability has been emphasized by Charles Mann in "The Wizard and the Prophet," [Mann 2018] who contrasts two competing value frameworks. One approach for sustainability emphasizes a societal response that seeks to preserve, reduce our impacts, and establish ourselves within a natural order that is imposed upon us. A different approach sees the solution lying in innovation, technology, clever management, and reshaping nature around human needs. These are not either/or questions but they are normative ones, where one's fundamental approach is based upon deep-seated moral values about the world and how we should interact with it.

Social Impacts of Technology

Technology is not "neutral" and has a range of impacts on society. Emerging technologies have large societal impacts, whether they are gene editing, automation, artificial intelligence, or influence techniques. Digital and networked technologies, from personal to assistive, and even medical, are becoming pervasive; new algorithmic processes take advantage of both the massive data now available from such devices as well as the intimate relationship individuals have with these devices and services.

As highlighted in the documentary *The Social Dilemma* (2020) [Orlowski 2020], social media was originally imagined by developers as a force for the consolidation of community. But as we have seen, it is equally well suited to pervasive marketing, psychological manipulation, and digital surveillance, allowing like-minded individuals to self-segregate into isolated information environments, a phenomenon commonly referred to as "information bubbles." The commercial advantage afforded by these technologies is provided through the hyper-specific personalization of content to each individual user, allowing for the monetization of targeted, behavior-changing content. This same specificity allows for previously unavailable inroads into changing values and behavior around commercial and political matters.

View From 2045: News Report

Today the U.S. announced the formation of a comprehensive Bias Review Board to address public concerns about social bias in AI-driven services. Any entity using AI-driven algorithms for public facing services will be reviewed by this board to ensure fair and equitable treatment for all members of society. While this board was put in place following a successful lawsuit from a coalition of religious groups, further conflict is likely as the group wrestles with specific cases from additional marginalized groups. No word yet on how this group will align with similar groups in China and Africa that operate under different guidelines.

Equity and Social Justice

Technology can either mitigate or promote inequity, as well as rectify or amplify historical injustices. Understanding these influences is both a research topic itself, as well as one where research institutions will face value-centric organizational challenges due to the tensions that arise from the categories in Figure 2.1 in order to sustain the modern research enterprise that upholds core values, particularly diversity and empowering and supporting all researchers. (See Chapters 3 and 5 for more detailed discussions.)

2.3 Challenges

A variety of challenges at the local, national, and global levels will profoundly influence the research university environment and motivate research that is done and how it is done. While our list is far from exhaustive, we describe a few of these issues here to provide context.

Climate Change/Sustainability

Climate change is leading to a variety of challenges, including rising sea levels affecting coastal areas, desertification, and changes in local temperature and water patterns. Population growth, deforestation, and biodiversity loss are other stressors that challenge sustainability of the planet. In addition, global decarbonization initiatives are changing the geopolitical landscape and international relations as oil and gas become less connected to the power of countries and regions, as well as sources of jobs.

Aging

Fertility and mortality rates tend to decline as countries develop economically, causing a shift in populations toward older people. This affects the direction of innovation, research workforce, and how public funds are distributed, which diseases government and corporate agencies focus on, housing, and healthcare. For example, a health research agenda increasingly focused on aging-related illnesses, fewer people of working age, and the increasing need to care for the elderly will influence new research and technologies in robotics, telemedicine, and artificial intelligence.

Sociopolitical Factors

Demographic shifts, the rise of new economic players, and increasing environmental pressures will continue to influence how regions, nations, ethnic groups, age groups, cultural affinity groups, or a range of other groups will self-identify and organize. The rise of nationalism could make global research collaborations more difficult and local research more burdened with oversight and process. Simultaneously, world leaders are also recognizing the need to come together to solve common global challenges, such as climate change and sustainability.

Political, Urban/Rural, and Regional Differences

Notable differences exist in how some key social trends are playing out across urban and rural communities [PEW 2018]. For example, urban and suburban counties are gaining in population and diversity while people leaving rural areas outpaced the number of those moving in. There are significant gaps in measures of economic well-being and resource allocations across urban/rural counties. Those differences extend to politics and perspectives. And these factors influence consensual democratic decision-making, views of our national identity, and the role of science and other expert knowledge in decision making and prioritization of research.

Epidemics and Pandemics

Large-scale outbreaks of disease, with accompanying societal disruptions, have occurred globally throughout history. However, new viruses continue to emerge, and whether the next pandemic occurs in a few years or a century, the repercussions of Covid-19 on globalization, research, and other areas will persist for many years to come.

Security

Security threats put at risk the fundamental bases upon which individuals and societies rely. The development of nuclear weapons in the 1940s profoundly altered the global security landscape. Since then, a host of additional, similarly global challenges provide a backdrop for national security and research, including cybersecurity and biological security.

Public Opinion

Recent events have shown how rapidly public opinion can be energized for or against an idea on a global scale. The fact that there is no central control of information means that vast populations can be reached immediately with specific messaging to cause rapid and extreme public response. In the coming years the desire by various groups to leverage this power will create more instability, which will in turn drive different research directions within two extremes: exploiting this power to cause instability versus responsible research to prevent such exploitation.

2.4 Innovation

Technological advances will continue to drive important changes to the way in which research is done, the research topics that are investigated, the future workforce, and societal structures as a whole. Below are several illustrative examples.

Artificial Intelligence and Machine Learning

Artificial intelligence and machine learning are increasingly used in a wide array of applications, including scientific discoveries, biomedical technologies, construction, industrial control and assembly, transportation, and information and communications technologies. Artificial intelligence is capable of guiding self-driving cars, performing automatic translation, identifying images, massive sets of data, and automating a host of other activities. To a large extent, recent advances in machine learning have improved the ability to gather and process massive data sets rather than creating breakthroughs in understanding the nature of human intelligence. Nonetheless, artificial intelligence will continue to influence nearly all disciplines, including healthcare, transportation, and manufacturing, and has the potential to spur the development of entirely new industries.

Data Science and Engineering

Broad deployment of data and image collection devices, alongside the 5G networks enabling rapid data collection, will continue to increase the amount of raw information gathered by society. Privacy concerns may lead to regulation that could impose burdens on those seeking to use data for research, as has already happened with HIPAA restrictions on healthcare data, the use of data involving minors, and so on.

Research in data collection, storage, and manipulation will become increasingly important to a broad family of research categories. Policies around archival storage, remote access, cross-institutional sharing, data retention, and related issues will need to evolve rapidly, and coordinating those processes across various levels of control (institution, university system, city, state, federal, and sovereign nations) is likely to be challenging.

Virtual Labs and Online Collaboration

Collaboration tools and connectivity have matured enough so that it is possible to be effective in a remote environment for many job types. These tools and processes will improve, making remote collaboration even more efficient. As more research is done with data and computers, the physical presence of a lab becomes less important for a growing family of research topics. This will drive laboratories that can configure remote access to lab equipment and make it available to a wider group of researchers, exemplified by Georgia Tech's Robotarium.

Once researchers can access labs remotely, research social networks with prearranged access to specific distributed equipment might emerge as more valuable than any physical campus location.

A potential benefit to the broader deployment of remote access and online collaboration tools is one of accessibility for researchers who otherwise would not be able to access them, such as those in developing countries, or who have disabilities or are caregivers. Moreover, increased digitization of resources, including automatically generated transcripts of conferences or conversations, would improve accessibility.

View From 2045: News Report

As Professor Anisa Haddad prepared for her first team meeting of the new semester, she wondered whether she would ever meet any of her 15 Ph.D. students in person. Even though they worked closely, it was unlikely they would ever meet face to face. It was more curiosity than concern since the virtual reality tools made it feel like they were together anyway.

As a chemistry professor at a small research university in the Middle East and a research fellow with a Fortune 100 company, Haddad had the responsibility to make sure the research projects across her team met the required 60%-40% split between applied company projects and investigative research for the university. It was a hard balance to keep but well worth it to gain access to the global UNET research management system. She could not imagine any of her work moving forward without access to that system.

The corporate appointment granted her Tier 1 membership in UNET, which offers virtual access to four of the most highly equipped chemistry labs in the world. It also allowed for high-tier computer power in the UNET cloud for analyzing results and building models.

Access to these resources was highly competitive and meant that her students and projects had to continuously provide both commercializable intellectual property and new basic research breakthroughs.

Haddad was selected for her position because of her excellent UNET academic credential score. She began working with the system early in her academic studies and knew how to maximize the scoring of her projects. Now that students and professors could distinguish themselves through their work in this global network, it reduced the influence of their university affiliation. Her closest rivals were from Brazil and Kenya. It was all about production and momentum, and the sponsor did not care where it came from.

But choosing her corporate sponsor did affect who she could work with and who could see or review her research. The UNET system monitored all activity and made sure only members in the same sponsored family would be able to collaborate. So, even though the system was global it did not mean collaboration was universal.

Simulation

Practical considerations impose limits on what kinds of experiments a researcher can run safely or within cost, but new simulation technologies, offering higher fidelity at reduced costs, are rapidly mitigating many of those concerns. For example, research on the effects of distractions while driving in traffic would be dangerously impractical in the real world. Using a realistic driving simulator, however, a variety of experiments can be carried out at minimal risk, and in a much wider range of scenarios.

Virtual and augmented reality (VR/AR) technologies may also play a related role. If VR/AR hardware continues to decrease in price and increase in fidelity, and consumer adoption of the technology ramps up, the next generation of researchers may be as comfortable working in virtual environments and with other VR/AR-based tools as the current generation is with email or spreadsheets.

Computing

The speed and size of high-performance computing continues to grow, enabling realistic calculations of a host of phenomena. Computational methods are increasingly shifting the nature of the research from reductionist methods to data exemplified representations. Several other technologies have the potential to reach breakthrough status soon.

For example, as quantum computing and communications mature, they will push hardware performance into an entirely new realm governed by the rules of quantum mechanics and creating new concepts for algorithm development. Algorithms and hardware that properly leverage quantum advantages will outperform previous methods in some domains, potentially allowing for detailed design processes that are currently impossible with classical computing models, as in molecular and biological engineering and large-scale simulation.

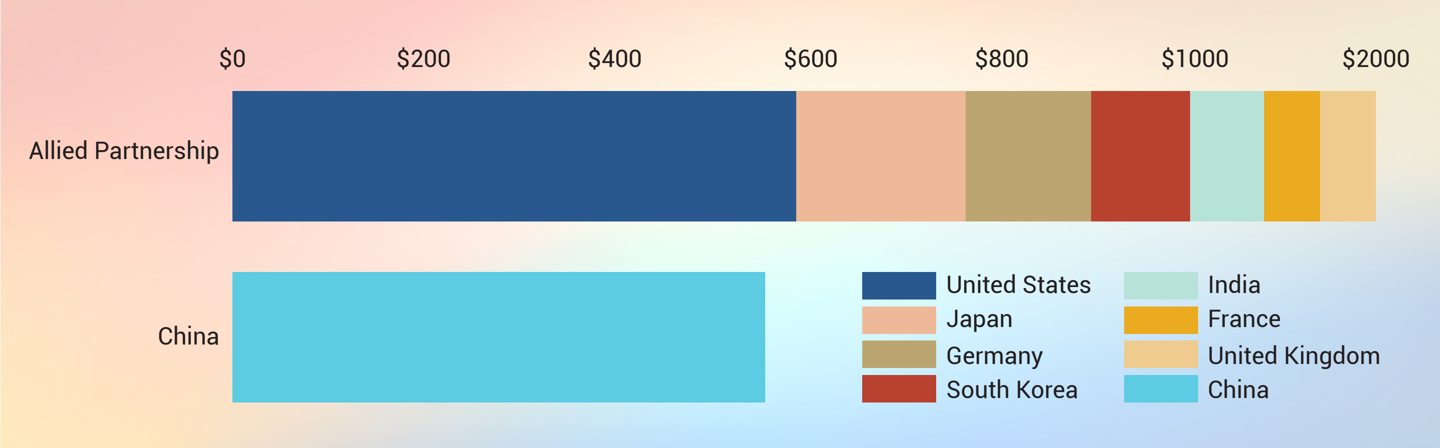
2.5 Policy

National and global politics play a pivotal role in defining the research environment. International research projects and initiatives will drive large-scale science and engineering programs and affect priorities at the national level. These will create a category of drivers that will create opportunities and challenges for university research programs.

Government Research Investments and Industrial Policy

Over the last two decades, global R&D investment has tripled, surpassing $2 trillion in 2018 [Flagg 2020]. The U.S. share of this investment has diminished from 69% to 28% since the 1960s, as increasing global investment has outpaced U.S. investment. The U.S. and China together account for more than 50% of these expenditures. The remainder of the R&D funding comes from other countries shown in Figure 2.2.

Figure 2.2 International research investments compared [Flagg 2020]



Globalization and proliferation of technology to peer, non-peer, and non-state actors means the U.S. can no longer rely on having and keeping the technological advantage.

In recent years, consolidation within the research and development industry has led to a winner-take-all model. As an example, in the aerospace and defense industry, four contractors — Lockheed Martin, Boeing, Northrop Grumman, and Raytheon — were formed from 51 companies in just a couple of decades. Historically, the concentration of companies reduces competition, which in turn leads to further concentration [GAO 2019]. Similar examples occur across the tech industry, including Facebook acquiring Instagram, and others. This principle maps to funding profiles as well, which drives funding toward a smaller number of larger contracts. This trend is difficult to reverse; innovation builds intellectual capital and establishes relationships that further perpetuate it.

Human and Capital Resources

The concepts and skills associated with a STEM-trained workforce are central to competitive positioning in applied research and technology-driven industries. As such, there is a positive correlation between economic activities around technological innovation, the promotion of STEM fields, and pursuit of advanced research capabilities.

U.S. and European research centers have depended on international graduate students as part of the innovation engine. Asian economies are undergoing major growth and may disrupt the supply chain of top-tier researchers who otherwise might have come to the U.S.

In the past 30 years, several Asian countries, including China, South Korea, and India, have followed the examples of Japan and Taiwan to move to the forefront of research innovation and technology development. Many of the leading scientists and engineers in this cohort were educated in, and developed groundbreaking research results under, the U.S. research enterprise. They have created a number of intellectually fertile and technologically productive innovation centers around the globe. These centers already attract world-class talent and can compete with the best U.S. research institutions for top-tier researchers.

As the local research environments mature in these countries, the demand for education and research from U.S. universities may decline, and lead to a fundamental shift in the relative distribution of global research resources. The U.S., for instance, has fewer STEM graduates than China, which had 4.7 million graduates, and India, with 2.6 million, in 2016. The U.S. had 600,000 [WEF 2016]. One driver of this trend is the so-called "youth bulge" in which "nine out of 10 people between the ages of 10 and 24 live in less developed countries" [Modley 2016]. This means the market of new students, engineers, and researchers will primarily come from less developed countries.

This could cause a pull of corporate research and recruiting dollars away from more developed countries.

View From 2045: News Report

Francisca Rodriguez was named the director for space agriculture at the world-renowned Space Sciences University (SSU) of Brazil in Macapá. The university was established with massive public and private funding to compete for global Grand Challenges around space flight. What began as a single contract win a decade ago has grown into a full-service space ecosystem, including launch systems, materials, service bays, service vehicles, launch pads, and communications. The space ecosystem grew around Macapá because of its easy equatorial water launch sites, making it easier and cheaper to launch there. SSU has emerged as one of only two global centers for space research. The rest of the former major centers of research around the world are now contracted to SSU to provide specific services related to these Grand Challenges.

The space agriculture focus was created to take advantage of recent breakthroughs in agriculture that leverage micro gravity, controllable sunlight, and hydroponics. This makes it possible to iterate seed and plant design in space at rates unimaginable compared to former terrestrial means.

Contract sizes for these Grand Challenges regularly exceed $1 billion, and competing for them is a high-stakes affair. Funding is often provided by private-public partnerships, mostly private, to advance commercial opportunities in space. But some, like the space agriculture project that Rodriguez is working on, are funded by a collection of countries in central Africa to address the growing need for more efficient food production.

Geopolitical Tensions

Geopolitical tensions and competition profoundly affect research priorities, such as the space race in the 1960s or artificial intelligence today. Moreover, there are inherent conflicts with the open and free development of ideas and innovation, and efforts of countries to restrict those innovations to in-country. The U.S. has implemented policies to protect federally funded and commercial research from information extraction attempts. The cooperative international research process is strongly influenced by covert and overt espionage activities [Wray 2020]. One example is China's talent and recruitment program called the "Thousand Talents Program" [Portman 2019], through which China encourages researchers in STEM fields to extract knowledge and innovation from other countries [Wray 2020].

View From 2045: News Report

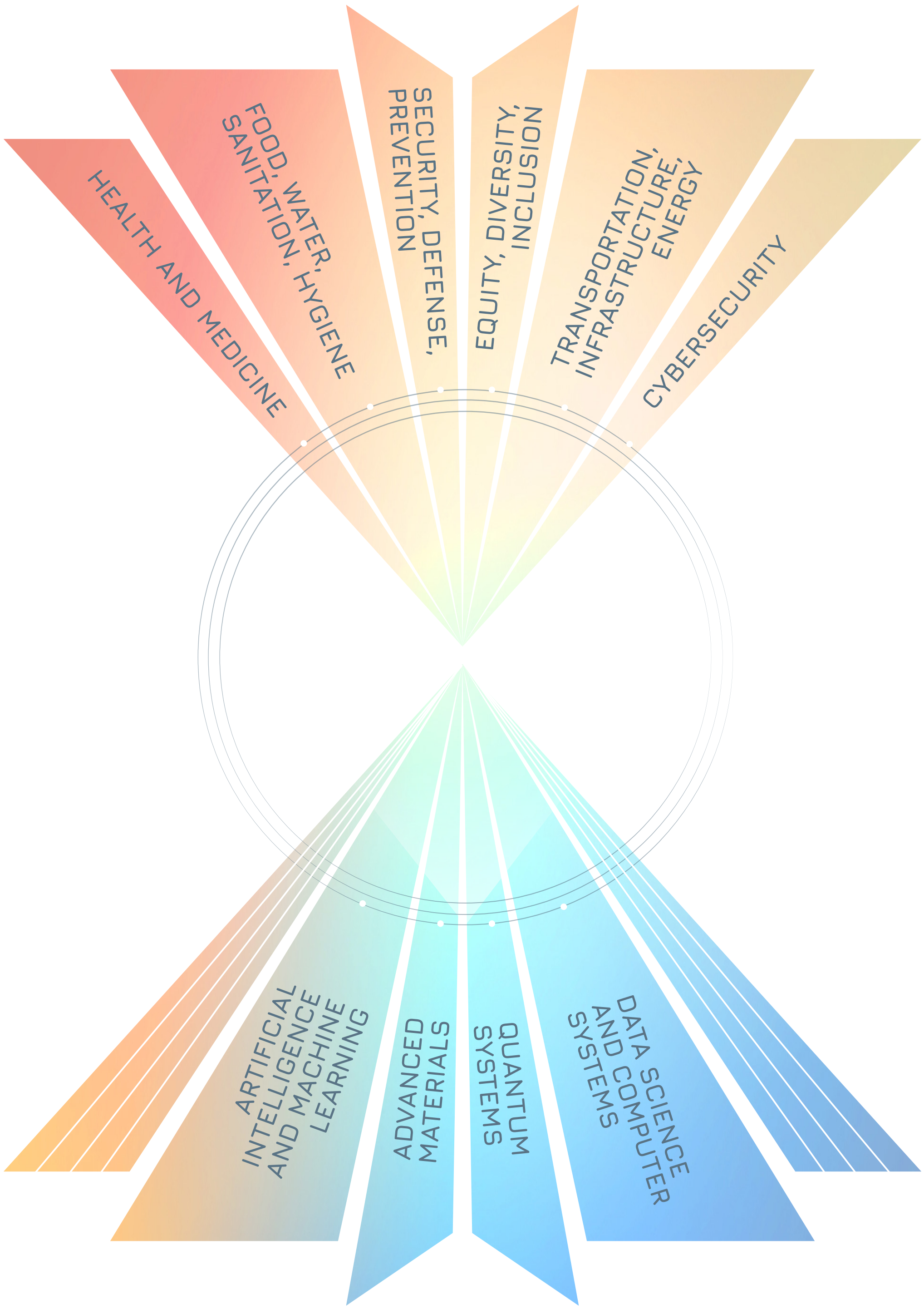
Today the Universidad de Sao Paulo announced a new billion-dollar investment to create The Ryu Bio Manufacturing Research Center. This center will advance methods for custom biological material design and be led by world renowned South Korean researcher Min-seo Ryu. This is the Universidad's second investment of more than $1 billion in the past five years and adds a new collection of corporations to its growing list of sponsors centering research in the country.

The flow of research dollars into Brazil has continued unabated for the past decade as global corporations remain attracted to its liberal research collaboration policies and tax incentives. Brazil has emerged as one of the only countries in the world where researchers can work freely with each other regardless of their nationalities. As long as the research originates in Brazil it can be exported anywhere with no restriction. The highly promoted policy of "From Brazil, to the world" continues to resonate with global corporations. Initially, progress was slow, but as more researchers and money migrated to the region, the pace of research has increased.

Geopolitical Tensions

Resource models that enable research and development for technology innovation are evolving. For example, the U.S. relies more heavily on commercial interests and decentralized processes to drive research, especially in artificial intelligence and quantum systems, while European and Asian nations favor different balances between public and commercial interests [Lee 2018], such as the role of public and private institutions in funding research or managing privacy.

CHAPTER THREE:
RESEARCH THAT MATTERS


HEALTH AND MEDICINE
FOOD, WATER, SANITATION, HYGIENE
SECURITY, DEFENSE, PREVENTION
EQUITY, DIVERSITY, INCLUSION
TRANSPORTATION, INFRASTRUCTURE, ENERGY
CYBERSECURITY
ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING
ADVANCED MATERIALS
QUANTUM SYSTEMS
DATA SCIENCE AND COMPUTER SYSTEMS

3.1 Introduction

Humanity is facing unprecedented challenges that will require the full engagement of research universities. This chapter identifies grand challenges, emerging topics, and requisite methods that will be addressed at research universities over the next 10 to 25 years. We have organized these research topics into the following three categories, recognizing that they intersect and overlap:

Societal Challenges:

These include food, water, sanitation, and hygiene; healthcare and medicine; transportation, energy, and infrastructure; cybersecurity and privacy; diversity, equity, and inclusion; education; and security, defense, and prevention of nuclear terror threats.

Innovations:

These are crosscutting and broadly enabling in nature, and include advanced materials; artificial intelligence and machine learning; data science and computer systems; and quantum systems.

Discovery:

A variety of research topics are not necessarily pursued for some applied end, but for reasons of curiosity, understanding, enjoyment, contentment, and beauty.

The overarching thesis of this chapter is that university-based research can contribute to improved living conditions and quality of life, by contributing solutions to food, water, sanitation, energy, health, well-being, climate change, community planning, infrastructure, security, and education [Valero 2019; Wowk 2017]. University research can also develop underlying technologies, tools, and methods of analysis that can lead to innovative future solutions, such as artificial intelligence or advanced materials.

3.2 Societal Challenges

Food, Water, Sanitation, and Hygiene

Sustainably supplying food, water, and energy to all will be increasingly challenging because of population growth, increasing standards of living, and climate change. Innovation will be crucial in augmenting supplies, improving distribution, reducing waste, increasing efficiency, and reducing demand. In addition to pointwise innovation and technologies, holistic, systems-oriented approaches are required.

Food. Research and education are needed to produce more food with fewer inputs, including water, cereal grains, pharmaceuticals, and labor. Advances in agricultural technologies, data collection, and computational science provide opportunities to further enhance efficiencies and increase yields. For example, sensors can detect and diagnose plant diseases to reduce lost agricultural productivity [Mahlein 2016]. Precision applications of pesticides, herbicides, and fertilizer can dramatically reduce agrochemical use without compromising yields [Schumann 2010]. A better understanding of the microbiome in agriculture will improve soil structure, increase feed efficiency and nutrient availability, and boost resilience to stress and disease [NASEM 2018]. Selective breeding, genetic engineering, and gene editing could be used to develop crop varieties that maintain productivity under changing climate conditions [NASEM 2016]. Advances in low-cost sensors and communication tools could provide guidance to farmers on appropriate application rates of seeds, water, and fertilizer to maximize yields and prevent unnecessary inputs.

Technologies and systems along the entire food chain — including harvest, transportation, processing, and storage — are needed to reduce food loss from farm to plate. Protective films can lengthen shelf life, possibly without refrigeration [Sharma 2017]. Low-cost sensors that indicate food quality and safety could further reduce food loss.

Water, Sanitation, and Hygiene. Safe drinking water, sanitation, and hygiene are paramount to improving standards of living and quality of life [Hutton 2017]. Research can lead to improved water treatment, handling, and storage; improved toilets; on-site excreta management; septage and sewerage management; and menstrual hygiene management.

Wastewater reuse is more expensive than conventional water supply alternatives such as imported water and groundwater, and public acceptance of potable reuse remains a challenge. Advances are needed to reduce the cost and energy requirements of alternative supply treatment and to develop sensors and mitigation approaches for contaminants [CDC 2020], such as membranes that remove specific pollutants while allowing nutrients to pass through. Technologies that improve the recycling of wastewater and sewage treatment so that water can be used for irrigation or industrial purposes are still needed. Recycled water has the potential to resupply aquifers, but effective purification methods and rigorous safeguards are necessary.

Desalination is currently costly and requires large scales. Nanotechnologies such as nano-osmosis using nanotubes, nanofibers, and heterogeneous catalysts have exceptional potential for their filtering abilities. In addition, technologies are needed to reduce water use. Agricultural irrigation consumes enormous quantities of water. For example, in developing countries, irrigation often accounts for more than 80% of total water use. Improved technologies can reduce agricultural water demand while providing enough water to cleanse the soil. Work is also needed to reduce water loss in urban supply systems.

Healthcare and Medicine

Healthcare and medicine are heavily driven by research. For universities, research related to the causes of cancer, diabetes, neurological diseases, viral transmission, and respiratory illnesses and, ultimately, mitigating symptoms, can improve the quality of life and life expectancies [NAM 2017]. In addition, there is continued opportunity for advancement of medical technology and health service research, which includes brain research, application of artificial intelligence in the identification of symptoms and to look for abnormalities in X-rays or CT scans, and systemwide approaches that incorporate social determinants to health outcomes [NAM 2018]. Research is needed to improve the force-feedback mechanism in robotics, to allow for remote surgical operations where a remote surgeon can perform surgery on an individual without the need to travel. Research into effective approaches to data integration, strategies for patient-centered care, health disparities, and the embedding of research into the care environment are also important areas [Bestsennyy 2020]. For example, through the Covid-19 pandemic, health professionals significantly increased the use of telehealth technologies to prevent potential patient and practitioner exposure. Research is needed in developing novel data collection strategies through personal wearable devices.

Coupled with these new technologies is the need for more secure data transmission and record keeping. The integration of volumes of data generated for each individual along with techniques tailored for big-data analytics may enable us to achieve precision medicine [Cattell 2013].

Finally, there is overwhelming evidence of health inequities in the United States [NASEM 2017]. Research is similarly needed to identify and understand these inequities and develop solutions that are frugal, robust, and easily accessible.

Transportation, Energy, and Infrastructure

Transportation is fundamentally important to humanity and integral to urban development, mobility, and economic growth. The primary modes of interdependent transport include road, rail, aviation, maritime, and pipeline. Opportunities for research include developing new, efficient strategies for manufacture, design, construction, operation, inspection, maintenance, and renewal or disposal of associated systems. Linking scales of research to practice via knowledge sharing, standardization, and technological adoption remains a particularly important challenge. These issues can be addressed through the development of sustainable materials, robust sensors, integrated GPS and wireless communications, battery power storage, automation, smart systems (for damage detection, automatic adaptation, and damage tolerance), and policy research [Polzin 2016; Polzin 2018]. For air travel, research is needed in the development of electrified airplanes, as well as supersonic and hypersonic flight [NASA 2020].

Energy is another area where the need for sustainability will drive major changes, and research will play an important role. Increasing the efficiency, decreasing the cost, and increasing the life of solar devices is just one example of vital research areas. All elements associated with the use of electric power — power electronics, wide bandgap materials, more efficient electric machines (e.g., motors), smart grids, and decentralized control — will also become increasingly important. Work is also needed to reduce the cost of net zero carbon chemical energy carriers, such as hydrogen or renewable hydrocarbons. Research is needed to reduce costs and increase reliability of decarbonized power generation [DOE 2015]. Finally, research is needed in energy efficiency and to reduce energy needs, such as in buildings, manufacturing, and transport.

Many of the improvements discussed here can only be delivered in a cost-effective way through public *infrastructure*. Aging infrastructure systems pose considerable risks related to maintenance, service, and upgrading. Future research areas include technologies rooted in the Internet of Things (IoT) designed to enhance condition monitoring, response prediction, maintenance, and operation. The grand challenge is to develop smart and adaptive materials (e.g., self-healing, self-sensing, self-cleaning, etc.), responsive sensors, data systems, and wireless technologies that provide interactive communications. Moreover, conception, development, and funding of infrastructure projects, in both developed and developing countries, will benefit from social science research.

Cybersecurity and Privacy

From power grids and air transportation to healthcare systems, physical infrastructures are increasingly controlled by computer systems, creating opportunities for adversaries to steal sensitive information, disrupt operations, or even destroy critical assets, all carried out through cyberspace. We have already seen a significant increase in cyberterrorism in financial systems and the power grid. Moreover, social infrastructure connections pose risks to fair governance and democracy, elections processes, and the safety of people. Research is needed to develop approaches to protect critical cyber-physical infrastructures and encourage partnerships among security and domain researchers, as the detection, mitigation, understanding, and attribution of attacks necessitates domain-specific expertise. There is also a pressing need to understand how people interact with their computers and information culture and to protect personal data and preserve privacy.

Diversity, Equity, and Inclusion

While equity and inclusion are values that drive the subjects and methodologies of our research, understanding and quantifying the many ways in which technologies, social structures, and a host of other factors create or reinforce inequity is a research topic in its own right. This work involves studying and supporting strategies focused on racial, gender, place-based, and other forms of equity, and identifying the structural barriers facing various communities. It is vital that researchers collect data, quantify change, and identify correlations to identify inequity. Research is also needed to identify the biases and discrimination that flow from new technologies, and to suggest approaches to harness their benefits while mitigating potential harm. For instance, while developing artificial intelligence (AI), we must make sure that our data sets do not implicitly bias a technology. Research is needed to evaluate disparate impacts that new technologies might have on workers. Finally, research is needed to understand bias in organizational decision-making, and how to prevent it.

Education

Higher education has dramatically evolved in the past decade, incorporating new ideas about classrooms, curricula, pedagogies, learner profiles, and the overall system, aimed at delivering more effective learning. Research will be foundational to devising pedagogical approaches and developing tools for building curricula that do not just pique learner interests and abilities, but also instill critical, creative, and cognitive thinking, acting as the base for lifelong skill development. Evidence-based educational ideas and platforms will integrate both previous and real-time data in conjunction with machine learning to inform practice in a timely fashion, to improve student outcomes, and to address current challenges. Data integration and data mining on a national scale will also provide larger sample sets that would prevent the ambiguities present in smaller data sets.

Security, Defense, and Prevention of Nuclear Terror Threats

National security not only includes guarding against military threats, but also fortifying a country's security across its economy, healthcare system, industries, supply chains, technologies, energy resources, and infrastructure. All of these involve a host of research problems, such as analysis of supply chains or geopolitical influence networks, or detection techniques of nuclear materials.

3.3 Innovations

Advanced Materials

Materials are an integral part of all physical technologies that cut across essentially every application field. As a result, designing and creating new materials with enhanced properties can have a transformative effect on the performance of next-generation systems, devices, components, and applications. In the coming decades, we can expect that materials will be developed that will have application-specific, performance-driven attributes.

Developing targeted materials requires the ability to model, fabricate, and measure properties across diverse length scales. The goal is to develop methodologies that enable stretching the limits of performance of existing materials, or designing and creating new materials for specific applications. These techniques can be used to make metals lighter and stronger, ceramics tougher, polymers degradable, and composites more affordable. Several grand challenge problems require advances in materials: new materials can significantly improve the performance of energy storage technologies, including batteries, capacitors, superconducting magnets, and flywheels [NASEM 2019]. New materials can make dramatic improvements in separation and filtration problems, such as filtering clean water or carbon capture. More efficient and sustainable construction materials could dramatically improve the energy efficiency of buildings and reduce the environmental impact of urban infrastructure.

As an enabling technology, the recent and projected growth of AI has the potential to make the next century one of the most transformative periods in human development. While the recent advances of automatic speech recognition, image recognition, and self-driving vehicles have been impressive, we will see further advances in healthcare, education, security, manufacturing, and scientific discovery. Already able to identify and locate some forms of cancer that are too subtle for the human eye to detect, AI systems in the future will have the potential for personalized, round-the-clock monitoring and diagnostic capability through low-cost and minimally invasive digital assistants. At the global scale, AI algorithms will make spatiotemporal connections between reported symptoms of patients and social media to identify, locate, and track potential communicable disease. Further, future AI systems will provide cognitive support to an aging population as well as early-warning detection and personalized mitigation strategies for depressive episodes in susceptible patients.

AI can improve predictive maintenance of airplanes, ships, bridges, and other complex systems and infrastructure, streamlining operations and ensuring a robust supply chain. AI can also improve efficiency through human-machine interfaces or human performance enhancements, whether physical with exoskeletons or mental with decision support systems. Autonomous systems can also remove the human from dangerous or tedious tasks, such as in nuclear power plants or war zones. Further, AI has the power to improve education, starting at the early stages of childhood development and continuing into retirement, such as through aiding teachers in designing personalized lesson plans to handle the different developmental speeds of pupils.

While artificial intelligence capabilities enable human-like perception and processing across the technical spectrum, the novel attributes of AI couple into control processes to create new vulnerabilities and exacerbate existing security challenges. Future AI systems will need to be able to identify deepfakes, ensure both national and personal privacy, and be robust against poisoning through manipulated data sets. Research is needed to integrate domain-specific scientific principles, expert feedback, and uncertainties in the algorithms to enhance the capability, accuracy, and defensibility of these models. One opportunity for domain-specific machine-learning research is in constructing modeling languages and frameworks that facilitate the inclusion of domain knowledge into training.

Another crucial need in scientific machine learning is to maximize the amount of learning in situations with scarce data sets, and to actively choose data or new experiments wisely. In active learning, there are opportunities for research to improve the design optimization process, especially for systems that are dynamically evolving in time. In particular, the availability of a physical model can provide predictions that enable look-ahead for future design choices. Research is needed to enhance these models to ensure the methods are stable, robust, and bias-free. To meet these challenges, an AI-friendly workforce is required, not as a separate field of study, but integrated throughout STEM.

Over the past decade, the ability to rapidly generate, store, and analyze data has had a significant impact on almost every sector. Data is now pervasive in nearly all aspects of modern life. Global internet traffic is greater than 200 Exabytes (1018 bytes) per month. There are billions of devices connected to the Internet of Things (IoT), generating massive amounts of data. Additional data is collected for research, medical, and national security applications. In order to be useful, all this data must be securely acquired, distilled, labeled, aggregated, and stored in an accessible way. As our ability to generate data continues to grow, we must continue to develop technologies for low-cost data storage and high-performance computing for data analysis, as well as efficient algorithms and optimization techniques. We need advances in edge computing systems to reduce communication costs and improve efficiency. End systems need to operate in real time and handle the deluge of data by providing real-time tagging and aggregation. Further, as devices fail or become compromised, techniques for identifying and mitigating malfunctioning sensors must be developed to provide robustness to an increasingly networked world. Finally, gains in advancing the data fabric must preserve privacy, and research should specifically address robust data science methods.

Proliferation of data will have an enormous impact on all sectors of society, including industry, education, medicine, science, national security, and government. Big data sets abound in genomics, systems biology, and proteomics. Advances in electronic medical records, computational phenotyping, personalized genomics, and precision medicine are driving predictive, preventive, and personalized healthcare. Large-scale data sets providing a microscopic view of materials, and scalable modeling and simulation technologies, are paving the way for the accelerated development of new materials. Advances in sensors and Internet of Things technology enable energy infrastructure monitoring. Data analytics brings unparalleled efficiencies to energy production, transmission, distribution, and utilization [Rockefeller 2020; Lytras 2019].

Dramatic improvements in computer hardware have driven data science advances. Hardware improvements deliver performance that unlocks new capabilities. Novel computing systems will be needed to leverage both new technologies and new architectures. While there has always been a strong link between the availability of hardware and advances in software and applications, the rapid growth of transistors per chip allowed hardware and software to be developed relatively independently. In the future, this will change as novel computing systems are developed to optimize algorithm performance for domain-specific applications. Conversely, the discovery and implementation of novel hardware technologies will drive innovation in new types of algorithms and applications.

There are several potential approaches to building novel computing systems, some more disruptive to the current development cycle than others. Some novel computing systems will not only use new technologies for the logic elements but will also use radically new computing paradigms. Potential applications include the design of complex electronic and optical materials, the integration of molecular-scale circuits for biological applications, and therapeutics that have programmable control over drug delivery [Passian 2019]. DNA and other synthetic molecules can also be used to store archival data with significantly reduced size or power requirements. Potentially among the most disruptive forms of novel computing systems are quantum computers, which have the potential to surpass the scaling limits of classical computers for certain algorithms, discussed further in the next section.

Quantum Systems

Quantum computers could have a transformative effect on society [Möller 2017], by enabling better solutions to a class of large combinatorial problems than any known classical solver. This means more efficient logistics and supply chain designs, better circuit designs, and superior protection against malware attacks, among other applications. Similarly, quantum materials are a promising and broad class of materials that should enable technologies of the future, just as advanced materials enable technologies like MRIs, biosensors, and disk drives today. But quantum physics also sets the limits of what is possible in other types of systems, and research groups around the world have demonstrated lab-scale devices that harness entanglement and/or coherence that outperform classical solutions. The transition from the laboratory to operational devices faces many scientific and engineering challenges, but quantum systems will likely play an important role in next-generation devices across a wide spectrum of applications. Bridging the gap between the current ability to characterize large quantum systems and the capacities of the smallest workable quantum computers is the immediate grand challenge for the field.

Quantum sensors are positioned to deliver solutions to critical problems, but techniques must be developed to extract this sensitive signal from the background, and technologies must be developed to decrease their size and power requirements.

Atomic magnetometers have the potential to transform a number of important fields. They could be used to map brain and heart activity without cumbersome cryogenic cooling, which would contribute to our ability to diagnose injury and disease and to understand the way the brain works. They can be used for magnetic anomaly detection, potentially allowing for the early detection of UAVs, submarines, and underground buildings and structures — all applications with enormous implications for national security. They could also be used for wide-area aerial high-resolution magnetic surveys to detect archeological or geological structures, mineral deposits, contaminated soil or maritime sediment, unexploded ordnance, or abandoned vehicles. The same technology can be used to do navigation using precise magnetic maps of the earth's crustal field.

Atomic clocks currently provide primary time and frequency standards for the United States as well as the very precise time data used for GPS signals. Efforts are underway to decrease the size, weight, and power of these systems while maintaining a high level of precision and stability. Improved compact atomic clocks could allow for long periods of silent navigation in environments where GPS is not available — underwater, underground, or in the battlefield where GPS has been jammed. Distributed systems of precise atomic clocks can lead to coordination of signals from multiple sources that can be used for improved geolocation, image analysis, and target tracking.

Antennas could surpass classical limits and allow the construction of compact communications systems. Measurements of quantum noise can enable the next generation of world-class instruments and facilities to create fundamental scientific knowledge and probe the cosmos.

3.4 Discovery

Curiosity and Understanding

Basic or discovery research is focused on the acquisition of general knowledge, understanding nature, and predicting outcomes or phenomena. Humankind has always sought to expand horizons and explore new frontiers. Such endeavors are rooted in curiosity about the unknown or to understand what is being observed. These topics include pure mathematics, the search for life on other planets, and understanding the chemical origins of life.

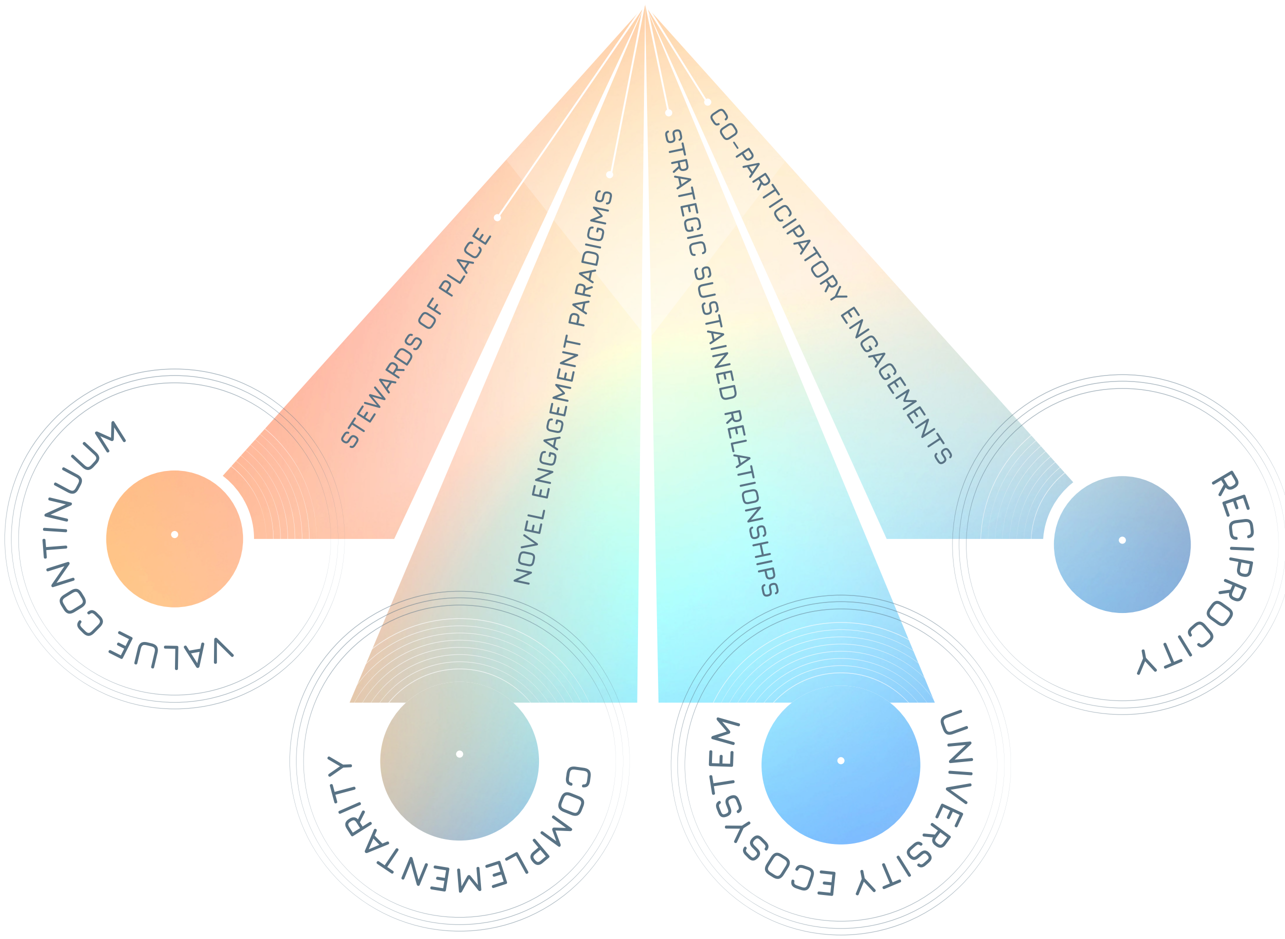
Such research is often performed without thought of the direct applications or practical ends. There is often a 10- to 20-year gap between fundamental discoveries and subsequent application [MIT 2015]. Moreover, intentional support of fundamental research contributes to the broader university culture that values the development of thought, the growth of ideas, and investment in intellectual talent.

Enjoyment, Contentment, and Beauty

Research in the creative arts represents an important area for any major research university. Art research offers the proposition of new concepts for the problems of contemporary society and the ability to offer alternative solutions or propose new questions, based on non-exclusive rational modes of thought. Art research fosters both conceptual and non-conceptual thinking. It spans multiple disciplines, including design, music, and composition, and offers other unique perspectives. For example, elements of music theory can be taught using mathematics. Architecture and building models can be directly influenced by artistic design elements and formulas. Art research also has a broader societal impact in existential enhancement (e.g., enjoyment, contentment, and beauty) and leisure activities as well as the economic impact of tourism and cultural industries.

CHAPTER FOUR:

WORKING WITH OTHERS


STEWARDS OF PLACE
NOVEL ENGAGEMENT PARADIGMS
STRATEGIC SUSTAINED RELATIONSHIPS
CO-PARTICIPATORY ENGAGEMENTS
VALUE CONTINUUM
COMPLEMENTARITY
UNIVERSITY ECOSYSTEM
RECIPROCITY

4.1 Introduction

The very nature of the societal challenges with which research universities must engage require collaboration and partnership. Increasingly, we must become more deeply integrated within the broader ecosystem of governments, companies, and local communities — and a leader in establishing and nurturing these partnerships. This chapter focuses on university partnerships, analyzing how research universities can cultivate a portfolio of purposeful strategic relationships, amplifying impact across individual, institutional, city, regional, national, and global dimensions.

This chapter was guided by the questions:

- What is driving universities to seek out more — or more meaningful — strategic partnerships?
- What factors affect the ability of universities to form successful collaborations, and what might the nature of these relationships look like in the future?
- What are primary considerations for universities seeking to employ strategic partnerships to amplify their impact?

These questions themselves are contextualized within the distinct attributes of a given research university. Returning to the Carnegie classification data described in Chapter 1, Georgia Tech is one of 25 institutions in the U.S. that are classified as very high research activity, public, comprehensive or STEM-focused at the doctoral level, and without a medical or veterinary school. That lens is important to understand the considerations for partnership, as the flavor of implementation must be driven by their unique mission and setting. Public universities, for example, are subject to different constraints than private ones, and institutions classified as or striving to be classified as very high research activity universities have goals and pressures beyond, but complementary to, the educational mission.

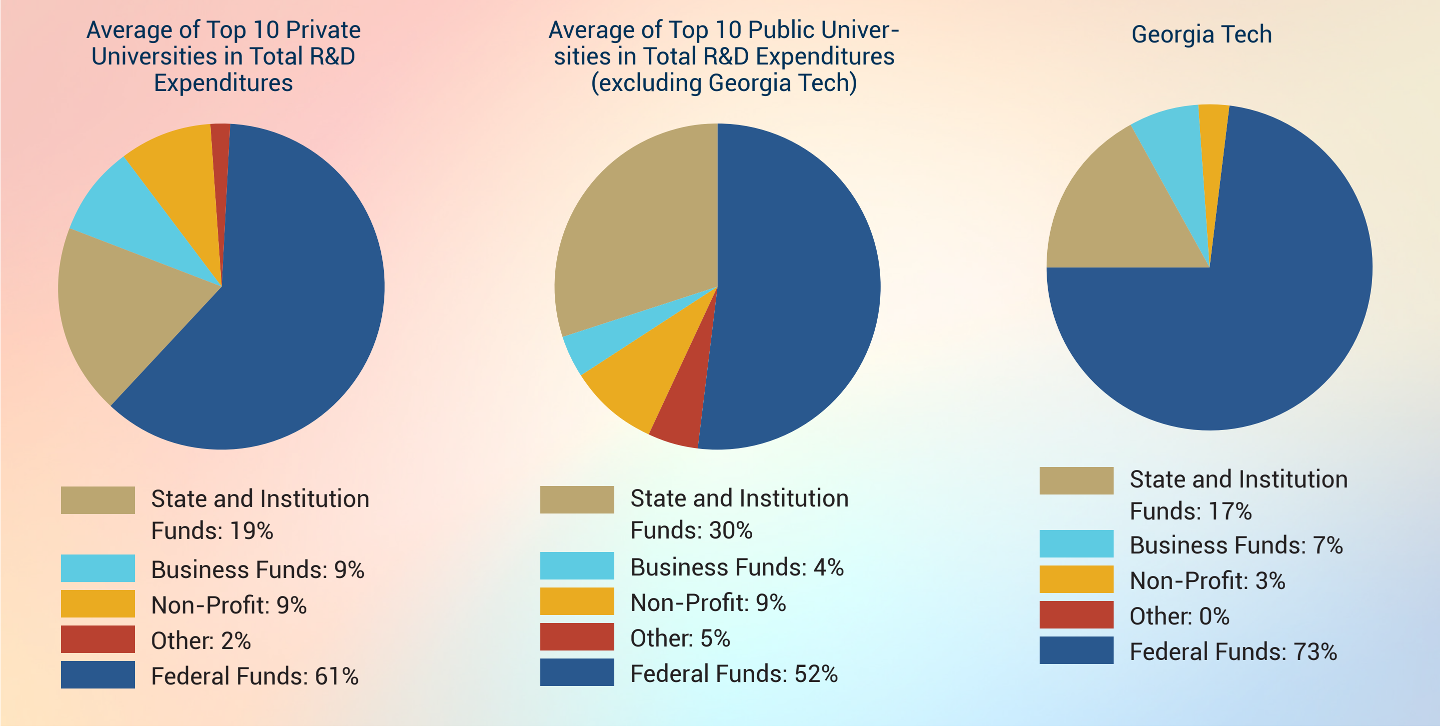
4.2 Elements That Influence Partnerships

Financial Environment and Defining a University's Niche

Fundamentally, finances drive strategic collaboration across many sectors, and higher education is no exception. Public institutions rely on state appropriations, which implies a local or regional impact responsibility and may constrain other activities, such as setting tuition or entering into legal agreements. As shown in Table 1.2, state R&D expenditures in universities fluctuated slightly, but generally decreased as a percentage of the total R&D expenditures over the past decade.

While state funds primarily support Institute operations, federal funds are typically directed to student support and research. Augmenting the data from Tables 1.1. and 1.2 with a recent Pew Institute analysis [Pew 2019], nearly 75% of total federal research funding to public colleges and universities in 2017 went to 16% of those schools. To gain a different perspective, we looked at the relative contributions of the R&D funding sources in 2018 [HERD 2018], averaging among the top ten private universities and the top ten public universities (excluding Georgia Tech), comparing them with the R&D expenditures at Georgia Tech. As shown in Figure 4.1, the top 10 private institutions and the top 10 public institutions, on average, had equal R&D expenditure funded by NGO and roughly equal (about 80%) combined R&D expenditures from federal, state and institution sources. Georgia Tech, by comparison, had a much higher share from federal, state, and institution sources combined and notably lower shares in other sources. In addition, Georgia Tech's share of business funds was more similar to that of the average of the private institutions than the average of the public institutions.

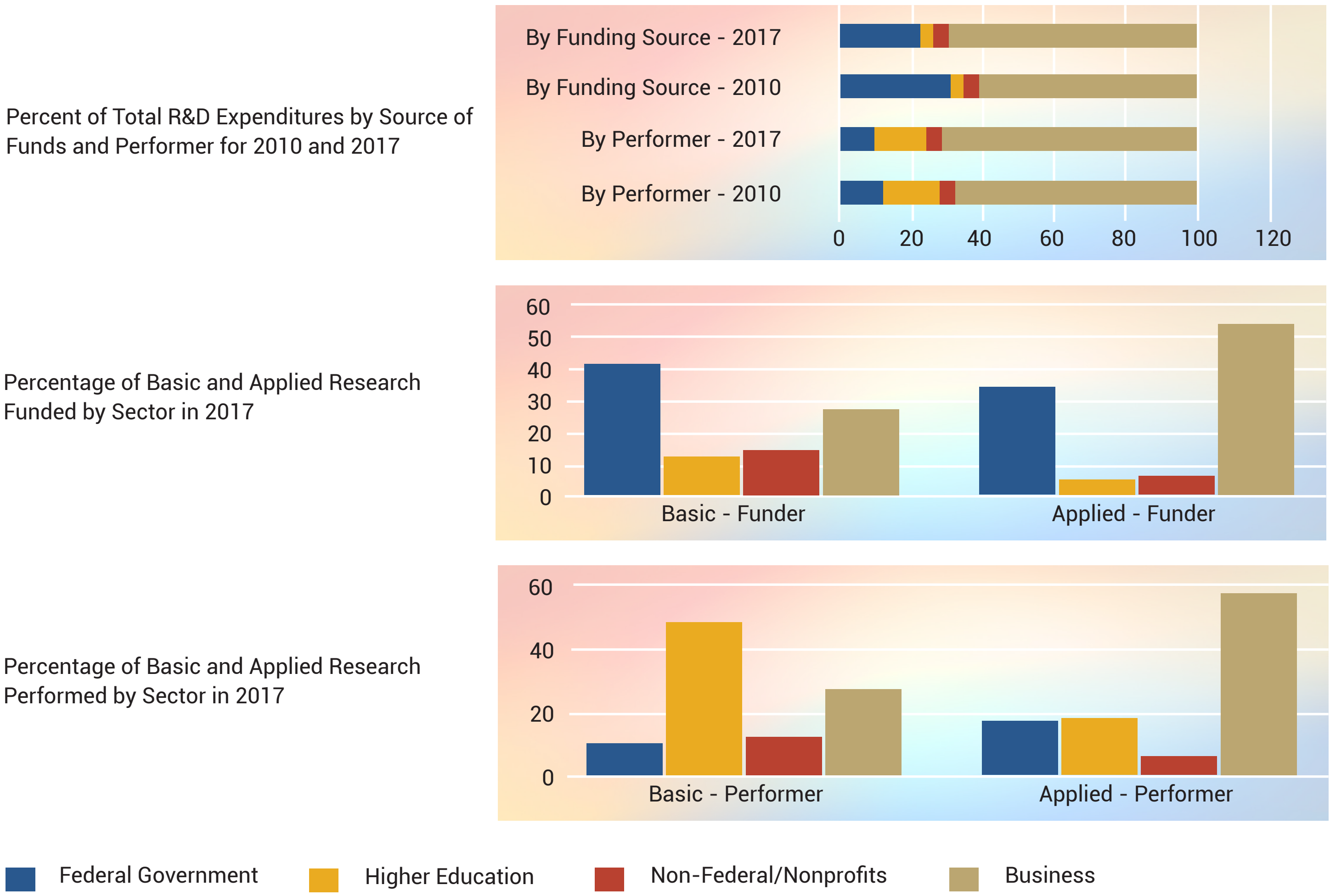
Figure 4.1 Average R&D expenditures in 2018 by funding source for the top 10 funded private and public (excluding Georgia Tech) universities and Georgia Tech



Data source: HERD 2018 Table 5: ncsesdata.nsf.gov/herd/2018

As seen in Table 1.1, following years of consistent increases in the commercial sector, industry performed and funded most of U.S. R&D, including basic, applied, and experimental development [NSB 2020, Sargent 2020]. By 2017, industry accounted for approximately 29% and 27% of basic research funded and performed, respectively, and just over half of all applied research, as illustrated in Figure 4.2. Additionally, of the total R&D funding in 2017, more than 80% went to research designated as applied or experimental development, leaving approximately 17% to support basic research. These are notable dynamics for universities, the second largest performer of R&D in general and for whom the impact of relatively flat federal funding is felt distinctly.

Figure 4.2 Illustration of National Science Board financial data highlighting landscape of basic and applied research

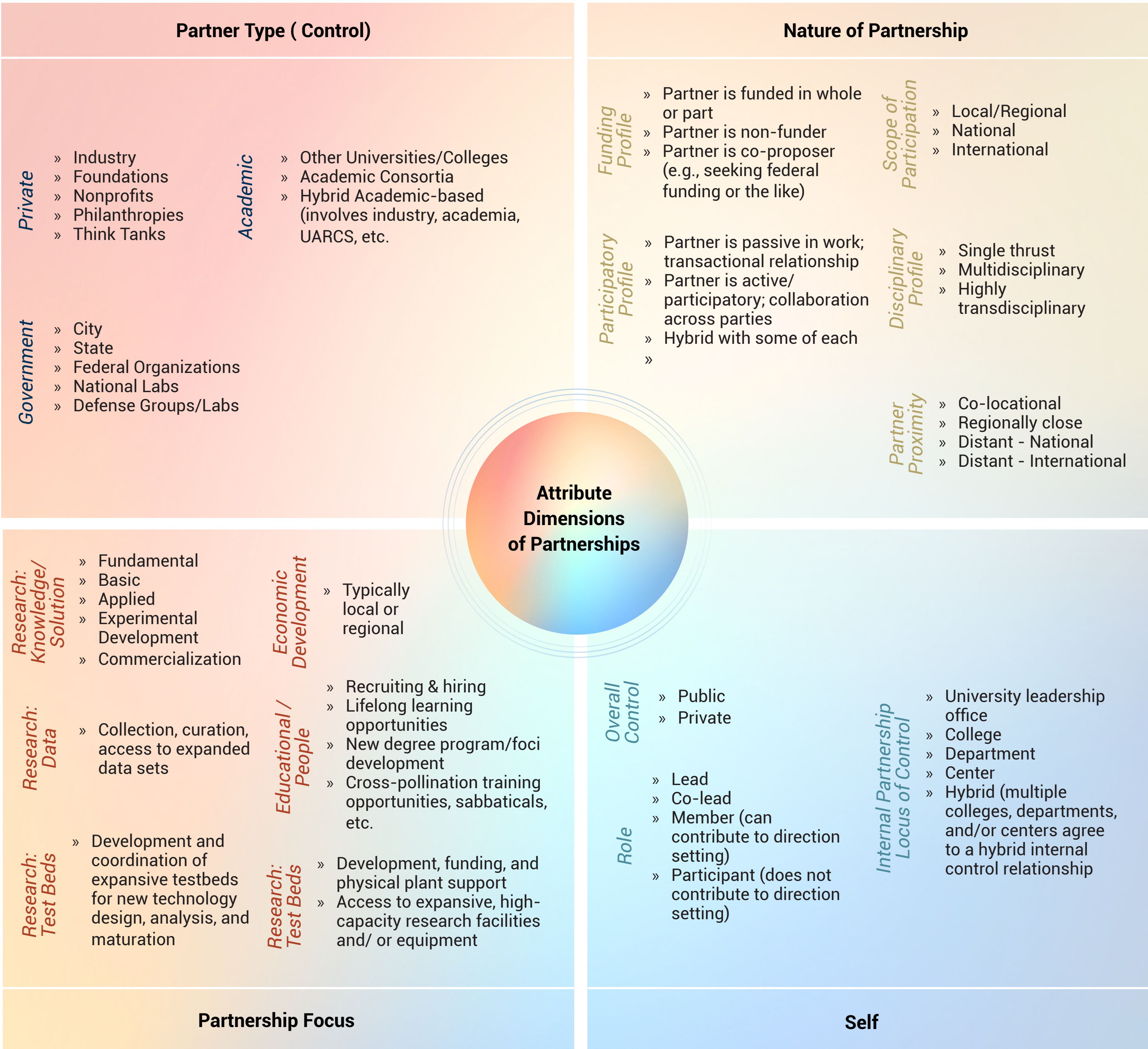


How research is classified can completely change the color of a strategic partnership. Higher education has historically held basic research as fundamental to its very identity. Industry, by contrast, generally focuses on applying research findings to solve problems, provide services, and to monetize the effort. The lines are not, however, quite so clear. The distinction between basic and applied research has been debated for years. Many organizations and federal funding agencies recognize the vital link between innovation and its acceleration with an integrated basic and applied R&D approach. Additionally, as highlighted in Figure 4.2, industry is performing just under one third of all basic research. Universities may dominate the category at just under 50%, but industry is indeed an important player.

Taxonomy and Partnership Attributes

Many factors define the nature of university strategic partnerships. In sustainable relationships delivering the most impact, all partners benefit by deriving meaningful value. Important factors include institutional factors of each party, relationship factors linking the partners, output factors in terms of desired results, and framework factors [Rybnicek 2019, Ankrah 2015, Randolph 1994, Makewa 2020]. Figure 4.3 summarizes key dimensions that characterize a strategic relationship. Attributes may be selected from subcategories in each major quadrant to describe a unique partnership profile that will have its own considerations, opportunities, and constraints.

Figure 4.3 Attribute dimensions of partnership



Some universities embrace risk or push boundaries with respect to the types of partnerships they form more naturally than others, largely due to a combination of history, institute control (public or private), state governance and risk acceptance (if public), and the local regional ecosystem. For example, universities situated in the middle of substantial venture capital and startup mindsets will derive influences quite distinct from those located in highly rural, agriculturally focused regions. Nevertheless, case studies of successful university partnerships [Donahue 2018, Belz 2016] reveal some consistent characteristics, captured in Table 4.1. These characteristics hold true regardless of whether the university is partnering with industry, federal, or nonprofit organizations, or other universities. The more co-participatory the relationship, the more people and resources are invested, and the more the partnership flourishes (or, conversely, exposes fault lines more quickly). Successful partnerships focused on long-range goals and were not limited by prioritizing quick results.

Table 4.1 Common characteristics of successful, sustained university partnerships

Characteristic	Description
Co-location of partners	At least one significant unit of an industry partner and the university are in close geographic proximity, facilitating access to leadership and continuous exchange of ideas. Community engagements are by definition proximal.
Co-location of people	Researchers/staff from private partner work in university labs or space dedicated to the partnership; university researchers commonly interact with industry colleagues and/or spend time on site in the locus of community engagement, such as participation in neighborhood association of equivalent organization meetings.
Active collaboration	Level of engagement between partners is active and participatory on both sides, not simply contractual research. Community engagements require reciprocity for sustained success.
Clarity on IP and publication terms	Intellectual property and publication terms for any research conducted as part of the partnership are pre-defined and well-articulated. This aspect is focused on industry.
Emphasis on workforce development through student education	Both sides place emphasis on student opportunities through research engagement as a means to augment educational experiences and training. Some partnerships even develop or enhance degree programs to provide increased training in a given focus area relevant to the partnership, facilitating recruitment of those well-trained students upon graduation.
Funding profile	Initial funding from private partner, university investment, state emphasis (initial though not ongoing direct support or incentive support from state), nonprofit or foundation; eventual growth and leveraging the relationship to pursue other sources of funding such as federal funding. Frequently, private partner continues to fund a significant portion of the work. Sometimes funding is partitioned, with a certain amount dedicated to open research and another line for proprietary research for the funding private partner.
Mission	Common if not directly complementary mission on all sides. Partners will have individual and common objectives, which must be complementary and support a shared sense of mission.
Engaged leadership on both sides	Strong leadership with a clear vision and a clear focus on the partnership (either a single focus of the university at the time, or one of a few, but not typically one of many).

All organizations are motivated by aspects they value and those they deem to add value. Value, or “fair return or equivalent in goods, services, or money for something exchanged,” is indispensable in any strategic partnership and is engaged in constant interplay with the concept of values, which are “principles intrinsically important or desirable to an organization” [Merriam-Webster 2020].

Corporate-university engagement in particular is shifting from *ad hoc*, contract-based, problem-specific efforts to increasingly strategic research endeavors intended to promote sustained collaboration [Frolund 2017]. One study of industry-university relationships [McConnell 2019] identified five key characteristics associated with successful alliances: mutually aligned university and industry strategic objectives; mutual commitment to collaborate across the entire innovation lifecycle; ability to leverage university resources to support the industry partner's needs, including a coherent face to facilitate interaction; dedicated partner liaisons within the university; and willingness by the university to tailor educational programs to support company partner innovation needs, thereby educating the future workforce in emergent technological areas and providing engagement opportunities between students and industry that promote recruitment [Perkmann 2013, Ankrah 2015, Belz 2016, Perri 2018, Rybnicek 2019, Giones 2019]. These considerations led Georgia Tech to revamp industry contracting practices, establish a dedicated office of industry research liaison to serve as a focal point, and establish interdepartmental and interdisciplinary research units. The literature details various dynamics and motivations behind these interactions, yet the essence may be distilled into the notions of value.

Specifically, these relationships are driven by the pursuit of strategic advantage, leveraging resources, and increasing impact, all of which are related to the interplay between the education, research, and technology transfer businesses. Companies aspire to develop products that compete successfully in the marketplace through a partnership that has both complementary and conflicting components, as academic institutions focus on generating and disseminating knowledge openly. Government organizations and nonprofits carry their own motivations, depending on their specific mission. When adding a mission to provide value in the form of technology transfer or entrepreneurial activity, the value offered inherently takes on a more applied flavor. Despite the differences, strategic partnerships can offer great potential for generating synergistic value across partners. One synthesis for the continuum of complementary benefit relationships between industry and universities is shown in Table 4.2.

Table 4.2 General categories of value complementarity for universities and industry engaged in strategic, sustained, collaborative relationships with exemplars for each category

University Value		Industry Value
Experiential learning Cutting-edge curriculum development Student employment Sabbatical opportunities	Talent/ Education	Expertise access recruitment access Sabbatical opportunities Professional development/lifelong learning
Build reputation for excellence and impact Potential for increased publications	Recognition	Build credibility for discovery and perceived reputation Potential for increased publications
Leverage corporate facilities, data sets, etc. Testbeds for contextual research discovery	Resource Access	Leverage university research facility infrastructure Leverage external capabilities, talent, and resources
Source of research funding Patent, licensing income (lesser degree) Catalyst for other opportunities/collaborative ventures	Financial Opportunity	Accelerate commercialization of innovation via access Preferred access to IP via corporate investment Access to government funds or other public funding
Knowledge creation in emerging problem areas that produce academically valuable insights Accelerate impact of innovation via partner	Innovation	Access to breakthrough/new scientific advances Accelerate commercialization of innovation via well-structured collaborations

A private partner must have risk tolerance, internal metrics, and financial capacity. Universities must understand that industry funding is undertaken at shareholder risk. Second, while some partnership outcomes are countable (such as research funding, number of commercial licenses, intellectual property, resulting commercial products and startup companies, number of students trained, or number of students hired by industry partners), other metrics may be qualitative but equally valuable to strategically position the partnership or future opportunities. For example, providing prestige and legitimacy, perhaps in the form of invitations to advisory boards or keynote presentations at influential conferences, yields influence and benefits beyond a simple enumeration.

The rubric expands further when considering research engagements with the community where the university is located. Universities across public and private sectors cite the twin missions of education and research, while public universities have an added mission to deliver value locally or regionally as “stewards of place” in service to the public good [AASCU 2018]. While that stewardship can fuel a commitment to community-based research, this motivation can be based in values or value. A review of the Harvard Catalyst Community Engagement Program, which seeks to improve translational research through small seed grants to community organizations, found that while funding for community-based research engagements supported participation from the community, the institution's researchers did not always have the time or interest in community-based research to make the interactions fully co-participatory and, thus, sustainable [Tendulkar 2011].

Funding can be a hurdle to community partnerships or partnerships with other local universities, and identifying financial needs or simply the time necessary to foster community engagement is crucial to success.

Trust and reciprocity of benefit are key attributes of successful university-community partnerships [Hacker 2013]. Trust must be earned and takes time, and so commitment to the community must be shown through active engagement, both before and after an individual project is initiated. Trust between an institution of higher education and its community can be built and co-participatory relationships achieved at any organizational level, but consistency of commitment is key to a successful partnership.

As with industry-focused strategic relationships, the investment of participants at high levels within each organization, as well as with those on the front lines of specific projects, ensure this consistency of commitment is communicated and understood by each partner. In support of this ideal of purposeful engagement, many successful community-based research programs have outlined a set of principles on which its community engagements must be fostered. For example, the Center for Community Health (CCH) at Northwestern endorses a set of ideals that demonstrates its commitment to the community: working meaningfully and mutually toward a shared vision, respecting diverse opinions and community goals, sharing power equitably, mutually agreeing upon goals and resources, promoting transparency in decision-making, communicating clearly, and demonstrating impact through outcomes that are meaningful and usable to the stakeholder and partner [Feinberg 2015].

While community-based research engagements have unique hurdles — more time and active involvement in the community are required to form relationships, mutually beneficial research programs, and novel funding mechanisms — the requirements of transparency and shared ownership of a relationship are equally relevant in industry strategic relationships. Adhering to a core set of engagement principles can help universities increase strategic, mutually beneficial research relationships with many different types of partners.

The business model for research universities has historically centered on providing traditional degrees and experiences in a campus-based system. The number and types of degrees conferred, the excellence and preparedness of the graduates when they join the workforce, the amount of research funding secured in awards, and the number of publications produced are all measures of performance in this model. Indeed, the reward system that flows out of these metrics influences the research that faculty pursue, including how far researchers are willing to cross over disciplinary divides toward broadly interdisciplinary programs. Elite-level research improves reputation, which attracts top-level faculty and students, and helps to secure the next round of funding – for high-ranking research universities "transform dollars into reputations, and then transform reputations into dollars" [Rouse 2018]. Without funding well above what is secured from tuition and the state (for public institutions), this combination of research and educational excellence is not reachable.

Universities also embrace other values. One is knowledge creation and the freedom to disseminate findings, unencumbered by outside interests. Industry, in contrast, may look at solutions to promote the public good as part of an intentional, strategic choice and branding, but necessarily focuses on profit. For industry, university-based knowledge generation is valuable if it helps the company profit in some way, whether through a new product, access to unique facilities, recruitment of talent, improvements to existing processes, or even increased visibility through branding. Because of the financial focus, industry may require preferential licensing terms or delayed or restricted publication. These fundamental motivation differences can, if not addressed directly, lead to organizational-level disconnects [Hillerbrand 2019]. Moreover, when receiving public funds, universities must navigate the perception of preferential private benefit (see Research Contracting, Section 5.2) to companies working with a university due to taxpayer-derived money.

We found that "entrepreneurial" and "value" in this context had no consistent meaning in our interviews. Some felt the university should increase its participatory relationships with high technology and knowledge-based industry; others were emphasizing startup companies based on the research of individual faculty members. One common concern was that faculty will be vulnerable to corporate objectives and not free to take the research where they believe it should go. This is indeed a risk, especially in situations where the university relies on an industry partner for research funding. Nonetheless, multiple studies did not find any meaningful decrease in scientific publication for academics engaging with industry. Instead, one [Perkmann 2013] discovered a possible inverse U-shaped relationship between publishing and level of university-industry engagement. Another [Schneiderman 2018] found a pattern of increasing citations per publication as the collaboration model progressed from single authorship to collaboration internal to the university, collaboration, national, international, and corporate in nature, the latter for which citation numbers were the largest.

4.3 Key Considerations

Self-Awareness

Research and technical capabilities are often quite similar across the top universities in a given discipline. Differentiation comes in the way an institution shapes its students and their experiences, the impact of its research outside its walls, and its relationship with strategic partners and across its ecosystem. For example, there are some things public universities cannot do with intellectual property assignment or certain clauses in formal relationship agreements. Varying degrees of accountability and transparency will be required, even if a partnership is not using state funds directly for its support. Private universities do not share many of the same constraints. Even so, an ecosystem is not merely an inhibitor and should not be viewed in a restrictive sense. Rather, ecosystem dynamics pose unique opportunities to be embraced and maximized.

Georgia Tech, for example, is a public university in Georgia, located in a major international logistics hub, one of the high research and dedicated institutes of technology in the nation, and a Department of Defense (DoD) University Affiliated Research Center (UARC). Our location provides us with opportunities for strategic relationships with leading industry, other universities, our community, nonprofits, and federal laboratories.

One study [Hacker 2013], observes that viewpoints differ with respect to the boundaries that define a community. For example, the community boundary can be defined geographically, by groups of people with certain characteristics, or by a shared condition or concern. Though research universities often aspire globally instead of locally, it is possible for them to engage a community through enhanced interdisciplinary research toward meaningful results.

Leaders should be honest about internal motivations, implicit values, and the consequences that realizing any particular aspirational partnership may have on its culture or actions. Certain partners and scientific disciplines will have values aligned with the fields or constituents they serve. For Georgia Tech, we must understand the balance between our aspirations for scientific collaboration on a global scale and our responsibility as a U.S. university and a DoD UARC to safeguard sensitive areas of research important to national security. When a university explicitly recognizes the forms of value it must receive, in accordance with its core mission and the direction it aspires to grow, then leaders can prioritize and strengthen existing relationships as well as seek new relationships that are a match in culture, values, value exchange, and expectation to cultivate a holistically complete portfolio.

No field, no ecosystem, and no relationship are static. When fostering long-term relationships, university leadership should consider what happens if a partnership ends for any reason [AASCU 2018]. What assets (e.g., equipment, facilities, data, intellectual property) are common to the partnership and how would they be apportioned? How long after the dissolution of a relationship would confidentiality agreements, publication restrictions, or other limitations on dissemination last? Fundamentally, do all parties share an understanding of what would constitute an end? Universities should strive to be agile, balancing commitment to a given relationship and strategic partner with the ability to pursue new engagement opportunities as the scientific landscape and global need evolve.

Organizing for Holistic Engagement

Once a university has defined its impact vision, leaders can identify the tradeoffs, priorities, and investments necessary to achieve leadership as a differentiated partner. Partnerships that cultivate research tools and modalities should not be limited to a specific research activity, which is largely a shorter-term focus. Moving from project-specific problem solving to strategic efforts aligned with grand challenges requires visions, structures, processes, and partners that support a more open-ended form of research activity. A shift — from serving as an extended workbench for sponsors to addressing strategic areas over a longer term and at a broader scale — will require different and significant demands on university-external entity relations. Specifically, embracing a grand challenge-oriented vision enabled by strategic partnerships highlights three primary considerations: building partnership types outside of the traditional contractual model, balancing focus and diversification of a research portfolio with finite resources, and ensuring a partnership survives leadership changes.

Not all partnerships need to center on research activity directly. An indicator of university research success is based on federally sponsored science and engineering research expenditures [Lombardi 2017]. This is where current perception of excellence and the playing field of competition primarily lies, but it creates a mental model that is stifling to creative thought about other partnership forms, those more active and co-participatory and with a different basis than work-for-hire or work-for-grant. For example, access to large data sets, expensive to collect and curate, has become a vital enabler of research across many disciplines. Cutting-edge, specialty facilities and research equipment are expensive. Testbeds permit evaluation of new high-technology and scientific approaches and their intersection with safety, security, application, and policy far beyond what is capable on benchtops in individual labs, potentially advancing progress significantly.

These are all valuable focal points for relationship models. Some partners may value preferred access to lifelong learning opportunities at a leading university, especially in emerging fields. Collaborators may strongly value improvement in student preparation through expanded experiences and exposure to new fields and business or government sectors. Universities must evolve along with every other evolving dynamic in the world, especially in today's rapidly changing knowledge-based economy, thinking beyond the traditional paradigms to novel structures that enable them to maximize their unique ecosystem.

Coupling the findings in this chapter with the integrated innovation model discussed in Chapter 1, innovative R&D — and its funding — may be better achieved through a more advanced model for industry-university partnerships.

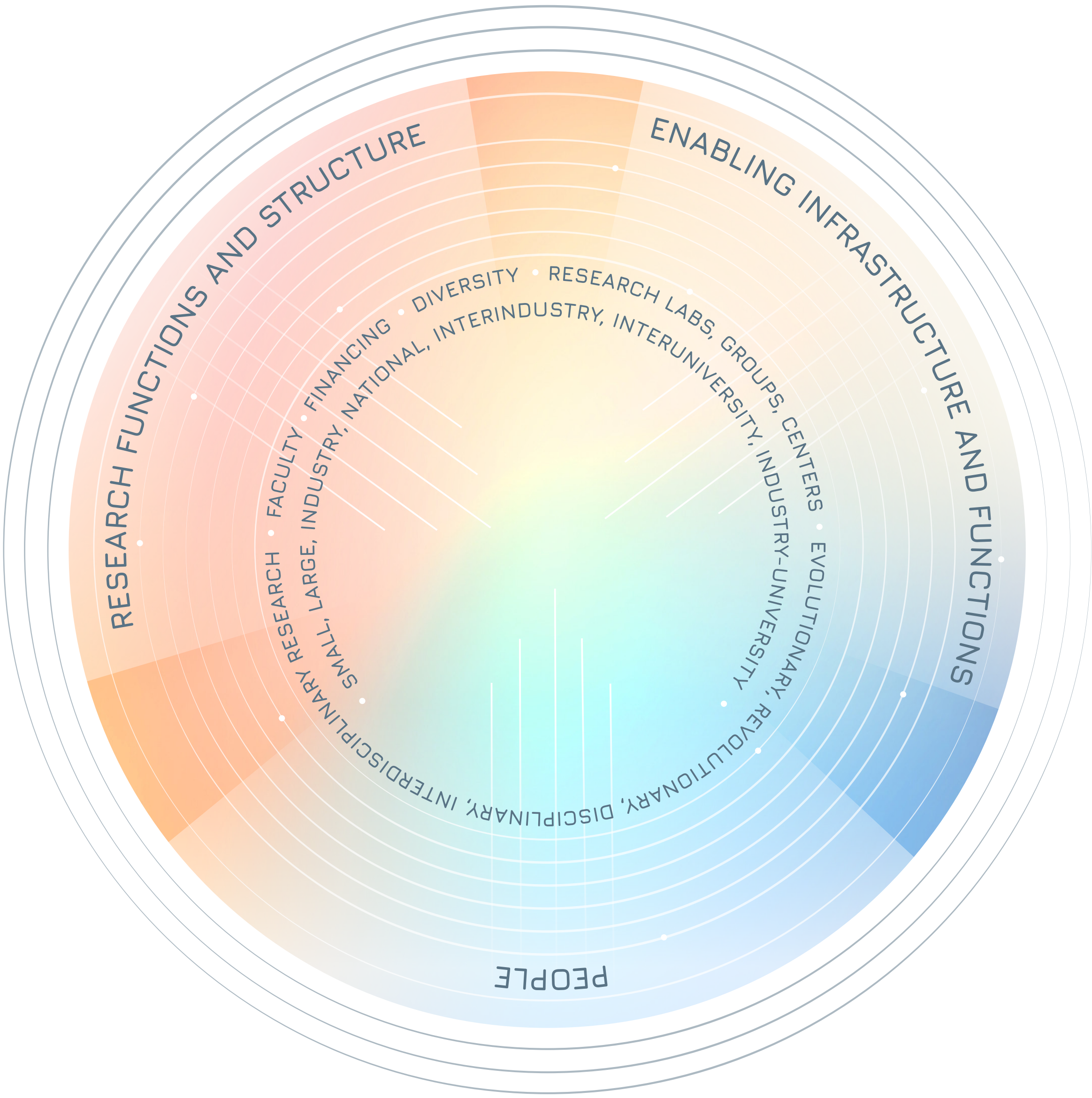
This could dramatically alter the landscape for higher education in terms of how universities create basic research capability and pursue emerging areas of research vital to a global knowledge economy. The notion of disruptive integration to accelerate science and technology is precisely what the President's Council of Advisors on Science and Technology (PCAST) envisions [PCAST 2020]. The report advocates a vision for Industries of the Future (IotF), specifically focused on emerging scientific fields and emphasizing the importance of multi-sector engagement supported by new, transdisciplinary, research-enabling structures. It calls for novel partnership models such as embedding industry partners on university campuses and creating joint academic-industry appointments for faculty and industry technologists. In all, the unifying thread is that science and technology innovation can be accelerated by radically and aggressively integrating all sectors. The commission was explicit that academic institutions bore responsibility to take a proactive, anticipatory role in creating new frameworks and incentives to support this future landscape.

Second, universities cannot excel at all things simultaneously. The PCAST report suggests an approach that emphasizes the importance of whole system, transdisciplinary partnerships to advance new scientific domains. Taking artificial intelligence as an example, a partnership need not limit its focus to novel algorithm development and robust performance under adverse conditions in a given application. Instead, taking a more transdisciplinary focus by bringing in complementary research areas may result in more successful, effective progress: AI-enabling microelectronics, trusted supply chains, commensurate advances in cybersecurity, new engineering practices to support traceability, emerging ethics in AI, novel advances in open access network technologies, and so on. An example of such a whole system, transdisciplinary focus is the C3.ai Digital Transformation Institute [C3 2020], a multi-university/industry consortium that leverages federal supercomputing resources.

Next, diversifying one's talent base must be integral to the partnership strategy. Diversity of thought is a strength, especially in research. Universities need strategies to recruit and expand domestic talent while also attracting global talent. This recruitment is realizable through active communication and tangible, visible manifestation of those values in internal culture as well as strategic partners.

Faculty promotion prospects depend on achievements as individuals; career trajectories are driven by the creation of independent bodies of scholarly work. Collaboration and the free sharing of ideas as a form of intellectual generosity only goes so far when the ingrained reward metrics focus on research output measured through direct credit for awards. This implies the need for new approaches regarding faculty evaluation and advancement. A recent description of the Highly Integrative Basic And Responsive (HIBAR) Research Alliance [Whitehead 2020], explicitly recognized the challenges inherent in trying to morph institutionalized cultural norms into a new, accepted way of practice. The HIBAR effort is striving to build a coalition of like-minded partners among other universities and non-academic collaborators to promote a shift to integrated basic and applied research activities buttressed by the structures and rewards to incentivize the vision.

CHAPTER FIVE:
THE WORLD WITHIN


RESEARCH FUNCTIONS AND STRUCTURE
ENABLING INFRASTRUCTURE AND FUNCTIONS
PEOPLE
DIVERSITY
FINANCING
FACULTY
RESEARCH
RESEARCH LABS, GROUPS, CENTERS
EVOLUTIONARY, REVOLUTIONARY, DISCIPLINARY, INTERDISCIPLINARY
SMALL, LARGE, INDUSTRY, NATIONAL, INTERINDUSTRY, INTERUNIVERSITY, INDUSTRY-UNIVERSITY

5.1 Introduction

How should the research university be organized to do the work it must do? What are the explicit and implicit functions and structures that are employed by the university research ecosystem to carry out its mission? The objective of this chapter is to explain the different organizational approaches to perform and support research. "Functions" refers to the activity or purpose for a given organizational unit. "Structures" explains how activities are directed, organized and coordinated, how information flows, and how decisions are made. Three traditional organizational structures are functional, divisional, and matrix [Devaney 2020]. Functional structures are departmentalized based on common job functions. Divisional structures comprise multiple smaller functional structures. Matrix structures combine elements of functional and divisional models and people are grouped into functional departments of specialization and further separated into divisional projects. This chapter describes a variety of structures for organizing research organizations. It also includes several examples and models for structuring partnerships between universities, federal labs, and industry.

5.2 Research Functions and Structures

Research is distinguished not just by its field, but also by its character, which can be captured across many dimensions, such as evolutionary (low-risk) versus revolutionary (high-risk) and disciplinary (fits within institutional structures) versus interdisciplinary (requires skills from different disciplines). Optimizing a mix of research across dimensions will produce, on average, better results than any single strategy [PCAST 2012]. It follows that in order to tackle complex societal issues, research universities should also strive to optimize a mix of research opportunities.

Departmental Labs and Research Groups

A defining feature of leading research institutions is the systematic combination of education and investigation [Arai 2007]. It is the university's talent pool, breadth of expertise, and infrastructure that ensures it will be a leading research institution in the years to come [UIDP 2020].

At the base of this infrastructure are "departmental" labs and research groups. These structures are operated and administered inside traditional departments, in close connection with academic activities. Specific formations vary. For example, Harvard reserves more than two dozen facilities exclusively for scientific research, and Texas A&M's mechanical engineering department has more than 40 faculty-led research labs and groups covering a range of engineering disciplines in the curriculum. These labs and groups typically support graduate student research and often involve undergraduate researchers as well.

Georgia Tech features a campus wide network of research labs in every major department, some managed by individual faculty members, making research a constitutive element of the educational enterprise on the whole. Experimental study through interconnected labs and research clusters is the organic base of teaching, learning, and discovery at every major research institution.

Interdisciplinary Research Institutes and Centers

Interdisciplinary research (IDR) refers to research by teams that integrate multiple bodies of specialized knowledge to solve problems whose solutions are beyond the scope of a single discipline or field [NAP 2005]. These research units have a variety of names — center, institute, laboratory, initiative, or program. We use the terms center and institute throughout this section to describe IDR units within the university that exist outside the traditional departmental structure.

Structures

A comprehensive look at interdisciplinary research structures is included in *Facilitating Interdisciplinary Research* [NAP 2005], which compiles data from 100 IDR activities, including academic, national labs, industry, interindustry, interuniversity, and university-industry. Table 5.1 summarizes the characteristics of IDR centers from this study.

Table 5.1 Interdisciplinary research structures (NAP 2005)

Small Academic (< 10 persons)
» Bottom-up initiation » Research is primary; training is byproduct » Loose management structure » Many participants have disciplinary research commitments as well
Large Academic
» Bottom-up initiation, top-down incubation and management » Research and training components » Management by directors who report directly to vice president for research or equivalent » Tend to be permanent features; new building, instrumentation » Some centers "co-hire" faculty, but faculty are affiliated with departments » Space allocation: mix of permanent and "hotel" facilities
Industry
» Top-down, product-driven research » Focused on research, not training » Structured management » Discrete timelines and end points » Fluid movement of researchers between teams
National Laboratories
» Blend of top-down, mission-driven research and bottom-up initiation » Research and training components » Structured management » Discrete timelines and end points » Fluid movement of research between teams
Interdisciplinary, Interuniversity, University-Industry
» Top-down, societal needs-driven research (can be basic and applied) » Research and training components » Part-time directors with advisory boards » Often initiated with large starting grants (such as National Science Foundation-funded Science and Technology Centers and Engineering Research Centers) » Except for seed grants, faculty must provide own grant money » Programs may offer an "immersion" IDR opportunity

The management structure of universities reflects a unique combination of attributes, and includes aspects of a functional structure, but also divisional structure. IDR centers in leading universities typically aspire to produce matrix-type organizations across the enterprise, bringing expertise from separate colleges and research organizations, including support staff, to help the center execute.

Organizing Model

Definitions for IDR centers and institutes vary significantly and often convey little or no information about their scale, scope, or degree of permanence [EAB 2009]. More important than a center's designation is where it falls within the university hierarchy. Tiering clarifies the institution's top priorities and ensures that the appropriate level of oversight and support is targeted at each level [EAB 2009]. High-performing centers can be moved up the hierarchy as they meet certain performance standards. Figure 5.1 illustrates one approach to differentiate four organizational levels based on breadth of research, funding sources, and reporting line.

Figure 5.1 Names and characteristics of centers encountered in Council interviews [EAB 2009]

	Research Focus	**Funding Source**	**Reporting Line**
University-Wide Institute	» Long-term university priority » Multiple colleges and disciplines	» President, provost, and major gifts » Extramural funding	*Provost, Chief Research Officer*
University-Wide Center / University-Wide Center	» Shorter-term, project specific	» Seed funding from university Institute » Extramural funding	*University Institute Directors*
College-Based Centers	» Disciplines within one college	» Seed funding from dean » Extramural funding	*Dean*
College / College Department-Based Centers	» Highly discipline-specific	» Seed funding from dean » Extramural funding	*Department Chair*

These organization levels are very similar to the work developed at Georgia Tech to define IDR [GT 2015] which included four types of organizations: Lab/Group, Center, Interdisciplinary Research Center (IRC), and Interdisciplinary Research Institute (IRI). Similar to the department-based centers in Figure 5.1, a Lab/Group represents the research of a single faculty member and their students and postdocs. A Center supports multiple faculty engaged in collaborative research, as represented by college-based centers above. An IRC supports interdisciplinary research spanning two or more units and addresses a strategic opportunity, similar to the university-wide center in Figure 5.1. Lastly, an IRI spans two or more units addressing a strategic opportunity, and includes economic development, thought leadership, and industry and external partner relationship management.

The differentiation between Lab/Group, Center, IRC and IRI provides institutions with structural approaches to expand a university's research portfolio (both in terms of technology readiness levels (TRL), infrastructure, or industry partnerships), as well as policies which can be created for establishing, reviewing, and sunsetting centers; priorities can be established for allocating space and making major investments; decisions can be made for allocating dedicated versus shared administrative support; interdisciplinary hiring initiatives can be developed to create maximum impact; and training and mentoring programs can be established to develop new leaders in the institution. This model also enables institutions to consider structures for creating university-wide centers or IRIs. For example, some may grow out of college-based centers, organizing around strategic research initiatives. Others may quickly form in response to an emerging need, such as a global pandemic.

This organizing model can also help reduce the administrative burden on self-organizing groups, where the work may be smaller than a full-scale Center but larger than a single investigator's Lab/Group [PCAST 2012]. For example, the University of California San Diego's Interdisciplinary Collaboratories initiative provides fellowship support for groups of students (undergraduate, graduate, or professional) who work jointly under the supervision of an interdisciplinary faculty group [UCSD 2020]. Another example is the University of Alabama at Birmingham's "virtual centers" — units that use resources on loan from other units and reset their budgets every three years based on rigorous performance evaluations [EAB 2009], resulting in a dynamic portfolio of centers that is aligned with the university's research focuses.

An example of an IRI that covers a broad spectrum of activities across TRL levels and partnerships is the Institute of Translational Health Sciences (ITHS) at the University of Washington. The ITHS is an interdisciplinary research "collaboratory" funded by the National Institutes of Health. A goal of ITHS is to advance translational research by taking medical discoveries from the laboratory into the clinic and into the community. This requires the collaboration of many groups: academia, industry, nonprofit agencies, government, and the community. ITHS programs and resources fall into one of three categories: innovative research partnerships, which are programs to develop partnerships and research links with communities, private partners, and governmental partners; research resources, which are programs to provide critical resources needed by translational researchers, from basic science to clinical outcomes to research; and educational and career development programs to provide education in all aspects of translational research as well as formal degree-

Applied Research Units

Applied research centers or institutes conduct open, proprietary, or classified projects that are more strictly controlled. Applied research units support a variety of core activities, including: interdisciplinary training for students; capacity-building technical assistance to government agencies and organizations; economic development; transforming basic research into commercial products and processes; transferring technology to industry through joint research with companies, licensing of technology, sale and auction of intellectual property, and spinoff of startup companies; and dissemination of leading-edge knowledge and practices [NRC 2013]. Applied research units receive external funding through grants, contracts, and cooperative agreements. Some also have a base of financial support from teaching professional development courses.

A special category of applied research units within the university ecosystem is the University Affiliated Research Centers (UARCs). UARCs are not-for-profit entities sponsored and primarily funded by federal agencies, the U.S. Department of Defense (DoD) in particular, through a long-term, strategic relationship with the U.S. government. They conduct R&D across multiple research classifications to provide federal agencies with capabilities that cannot be effectively met by the federal government or the private sector alone [Gallo 2020]. In addition, UARCs function as trusted advisors for the government, operating in the public interest with objectivity and independence.

Today, there are 13 DoD-funded UARCs, tasked with providing DoD direct access to scientific expertise in emerging technical areas to quickly apply basic scientific knowledge to their mission-critical problems [GAO 2018]. Examples of DoD UARCs are Johns Hopkins University Applied Physics Lab, Penn State University Applied Research Lab, and Georgia Tech Research Institute (GTRI). UARCs affect university R&D expenditures significantly [NSF 2019]. In 2018, six universities with UARCs were ranked in the top 25 for R&D expenditures, including Johns Hopkins, Penn State, and Georgia Tech. While R&D funding is one measurable attribute associated with UARCs, the impact of these organizations on their home university is far more extensive. They have the potential to play a greater role in DoD's outreach to companies and organizations not traditionally affiliated with DoD [DBB 2016]. This unique expertise can benefit universities in working with industry and transitioning technology into the user community.

Developing trends in the scope and function of applied research units show a growing demand for expanded services. For example, the Illinois Applied Research Institute performs translational research focusing on the development and validation of technologies and serves as a facilitator between industry and the university's engineering campus. The Texas A&M Engineering Experiment Station solves problems through applied engineering research, technology development, and collaboration with industry. Arizona State University's ASURE lab serves as a tech-translation incubator. Applied research units also provide unique opportunities for students to gain real-world expertise to complement their academic pursuits. Many UARCs have established undergraduate and graduate research assistantships or internships, providing students with opportunities to conduct research on a variety of topics with real-world applications. Examples include the Research Internships in Science and Engineering (RISE@APL) program at Johns Hopkins, Penn State's Open Diversity Outreach Opportunities in Research (DOOR), and GTRI Undergraduate Research Internship Program (URIP) at Georgia Tech.

University-University Collaboration

Collaboration among universities is a powerful mechanism for tackling bigger and more complex problems. This section provides several models and examples of these collaborations.

The NSF Engineering Research Centers (ERC) support convergent research, education, and technology translation at U.S. universities. These ERCs create "interacting foundational components that go beyond the research project, including engineering workforce development at all participant stages, a culture of diversity and inclusion where all participants gain mutual benefit, and value creation within an innovation ecosystem that will outlast the lifetime of the ERC" [NSF website].

Another model is the NSF Big Data Innovation Hubs program. The data hubs play four key roles: Accelerating public-private partnerships between industry, academia, and government; growing R&D communities that connect data scientists with domain scientists and practitioners; facilitating data sharing and shared cyber infrastructure and services; and building data science capacity for education and workforce development [BD Hub 2020].

The National Institutes of Health Clinical and Translational Science Awards program supports a national network of medical research institutions — also called hubs — that work together to improve the translational research process. The hubs collaborate locally and regionally to bolster innovation in training, research tools, and processes, and to enable research teams to tackle scientific and operational problems in clinical and translational research.

The Big Ten Academic Alliance includes 14 universities that share expertise, leverage campus resources, and collaborate on innovative programs. Faculty benefit from shared network infrastructure and leadership potential, and Alliance members saved $37 million in library licensing and $100 million in combined purchasing power over a five-year period [BTAA 2018].

A different example of university-university collaboration is the Menus of Change University Research Collaborative (MCURC). The MCURC is a collaboration of scholars, food service leaders, executive chefs, and administrators. The MCURC is a nationwide network of 60 colleges and universities that use campus dining halls as living laboratories for behavior change [MCURC 2020]. The Collaborative advances research focused on plant-forward diets, food waste reduction, and drivers of consumer food choices to transform eating habits and food systems.

University-National Lab Collaboration

Universities also have numerous partnership opportunities with national laboratories. The U.S. Department of Energy (DOE) has 17 national laboratories whose purpose is to advance science and technology to fulfill the DOE mission. These laboratories span a range of R&D topics, from clean energy to particle physics to human health, materials science, and biology.

National laboratories are administered and managed by external organizations (with the exception of National Energy Technology Lab), and some are located within and operated collaboratively with universities. In these joint operation relationships, faculty members hold appointments, laboratories support students and postdoctoral researchers, and they partner on major research efforts. Examples of these joint operations include: Lawrence Berkeley National Lab at the University of California, Berkeley and the Oak Ridge Institute at the University of Tennessee. A number of models for collaboration and strategic alliances have been developed.

These alliances represent expansive research relationships governed by a longer-term commitment to collaborate in interdisciplinary subjects. For example, Sandia National Laboratory's Academic Alliance program consists of major partnerships with five universities (including Georgia Tech), and also has a program focused on historically Black colleges and universities [SNL 2020]. Similarly, Oak Ridge National Laboratory (ORNL) has developed strategic relationships with seven universities [UT-Battelle 2020] (including Georgia Tech), and developed the Oak Ridge Associated Universities program, a consortium of more than 120 universities. ORNL has also developed a joint appointment program with universities in Tennessee called the Governor's Chairs program. Funded by the state and ORNL, the program attracts top researchers to work jointly across both institutions in selected areas.

Other models of university-national lab partnerships include joint research-education programs and joint operations. For example, the National Renewable Energy Laboratory and the Colorado School of Mines have developed an Advanced Energy Systems degree program.

University-Industry Collaboration

Policymakers have long regarded collaboration between industry and research institutions as fundamental to global innovation and economic development [Papermaster 2008)]. Below are a number of such engagement models.

<u>Triple-Helix Engagement.</u> The convergence of government, universities, and industry in a tripartite collaboration can take place in multiple ways. A prominent example is Manufacturing USA, the network of 14 institutes led by heads of government, industry, and universities and administered by the Advanced Manufacturing National Program Office [America Makes 2020]. Another example is the National Institutes of Health National Center for Advancing Translational Sciences, which initiates collaborations among government, academia, industry, and nonprofit patient organizations to develop translational interventions that improve healthcare [NIH 2020].

<u>Corporate Initiatives.</u> These stem from strategies constituted directly by corporations for the purpose of leveraging intellectual resources to achieve broader impact than could otherwise be achieved by the corporation alone. A recent example is Google's announcement concerning Covid-19 research in collaboration with 31 universities and research institutes [Dyrda 2020].

Corporate Affiliation Programs (CAPs). CAPs provide structures for corporations and their representatives to interact and collaborate with academic researchers and students in areas of common interest. CAPs include multiple corporate members to create a forum for a specific research area, to connect students with industry, and to connect companies with the academic community. Examples include relationship-focused CAPs, such as the Allen School of Computer Science and Engineering Industry Affiliates Program at University of Washington, and research-focused CAPs like Carnegie Mellon University's CyLab.

Corporate Partnerships. A large percentage of university-industry collaboration takes place by means of project-specific engagements governed by bilateral research contracts. There is a growing trend among industry and research institutions to create clearly defined frameworks for engagement, increasingly through strategic partnerships with a select number of carefully chosen universities. Such partnerships allow these companies to develop joint programs in which they work closely with researchers over a sustained period. In many cases they invest in a joint laboratory or in setting up their own research center on a campus. Examples include the Siemens Knowledge Innovation Centers, the Boeing Strategic University Program, the BMW University Cooperation Program, and the BP Energy Biosciences Institute.

Corporate Innovation Centers. These comprise a range of concepts designed to co-locate corporate researchers and developers, university researchers, and startups to promote exposure and collaboration. Research-driven constructs include Penn State Behrend's Advanced Manufacturing and Innovation Center and the Children's Healthcare of Atlanta Pediatric Technology Center at Georgia Tech. Business-focused constructs include MIT's Kendall Square Initiative. Finally, student-centered initiatives allow companies to engage students on campus or on corporate sites to work on customized solutions for specific problems in unique, applied-work experiences, such as Arizona State's Practice Labs.

Competition for industry-funded research is fierce. Among the top 50 research universities in terms of total research funding, the top 10 have, on average, five times more industrial support for university research than the bottom 10 [Atkinson 2018]. These leaders have either strong biomedical research programs, like Duke or Stanford, strong engineering programs, like MIT or Georgia Tech, or both, like PSU [Atkinson 2018]. There is an unmistakable correlation between the top research universities in industry funding and the top research universities in research funding overall [NSF 2019]. This finding supports the theme that government-university-industry activity operates as a feedback continuum. Government and industry do not merely accept this dynamic — they welcome, support, and rely upon it [PCAST 2020].

5.3 Enabling Infrastructure and Functions

This section examines infrastructures and functions that support university research ecosystems in fulfilling their research missions.

Sponsored Research Practices

Research administration (RA) has been recognized as a specific organizational structure within research universities. It is the middle line between the university president, or the president's delegate for research governance, and the faculty, scientists, and students who perform the research [Kaplan 1959]. Crucially, the object of the research enterprise, scientific investigation, depends upon expressly non-scientific operational aspects in order to ensure the health and integrity of the program [Kaplan 1959]. In the contemporary era, the sheer scale and scope of research activities at major universities and their interface with sociological, political, legal, institutional, and economic forces have created specific bodies of knowledge and procedure that must be mastered, monitored, and assessed independently of the scientific investigations that they enable and protect. These resources are instantiated within RA. Institutions' organizational RA structures vary, but there are responsibilities that must be satisfied regardless of organizational structure. These spheres include:

Research Relationship/Business Development

A fairly recent trend within the academic research ecosystem is the research or "business" development office (Development Office), which allocates resources specifically to the cultivation of relationships with potential sponsors and collaborators to improve funding, increase capital resources, and enhance and expand networks to achieve university research goals [Ross 2019]. In a workshop hosted by UDIP, 86% of more than 30 participating universities reported operating centralized Development Offices, in conjunction with decentralized researcher-managed relationships on an ad hoc basis [UIDP 2020]. Virginia Tech exemplifies an alternative model, and centralizes the management of all industry relationships, reserving the right to transfer relationship management to research departments as appropriate [VT 2020]. A substantial majority of the organizations interviewed for this study, both sponsors and peer institutions, favor a centralized function for connecting sponsors with researchers and tracking systems that make overall activity levels and key personnel between the research institute and its collaborators visible.

Research Integrity

"The public will support science" only if it can trust the "institutions that conduct research" [NRC 2002]. The modern research enterprise is complex, supporting far-ranging activities that transcend disciplinary, institutional, and national boundaries. This serves to multiply the responsibilities of "managing integrity at scale." Reliance on the competence and character of individual researchers or local operations within units and labs is insufficient, as the actions of single individuals can have far-reaching consequences for the larger organization. Universities implement both top-down and bottom-up strategies around the conduct of sound research; continuously educating researchers in the elements of responsible research, ethics, security, and safety; establishing organizational structures to manage compliance; establishing a culture that inspires integrity; and developing and maintaining processes to evaluate and enforce positive behavior [LERU 2020].

A sine qua non of any serious system of integrity is a centralized office of research integrity and assurance (ORIA). Common domains include conflicts of interest, research safety standards and protocols, ethics in human and animal research methodologies, and export control. New risk vectors in foreign influence and espionage are the latest to receive heightened investigation [UCA 2019].

Research Contracting

Sponsored research contracting carries a number of risk factors. Federally sponsored research activities must conform to federal rules while avoiding conflicts with state law. The complex interplay of the two regimes requires knowledge and expertise. Industry contracting is equally complex. Industry contracts are subject to state law in all cases, yet are not subject to imposed federal contracting frameworks. This invites negotiation on every term. An additional layer of complexity emanates from federal tax law, as most educational institutions are subject to regulation under Section 501(c)(3) of the Internal Revenue code of 1986, as amended. A governing precept under Section 501(c)(3) is the "private benefit doctrine," which prohibits a nonprofit entity from conveying benefits to a private entity that are any more than incidental to the nonprofit's authorized activities. The private benefit doctrine runs the length of all research contracts between nonprofit institutions and all third parties, affecting nearly every major heading of a sponsored research agreement.

Beyond the general complexity of negotiating the contracts that underpin industry-sponsored research agreements, each contract carries its own challenges based on the uniqueness of the underlying project. For example, some projects are in areas with greater likelihood of marketable intellectual property, while others enact more fundamental investigations with a lower probability of invention disclosure. Similarly, some projects rely on industry-owned or controlled background intellectual property, while others have university-owned or government-funded background intellectual property as a basis. In all these cases, the impact on contracts is significant, potentially affecting nearly every section of an agreement.

Simultaneously, each negotiation requires an understanding of the "big picture" — that is, the overall impact of each agreement on departments, individual faculty and students, and the university as a whole.

A related responsibility is helping industry sponsors understand the academic landscape, which is quite different from working with commercial partners. For example, a university's need for indemnification for a sponsor's commercial use of intellectual property is the opposite of a company's usual expectation to be indemnified for imperfections in the intellectual property it makes use of. Other terms, like a university's mission of open dissemination of knowledge through publication, can be at odds with industry's need for secrecy around research and development efforts.

A practice employed by some universities is the use of standard contracting models. These models present a framework for universities to address critical terms and conditions and eliminate the need for companies to struggle in developing forms that fall outside the lines of their commercial activities. Negotiators of industry-sponsored research agreements can access resources from the University-Industry Demonstration Partnership (UIDP) in Columbia, South Carolina. UIDP has developed model forms known as the Contract Accords [UIDP 2020a]. The set consists of 16 contracting topics, including statements of work, indemnification, publications, background and foreground intellectual property, export control, research gifts, specialized testing and services, and conflicts of interest. Georgia Tech is a major contributor to this effort.

Georgia Tech has also created a series of published forms known as the Contract Continuum [GT 2020b], designed to enable industry sponsors to view four possible ways of engaging with the university. The unifying theme is a modal allocation of intellectual property and academic freedom rights that correspond to the maturity of the science and/or technology under study: a Basic Research Agreement for earlier stage fundamental investigations, an Applied Research Agreement for mid-stage proof-of-concept collaborations, a Demonstration Research Agreement for later stage improvements and/or expansions of existing technology, and a Specialized Testing Services for the validation of proposed use cases. Other notable programs include the University of Minnesota's MN-IP program [UMN 2020] and Cornell's Gateway to Partnership Program [CU 2020].

Research Accounting and Financial Management

Financial risk and compensation for sponsored research activities exist largely outside of the institutional budget for educational activities. Schools that receive federal funding for research are subject to an entire regulatory regime under 2 CFR § 200. Centralized management of financial effects of sponsored research activities through RA is a standard best practice to ensure compliance.

IP Management and Commercialization

A critical process in the U.S. innovation ecosystem is the transfer of emergent intellectual property to the public. Technology Transfer Offices (TTOs) are the standard structures in major research institutions serving to evaluate, protect, manage, and disseminate its intellectual property [Nag 2020]. TTO activities include identification of protectable intellectual property, determination of ownership, attachment of property rights at law, determination of the appropriate method of dissemination, determination of appropriate measure of compensation for third-party rights, if any, and negotiation of third-party rights, as applicable.

The Bayh-Dole Act imposes a comprehensive framework for the allocation of intellectual property arising from federally funded research. Standard university policies arising from this nexus are:

Respect of the inventor's ownership rights under U.S. patent law [COGR 1999]. This requires TTOs to have reliable means of discovering inventions through a sound internal disclosure system and making the correct legal analyses of inventorship. Universities must also understand and take the actions required to ethically and legally obtain ownership rights from individual inventors before attempting to exercise property rights for the university's own purposes.

Allocation of third-party rights via licenses rather than outright sale or assignment [COGR 1999]. The intent of Bayh-Dole is for universities to retain ownership of inventions in view of universities' particular mission to disseminate research results, including intellectual property, for the public good [NRC 2011]. Universities lose the ability to regulate the development and deployment of technology when ownership is assigned. Accordingly, the overwhelming majority of leading universities that work extensively with industry retain ownership of intellectual property and offer licensing rights to intellectual property resulting from sponsored research efforts [UIDP 2020c].

Sharing royalties with inventors. This is standard practice among universities that work extensively with industry [MIT 2020], [GT 2020b]. It has the added effect of standardizing metrics to market norms to avoid fairness concerns for inventors. Upfront licensing compensation models for sponsored efforts are still in the minority among leading research institutions [UIDP 2020c]. Among those institutions that offer upfront compensation models, metrics are typically based on historic data that are thought to generate reliable averages [UIDP 2020c].

It is important to remember that there are several methods and goals for the dissemination of IP. Most institutions reflect the "entrepreneurial university" model [Walshok 2014], whose goal is the efficient and broad dissemination of university-generated ideas and technologies across a variety of modalities, including publication of results, open source release and development, third party licensing, and startups [NRC 2011].

A useful range of measures includes number of publications, invention disclosures, patents issued, and licenses issued; average revenue per license; and volume and scope of organic development efforts such as startups and accelerators represent. Data shows that universities with high engagement in federal and industry sponsored research tend to reflect correspondingly high technology transfer outputs [Nag 2020].

Interdisciplinary Work

While the incentives to participate in interdisciplinary work are many, there are also hurdles to overcome. Disincentives can include: units do not value or reward interdisciplinary work; the annual review process doesn't respect the time to develop interdisciplinary collaborations; tenure models lack incentives for interdisciplinary work; academic turf wars; and difficulties in communicating across disciplinary cultures [UD 2011].

A consortium of 10 universities held a conference on Fostering Interdisciplinary Inquiry to understand the barriers [Dubrow 2008] and discussed eight functional areas where institutional policies and practices can hinder or facilitate interdisciplinary activity: academic administration and faculty governance; education and training; research; development and fundraising; finance and budget; space and capital planning; equity and diversity; and collaborative technologies. Pertaining to the functional area of research, other details include: whether the university has IDR faculty positions and how they are assigned; the university's infrastructure for producing and enhancing large interdisciplinary grant applications; the allocation of overhead return and scholarly credit for grant awards at the university; and institutional efforts to foster IDR and successful IDR collaborations or centers [Dubrow 2008]. In this section, we consider four areas — IDR positions, interdisciplinary hiring, financial incentives, and culture of collaboration — and how institutions foster inclusive communities for interdisciplinarity.

Interdisciplinary Research Positions

Traditional approaches to collaboration across units, including joint, courtesy, and adjunct appointments, are focused on teaching. While these roles are important for the execution of mentoring and advising students in particular colleges, they do not inherently foster collaboration, nor create a culture of interdisciplinary collaboration. In fact, they often create barriers between tenured and non-tenured faculty. Non-tenure, interdisciplinary leadership roles can serve as a reward for past accomplishments, and also as an incentive to continue serving the university's mission to strengthen interdisciplinary teaching and research. A variety of non-tenure roles have emerged to break down these barriers, ranging from distinguished professors to fellows to new campus leadership roles in academic units. A few are described below.

Brown University's professors-at-large invite exceptional scholars to participate in the intellectual and academic life of the university. The JHU Bloomberg Distinguished Professors bridge academic divisions, conduct and stimulate innovative research that crosses disciplinary boundaries, and train a new generation of native "interdisciplinarians" [JHU 2020]. Fellow-in-residence positions devote time to projects within an interdisciplinary community; examples include the Center for Ethics at Harvard and the Obermann Center at the University of Iowa.

The Michigan Society of Fellows selects outstanding applicants for appointment to three-year fellowships in the humanities; the arts; the social, physical, and life sciences; and in the professional schools [UMI 2020c]. The Princeton Society of Fellows in the Liberal Arts is an interdisciplinary group of scholars in the humanities, social sciences, and selected natural sciences. Fellows are appointed for three-year terms to pursue research and teach half-time in their academic host department [PU 2020].

Creating opportunities to more tightly connect academic units and applied research organizations on campus through leadership roles can help break down boundaries and enable connections across the research enterprise. These types of positions signify the importance of translational research relationships; titles include Associate Chair for Applied Research, Partnerships, and Outreach; Associate Dean for Applied Research and Innovation; Associate Dean for Industrial Relations; Associate Dean for Outreach; and Associate Dean for Research and Entrepreneurship.

Hiring

In the pursuit of IDR, institutions are often impeded by traditions and policies that govern hiring, promotion, tenure, and resource allocation [NAP 2005]. The challenge is how IDR centers, which generally operate without the ability to hire faculty or grant degrees independently, attract faculty and students.

Joint appointments are a traditional approach; they can serve as a bridge between disciplines, increasing awareness and building collaborations, and can also be a form of cost sharing. However, there are challenges in promotion and tenure, apportion and credit of time to units, and divided loyalties. To address this, Michigan State has posted best practices for managing joint appointments [MSU 2015].

Co-hiring between colleges and centers is another approach. The University of Washington Program on the Environment (PoE) is a horizontally organized university-wide institute. The PoE does not have faculty of its own. Instead, it brings together faculty and students from across the university to augment existing programs and offer integrated, interdisciplinary programs. Instead of allocating faculty lines, the university president sets aside a permanent budget that the PoE uses to hire faculty in collaboration with departments and schools. Co-hiring enables the university to benefit from the presence of scholars who would not readily fit into preexisting departmental frameworks [NAP 2005].

Cluster hiring is a third approach, which enables an institution to build a strength in a targeted area that cuts across multiple departments and can be used to attract star researchers. While several challenges have been documented on this hiring approach [Eyrich 2020], a number of universities have a cluster program. For example, the cluster hiring initiative at Wisconsin was launched in partnership between the university, the state, and the Wisconsin Alumni Research Foundation [UWM 2020].

Financial Incentives

Interdisciplinarity can begin with simple steps and behaviors that promote the culture and practice of collaboration. Funding opportunities to work across disciplines and departments can take many forms. For example, fellowships, indirect cost return, and accelerator/seed grants that support basic, application-driven, and interdisciplinary research are incentives that can help change behavior [PCAST 2020].

Interdisciplinary faculty and students are hard to attract because they don't easily fit in a single college, but have expertise across many colleges. Further, it is hard to recruit students in non-STEM units due to limited research funding. Thus, universities are creating fellowship programs to engage students in IDR. The Stanford Interdisciplinary Graduate Fellowship awards three-year fellowships to doctoral students engaged in IDR [Stanford 2020c]. The University of Minnesota Interdisciplinary Doctoral Fellowship enables Ph.D. students engaged in IDR to study with faculty at one of the university's interdisciplinary research centers or institutes [UMN 2020].

Revising and standardizing systems of indirect cost return, overhead return, and cost-sharing arrangements to make them simpler, explicit, and more equitable is another financial incentive for promoting IDR. Several examples of these approaches are described in [Dubrow 2008].

Offering seed grants to scholars from different disciplines can be used to start conversations, fund students, or jointly develop research proposals. Over half of the institutions represented in the Facilitating Interdisciplinary Research survey indicated they provide “venture capital” for interdisciplinary work. Amounts ranged from $1,000 to $1 million, but centered at $10,000-$50,000 [NAP 2005]. Grant duration varied, but most tended to be one- to two-year awards.

A key challenge in such programs is balancing broad distribution with a small number of strategic priorities. A number of models have been developed. The Stanford Bio-X interdisciplinary seed grants fund proposals that enhance research related to bioengineering, biosciences, and biomedicine [Stanford 2020b]. They award approximately $4 million every other year in the form of two-year seed grants at $200,000 per project. The University of Michigan's Mcubed seed grant program [UMI 2020b] calls for faculty from at least two different campus units to form a collaborative trio, or “cube,” and request either $15,000 or $60,000 to advance their idea.

Culture of Collaboration

A collaborative interdisciplinary culture needs to cross academic units, applied research institutes, government partners, and industry. A number of methods can be used to create this culture, including centers, degree programs, co-advising students, and campuswide initiatives that foster innovation. A few examples are described below.

The University of Maryland, Baltimore County (UMBC) Center for Interdisciplinary Research and Consulting (CIRC) is a consulting service for mathematics and statistics. The CIRC supports interdisciplinary research for the UMBC campus and general public, providing services from free initial consulting to long-term support for research programs [UMBC 2020]. The CIRC also strives to provide mathematics and statistics students with consulting experience for industry and academia jobs.

The University of California, Berkeley and Lawrence Berkeley National Lab have partnered on a number of efforts such as the Joint BioEnergy Institute, as well as partnered with the University of California, San Francisco on innovative brain research. This collaboration provides UC Berkeley personnel with ongoing access to cutting-edge technology and opportunities to collaborate with the national lab [UCB 2020]. These partnerships have led to numerous Nobel Prizes and scientific breakthroughs.

The Colorado School of Mines and the National Renewable Energy Laboratory's (NREL) Advanced Energy Systems have partnered on M.S. and Ph.D. degree programs. The Mines NREL program provides researchers with a broad background in the energy sector, expertise in the selected area of focus, and dedicated research under the guidance of Mines and NREL advisors [UCSM 2020]. Similarly, the Draper Labs Fellow program gives graduate students the opportunity to conduct thesis research at Draper with their faculty advisor (there are 10 participating universities, including MIT) and a member of Draper's technical staff.

In 2012 the University of North Carolina at Chapel Hill developed a two-year campuswide academic theme called "Water in Our World" [UNC 2012]. Tackling this key issue facing society was a top recommendation in the institution's strategic plan, and this initiative enabled faculty to share ideas and collaborate across disciplines, as well as with other local universities [COACHE 2014].

5.4 People

Sustaining the modern research enterprise requires mobilizing, empowering, and supporting all who are willing and able to serve.

Diversity and Inclusion

Enhancing the diversity and inclusion of underrepresented groups in the academic enterprise encompasses both equity and the overall quality and outcomes of scientific work [NASEM 2020]. STEM disciplines have lower representation of women and people of color in tenure-track and leadership positions. A recent NAS study on this topic emphasizes the need for an intensive, data-driven approach to understanding, addressing, and assessing initiatives within institutions.

A key first step is access to data. Institutions typically track research metrics at broad unit levels without incorporating demographic details relating to research operations. Data tracking and related assessment efforts are typically siloed, and sponsored research program data are separate from human resource data. Data systems within institutions can also be expanded to incorporate demographic data (including rank) with various research activity data (seed funding, proposals, cost sharing, awards, center affiliation, engagement in collaborative teams, leadership, and publications, among others). An effort currently underway at Arizona State University [ASU 2020] studies interdisciplinary production of the full faculty using bibliometric data through an intersectional lens, that is, the ways in which faculty experiences are shaped by gender, race, ethnicity, foreign-born status, sexual orientation, disability, rank, and discipline.

Leadership Training

Management and leadership competencies in faculty and staff are necessary for research institutions to thrive. Management knowledge and skills are necessary to control and provide the processes that enable research and creativity.

Management of administrative process improvements and other efficiencies enable creativity and innovation that are at the heart of research universities.

Models for leadership development exist, ranging from on the job training and formalized office-level or university-wide programs, to tapping into external organizational offerings. Examples of universities with modules for academic and grant management or basic and advanced leadership development include Virginia Tech [VT 2020], University of Michigan [UMI 2020], and Tufts University [Tufts 2020a]. These modules encompass coaching and mentoring, basic budgeting and day-to-day operations, leading change, and building and leading a diverse community. Programs that administer modules targeted specifically for effective leadership in STEM research settings tend to be affiliated with medical schools. Examples of such programs include those at Tufts [Tufts 2020b], Duke [Duke 2020], and Stanford [Stanford 2020].

Research Faculty

University research is conducted by both tenured and non-tenure track faculty. Tenure-track academic positions commonly include teaching, research, and service, with ranks that include Assistant, Associate, Full, and Distinguished Professor titles. In contrast, non-tenure track faculty may be focused entirely on research, and are often exclusively funded by grants and contracts. Common research titles include scientist, engineer, and associate, and can be further classified by rank (e.g., junior, senior, principal). For simplicity, we will distinguish these types of university researchers as Academic Faculty (AF) and Research Faculty (RF).

Research Faculty are critical in enabling universities to build and optimize research capacity. They appear in universities in two ways. First, they are hired within academic colleges and may lead projects, or support AF on their projects. As part of a college, they may also take on additional responsibilities such as teaching and advising students. Second, RF are hired by applied research institutes or centers, where they work primarily with other RF on projects.

While conducting research is a common activity of AF and RF, the goals for AF and RF are often quite different, and so are evaluation metrics and promotion processes. For example, AF focus on teaching and training students in addition to conducting research, whereas RF focus on project development, deliverables (software and hardware), and program management. A common challenge is the implicit creation of “pecking orders,” in which RF are not seen as peers or the same caliber of researchers. Because RF are often 100% paid by contracts, they often do not receive comparable professional or career development opportunities (such as organizing conferences or writing papers that are not direct contract deliverables), or have deliberate reflective time for development of new ideas, as AF. This can lead to RF losing opportunities and even being terminated, implying a significant level of vulnerability in these “soft money” roles [Ulm 2014].

A number of efforts have been directed to improving the system of support, promotion, review, and definition of academic rank for non-tenure track faculty. For example, Penn State established new ranks for non-tenured teaching and research faculty, including Assistant Research Professor, Associate Research Professor, and Research Professor. This signals a peer relationship between AF and RF, while differentiating their areas of focus. Similar research ranks have been established at Carnegie Mellon University and Cornell.

Other efforts include building community in RF across different units, optimizing promotion criteria for distinct RF roles, including RF in broader university leadership development efforts, and creating dedicated financial resources for career-enhancing activities.

Recognition and Rewards

Universities take pride in receiving accolades through winning external honors and awards, as recognition by external communities is broadly viewed as an indicator of research university success.

Major research universities have their own internal recognition and rewards programs as well. Internal publicity is a powerful tool to build morale and a positive sense of community among colleagues. Most major universities have a large number of internal awards programs, and an annual awards ceremony to recognize their researchers in various categories (e.g., Best Paper, Teaching Excellence, Outstanding Program Development). Some university systems bestow awards recognizing lifetime achievement. Often, such lifetime achievement awards come with extra compensation and long-term benefits to the organization by way of new research and mentoring of junior researchers. In order to provide development tracks that do not require increased managerial/budget responsibilities, but promote technical achievements, many companies, including IBM, Boeing, and United Technologies Research Center, have a Technical Fellow program. This title is bestowed upon the organization's “most exceptional" technical professionals.

CHAPTER SIX:

CLOSING REMARKS

A core thesis of this landscape analysis is that research universities have a key role to play in addressing the dominant opportunities and challenges facing society, including climate change, equity, health and aging, security, maintaining peace, and strengthening our democratic institutions. More than ever, research universities must be deeply engaged in these discussions. Coupled with these societal challenges and opportunities are also deeply concerning issues in the national discourse – growing polarization in thought, growing distrust in foundational institutions, and growing distrust or cynicism regarding experts. We must be engaged, but we must engage in new ways. Referring to the societal engagement models discussed in Chapter 1, universities will continue to serve as homes for innovative "pure scientists" or "pure technology developers." However, we must increasingly serve as trusted partners and step into "honest broker" roles – bringing more ideas and options into discussions, enabled by deeper understanding of the broader set of political, regulatory, and equity issues. We must be vigilant to avoid "stealth advocacy," which contributes to cynical ideas that everyone can bring their expert to bear for a price, thereby discounting the important role of subject expertise.

Fulfilling this potential will require developing, fostering, and contributing to a widening network of partners that share our core values and add to our execution of the research university mission. Increasingly, research universities will be relied upon to be conveners and partnership builders for local communities, government, industry, and other non-governmental organizations. Some of these partnership models and support structures, such as federal engagement, are well developed. Others, such as serving as anchor institutions and fully engaging local communities, are less so. A key point of Chapter 4 was the need for universities to define and understand their ecosystems when framing partnership opportunities. No university can be all things to all sectors. Universities should strive for clarity, complementarity, shared values, and transparency around intellectual property, publishing, impact on student education, how activities will be guided and reviewed, as well as overarching goals of a given partnership; e.g., advancing knowledge in a particular domain or the development of processes or prototypes. This will, by its very nature, promote an ethical, responsible brand. Additionally, the values of long-term strategic partners will reflect on and become living dimensions of a university's brand via the purposeful, chosen association.

Diversity, equity, and inclusion issues cut across all of these chapters, and we embrace them as core values and enablers of more innovative approaches and better solutions. Bringing the full fruits of research and innovation to everyone in society, and engaging the full representation of humanity into the research enterprise, will continue to require attention, monitoring, and new models to include more minds, all voices, and diverse perspectives. Similarly, understanding how innovation and technology and the fruits of research promote equity or inequity must be a topic of research itself. It is core to our being a trusted partner. Finally, it must be integral to how we organize ourselves to carry out the research mission.

We envision many exciting innovations in how research organizations are organized to execute on their mission. Commercialization and licensing, interdisciplinary research, external partnerships, and the other functions within the research enterprise all cut across many of the current departments and people in existing universities, and there are many possible ways to organize these functions. Continued effort, thoughtful experimentation, and sharing of best practices will be key to continued improvement in research organization.

In closing, research universities have unparalleled opportunities to serve as contributors to, and enablers and producers of, innovation and solutions. They can be enablers of economic prosperity. They can play critical roles as conveners, bridge builders, and partners, not only reacting to, but also influencing broader conversations. They can — and must be — indispensable, trusted partners to society.

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METHODOLOGY AND CONTRIBUTORS

Research Next is based on literature reviews and interviews. We have also gathered information from Georgia Tech institutional databases, national databases focused on higher education, and a variety of governmental reports about the future of industry, research, national laboratories, and partnerships across these sectors.

Interviews were conducted with internal stakeholders and external collaborators. The internal stakeholder group comprised members of Institute leadership, including the president, provost, executive vice president for Research, vice president for Interdisciplinary Research, vice president for Research Operations, and various members of research leadership from the colleges and labs, including deans, associate deans, Interdisciplinary Research Institute directors, and the director and deputy directors for Research at the Georgia Tech Research Institute. External interviewees consisted of research leadership from several corporations, other research universities, and several research laboratories, across an expansive array of disciplines and markets.

Research Next Co-Chairs, co-leads Chapter 1: Framing the Landscape, and Chapter 6: Closing Remarks

Tim Lieuwen, Regents Professor, David S. Lewis J. Chair in the Daniel Guggenheim School of Aerospace Engineering, and executive director of the Strategic Energy Institute

Wen Masters, deputy director, Information and Cyber Sciences, Georgia Tech Research Institute (GTRI)

Co-Leads, Chapter 2: The World Beyond

John Avery, director, Advanced Technology Development Center (ATDC)

Clayton Kerce, principal research scientist, Cybersecurity, Information Protection and Hardware Evaluation Research Laboratory, Georgia Tech Research Institute (GTRI)

Co-Leads, Chapter 3: Research That Matters

Stefan France, associate professor, School of Chemistry and Biochemistry

Devesh Ranjan, Interim Vice President for Interdisciplinary Research, Ring Family Chair, professor and associate chair for Research, George W. Woodruff School of Mechanical Engineering

Co-Leads, Chapter 4: Working With Others

Gage Ramos, senior associate, Enterprise Agreements, Office of Industry Engagement, Georgia Tech Research Corporation (GTRC)

Valerie Sitterle, principal research engineer, Electronic Systems Laboratory, Georgia Tech Research Institute (GTRI)

Co-Leads, Chapter 5: The World Within

Jarrett Ellis, associate director, Industry and International Contracting, Office of Industry Engagement, Georgia Tech Research Corporation (GTRC)

Margaret Loper, Regents Researcher, Information and Communications Laboratory, Georgia Tech Research Institute (GTRI)

Members, Chapter Groups

Krish Ahuja, Regents Professor, Daniel Guggenheim School of Aerospace Engineering

Ken Allen, senior research engineer, Advanced Concepts Laboratory, Georgia Tech Research Institute (GTRI)

Terry Blum, professor, Ernest Scheller Jr. College of Business

Lakita Brooks, research associate, Office of Sponsored Programs

Lori Brown, director, Corporate Development

Polo Chau, associate professor, School of Computational Science and Engineering

Russell Clark, senior research scientist, School of Computer Science

Jeff Cullen, associate director, Federal Relations

Munmun De Choudhury, assistant professor, School of Interactive Computing

Shatakshee Dhongde, associate professor, School of Economics

Emanuel di Lorenzo, professor, School of Earth and Atmospheric Sciences

Courtney Ferencik, director of Development, College of Sciences

Jeff Garbers, extension professional, Enterprise Innovation Institute

Alexa Harter, director, Cybersecurity, Information Protection and Hardware Evaluation Research Laboratory, Georgia Tech Research Institute (GTRI)

Marta Hatzel, assistant professor, George W. Woodruff School of Mechanical Engineering

Jonathan Holmes, senior research engineer, Aerospace, Transportation, and Advanced Systems Laboratory, Georgia Tech Research Institute (GTRI)

Cynthia Hope, director, GTRC/RI Grants and Contracts, Office of Sponsored Programs

Matt McDowell, assistant professor, School of Materials Science and Engineering

Julia Melkers, associate professor, School of Public Policy

Colin Parker, assistant professor, School of Physics

Katrine Pate, grants administrator, School of Physics

Siva Raghupathy, professor, School of Electrical and Computer Engineering

Jyotsna Ramachandran, graduate student, School of Materials Science and Engineering

Chandra Raman, professor, School of Physics

Jeremy Reed, head, Sensor Artificial Intelligence and Learning Program Office, Georgia Tech Research Institute (GTRI)

Juan Carlos Rodriguez, associate professor, School of Modern Languages

Dene Sheheane, vice president for Alumni Affairs, Alumni Association

Brian Stone, professor, School of City and Regional Planning

Adam Stulberg, chair, Sam Nunn School of International Affairs

Steve Usselman, chair, School of History and Sociology

Olof Westerstahl, associate director, Office of Industry Collaborations

Michelle Wong, assistant director, Parker Petit Institute for Bioengineering and Bioscience

Charlie Wood, undergraduate student

Jan Youtie, principal research associate, Enterprise Innovation Institute

Project Management

Michelle Powell, senior consultant, Georgia Tech Strategic Consulting

Design and Illustration

Jessica Brandon, graphic designer, College of Design

Editors

Stacy Braukman, senior writer/editor Senior, Institute Communications

John Toon, assistant vice president for Research Communications, Institute Communications/Office of Executive Vice President for Research

Website Production

Alfred Bacon, lead applications developer, GTRI Enterprise Systems Department

Mel Goux, digital designer, GTRI Communications

Robert Macedonia, digital communications specialist, GTRI Communications

Michael Martin, senior applications developer, GTRI Enterprise Systems Department

Website Photography

Branden Camp, digital project specialist I, GTRI Advanced Concepts Laboratory

Rob Felt, photography manager, Institute Communications

Sean McNeil, photographer II, GTRI Communications

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