

Executive Summary

President Peter Salovey, in November of 2016, identified science as a top academic priority for Yale University. Science can change - and improve - the world. Tomorrow's leaders need a solid grounding in science, technology, engineering, and mathematics (STEM) so they can understand the world and shape its future. Yale must invest strategically in these areas to remain a great research university and meaningfully contribute to addressing the world's present and future challenges.

To better define that goal, the University Science Strategy Committee (USSC) was charged to develop a strategic plan for STEM at Yale that could be implemented in the coming decade. We were asked to identify changes to organizational structures that will support excellence in science and engineering and to recommend a prioritized set of 'big ideas' for new investment. We were asked to dream big, realizing that Yale will not be able to do everything that we could imagine. We were also asked to prioritize the ideas and make difficult choices among many excellent possibilities.

The USSC took its charge seriously. We devoted significant time to gathering information and conducting our deliberations. To accomplish our charge, we solicited input from the community broadly, both at departmental and individual faculty levels. Each science department or school was invited to prepare a self-reflection for consideration by the USSC. We also solicited recommendations online from all science and engineering faculty in the University and held one-on-one interviews with faculty and deans. During the 2017-18 academic year, we organized over a dozen faculty panels in which we invited colleagues to guide us to the scientific frontiers of their respective disciplines. In this format, we met with over 100 faculty members who have primary appointments in almost 50 departments and five schools. We also attempted to identify the scale of the resources needed for each of the ideas and to project their annual cost if implemented. A similar process was followed during the consideration of several cross-cutting investments and structural recommendations.

The USSC gave careful thought to the criteria it should use for evaluation of the ideas. We established two overarching criteria, Impact and Feasibility, as well as a series of questions that we used to consider each of the ideas. No single question served as a litmus test for evaluation of any idea, but these questions provided a framework for considering how to prioritize them.

Based upon this process we recommend **five ideas for top priority investment**. For each of these five ideas, which are listed in their order of priority, we offer a set of recommendations for implementation. We also identify a second set of **five additional priority ideas**. Each of these ten areas is highly interdisciplinary and integrative - and implementation should include, where appropriate, scientists, engineers, mathematicians, and clinicians. These ideas were selected for their impact and feasibility at this time, but they do not represent a comprehensive list of the many areas of excellence at Yale. We recognize that not all excellent science fits into a short list of ideas, therefore we recommend **four areas for cross-cutting investment** that will support all STEM fields. We also recommend **ten changes to organizational structure** that will improve support for science and engineering at Yale. Science is a dynamic enterprise. These cross-cutting and organizational changes will allow Yale to better realize its current and future scientific initiatives.

Our recommendations are as follows:

Four Cross-Cutting Investments

Graduate Student Support:

Graduate students help drive discovery through the research that they conduct within the training environment of their faculty mentors. Graduate students are the future of scientific innovation. We recommend a major investment in the funding of STEM graduate education to ensure sustained scientific excellence at Yale.

Diversity across the STEM Pipeline:

Improved diversity and inclusion is critical to our society. Science is no exception. Diversity leads to improved outcomes for laboratories, academic departments, and even individual publications. We recommend initiatives that will allow Yale to further promote and nurture diversity in all our scientific enterprises.

Instrumentation Development:

The development of new tools and measurement techniques is an essential component of the scientific process, allowing researchers to open entirely new avenues for investigation. We recommend that Yale develop high-capacity centralized instrumentation and engineering facilities to serve as intellectual “hubs” for instrumentation development.

Core Facilities:

State-of-the-art core facilities are crucial for innovation across the University. Research in every laboratory is dependent upon these services. We recommend making strategic investments to better organize, coordinate and support the University cores.

Five Ideas for Top-Priority Investment

Integrative Data Science and its Mathematical Foundations:

We recommend a University-wide Institute for Integrative Data Science and its Mathematical Foundations. The world is currently undergoing a data revolution. The confluence of the volume, speed, and availability of data is transforming information and knowledge production. Harnessing data streams from sensors, instrumentation, medicine, and the internet, among other sources, will require developing algorithms, machine learning techniques, and innovative mathematical models to enable new understanding and predictive power.

Quantum Science, Engineering and Materials:

We recommend expanding the existing Yale Quantum Institute into a University-wide initiative in the areas of science and technology associated with quantum-mechanical phenomena and materials science. This research arena, which has emerged in the 21st century, is a frontier of fundamental knowledge about how the universe works. The “Quantum” is rapidly becoming a

radically new source of practical technologies. As part of this initiative, we recommend the construction of a new building for the physical sciences with Quantum Science, Engineering and Materials as its major focus.

Neuroscience, from Molecules to Mind:

We recommend an integrated Neuroscience Institute that unites research across the Yale School of Medicine (YSM) and Faculty of Arts and Sciences (FAS). By integrating knowledge across scales, from molecular and cellular neuroscience to organismal behavior and cognition (systems neuroscience), the Institute will facilitate new fundamental insights into the function of the mind, the development of the brain and the causes and cures of neural disease.

Inflammation Science:

We recommend a new Institute of Inflammation Science to focus on the inflammatory basis of both homeostasis and disease. Inflammation has emerged as a key factor in diseases that are the leading causes of death in the United States. This initiative will explore the full extent of the interplay among inflammation, organ systems, the immune system, environmental factors, and genetics.

Environmental and Evolutionary Sciences:

Human-accelerated changes in the environment present one of the greatest challenges of the 21st century. We recommend an Institute in Environmental and Evolutionary Sciences that has the goal of modeling environmental changes and understanding how organisms evolve in response to a rapidly changing Earth that will help us conserve ecosystems.

Five Additional Priority Ideas

The ideas above constitute the top priority recommendations. The Committee gave serious consideration to many others. The USSC endorses efforts underway in the following areas, and would support additional investment if additional resources were available.

Climate Solutions:

Climate change is a defining issue of our time. One of the most overwhelming challenges in addressing climate change is to identify practical mechanisms to capture CO₂ directly from the ambient atmosphere and to sequester it.

Computer Science:

New opportunities are arising at the intersections of computer science and other fields – referred to broadly as “CS+X,” where X can range from Biology, Engineering, Law, and Medicine to Business, Economics, Music, and beyond. The success of artificial intelligence will greatly increase the fraction of our world controlled by information systems and augment human interaction with technology.

Conquering Cancer:

Cancer remains a leading cause of death in the United States. The grandest challenge in cancer research is to develop and apply new patient-specific therapeutics so that all patients can be cured. Opportunities abound at Yale to integrate advances from other strategic areas within cancer research.

Precision Medicine:

Medicine is entering a new era in which the acquisition and interpretation of vast quantities of data from human populations will enable individually-tailored medical care. The integration of clinical and genetic information promises to transform our understanding of human biology and the treatment of disease.

Regenerative Medicine:

Regenerative Medicine seeks to repair, replace, or regenerate cells, tissues, and organs. It exploits advances in genomics, biomaterials, immunobiology and mechanobiology, and advanced cell therapies (particularly stem cells), and it can be enhanced by high-resolution medical imaging and computational modeling.

School of Engineering and Applied Sciences (SEAS)

The USSC was not tasked to provide a strategic plan for any individual school or department, but we emphasize that engineering and applied sciences will play a vital role in implementing many of these ideas. To make this possible, SEAS must be fully integrated into the fabric of the University, across all three of Yale's campuses. We offer ideas for an Engineering +X strategy for the future of SEAS.

Ten Recommended Changes to the Organizational Structures that Support Science

- Build improved mechanisms for interdisciplinary faculty appointments
- Increase computing and data management support
- Provide more organized support for large grant submissions
- Increase input for well-coordinated space planning in the sciences and engineering
- Enhance support for professional staff scientists
- Offer faculty development training in leadership
- Better support for commercialization and entrepreneurship
- Improve research communications and dissemination
- Increase connections with Brookhaven National Laboratory
- Improve support for clinical trials research

Additional scientific ideas of interest are briefly described in Appendix #1.

Acknowledgments

The Committee is grateful to the many members of the Yale community who assisted in this process. We thank those who prepared departmental self-reflections and individual faculty who provided input to the Committee in response to our requests. We are particularly indebted to Daniel Bennett, Tamara Chiba, Katherine Haskins, Melissa Hey, Angie Hofmann, Roopa Narasimhaiah, Zandra Ruiz, Jeremy Toyn and Tammy Wu, who helped create initial drafts for sections of this report. We thank Sara Epperson for staffing the Committee and Kelly Locke for managing the Committee's many administrative needs.