Cornell Institute for Engineering Innovations in Medicine | Cornell Engineering-Weill Cornell Medicine
October 2021

The Big Idea

The human impacts and complexities of diseases like Alzheimer's, cancer, and diabetes are driving the search for new treatment options. Future solutions will require contributions from a range of disciplines, easily transcending the boundaries of traditional academic structures.

The convergence of the fields of engineering and medicine offer fertile ground for strong intellectual cross-fertilization and a foundation for educating trainees who thrive at the interface between these disciplines. Cross-campus collaborations between the College of Engineering (COE) and Weill Cornell Medicine (WCM) have already elucidated pro- and antimetastatic microenvironmental signatures of cancers; led to discovery of and clinical trials for cancer-destroying nanoparticles; produced innovations in microscopy for mapping the human brain in unprecedented detail; and are now defining the foundation for omics analytics for characterizing diseased states at the molecular and cellular levels. We propose to establish a **Cornell Institute for Engineering Innovations in Medicine** (CEIM) that would span COE and WCM programs to catalyze research, education, and clinical care innovations at the intersection of engineering and medicine.

A task force composed of COE and WCM faculty leaders considered this opportunity and concluded that strategic partnerships between the Ivy League's highest-ranked engineering school and one of its top academic medical centers would yield immediate impacts in **educating future-ready physicians and engineers** and in **advancing the frontiers of clinical and translational medical research**.

Strategic Initiatives

Create inter-institutional models for educating future-ready physicians and engineers.

- **M.D.-M.Eng.**: CEIM will host a dual medical degree and master's in engineering program that provides graduates with a competitive edge at the intersection of critical fields.
- **M.D.-Ph.D. in Biomedical Engineering**: This dual degree program will expand the current Medical Scientist Training Program at WCM to enable graduates to receive engineering doctorate degrees.
- **Intercampus training for *all* students:** CEIM will develop competitive funding, staffing, and housing support mechanisms to facilitate student and faculty rotations between the COE & WCM.
- **Technology Innovation Partnership:** A new program leveraging the strengths of both colleges will train students to lead technological innovations that enhance patient care.

Advance the frontiers of clinical and translational medical research.

- **Create a world-class community of researchers in existing areas of strength.** CEIM will establish a fund that supports new COE-WCM early & mid-career seed grants, faculty & student rotations, and technology translation programs that enable long-term collaborations in core areas of technical strength, including cancer, imaging, immunology, and neurotechnology.
- **Develop new partnerships for diagnosing, preventing, and treating disease**. CEIM will leverage the radical collaboration model to recruit faculty and for creating associated infrastructure to build strength in emergent areas, including tissue engineering & organoids, nano-biotechnology, data-driven decisions & machine learning.

Outcomes

- CEIM will provide a unified, radical collaboration spanning teaching, research, and technology innovation across Cornell's Ithaca and New York City campuses to aggressively build a community of scholars broadly recognized as innovators at the intersection of engineering and patient care. The Institute will establish models for training physicians of the future, for holistic diagnosis of disease, and for delivering precision medical care to patients. CEIM will place Cornell at the forefront of an emerging research domain and will attract a diverse cohort talented trainees and faculty. The scope and scale of these impacts are supported by **five specific cases** summarized below.

Case 1: Educating future-ready physicians and engineers

What is the problem or unmet need?

The human costs and complexities of diseases such as Alzheimer's, cancer, and diabetes are extraordinarily high — and rising. We now understand that the search for treatment options and cures for any of these diseases will require contributions from a large number of disciplines, transcending the boundaries of traditional educational structures at universities. The convergence of the fields of engineering and medicine, in particular, provides grounds for strong intellectual cross-fertilization. Quantitative approaches from engineering can be imported into biomedical research, whereas conceptualizations of complex evolutionary systems from the biomedical sciences and clinical practice bring new perspectives to engineering. Educating the engineers and physicians of tomorrow — and ensuring that these individuals are capable of leading future transformations — requires new educational models.

What is the proposed solution?

We will create the following educational programs at the interface of engineering and medicine:

- **M.D.-M.Eng**.: a new dual medical degree and master's of engineering program
- **M.D.-Ph.D**.: a new program combining medical and engineering doctorate degrees
- **Intercampus research immersions:** opportunities for undergraduate, Ph.D., and postdoctoral students

These interdisciplinary educational programs all will focus on providing students with a deep understanding of the biomedical sciences, a strong quantitative engineering foundation, and extensive hands-on clinical experience. Students participating in the programs will engage in translational research projects; collaborate with Cornell faculty across COE and WCM; develop next generation diagnostic, therapeutic, and omic analytics innovations; and become the thought leaders of tomorrow in developing and deploying precision medicine for improved clinical outcomes.

What is the expected impact?

The dual M.D.-M.Eng. degree would make WCM the only medical school in New York state to offer a master's degree in any engineering field, allowing us to become a leader in the nation in educating physicians with the advanced quantitative, design, and analytical skills typical of graduates in engineering and the physical sciences. More generally, the proposed programs would provide opportunities to prepare physicians who are able to harness technology — including imaging and data analytics tools for clinical care and for diagnosing and treating disease — and engineers who bring clinical perspectives to their work.

The distinctiveness of the programs will also help Cornell recruit the most highly qualified premedical students, especially those who have prior experience and interest in science and engineering. Dual degree graduates would likewise have a competitive edge as they pursue residency training programs. Finally, these programs would train a new generation of graduates with skills that transcend traditional educational boundaries, making them uniquely qualified to perform at exceptional levels in research and innovation. The close proximity of WCM to the Health Tech Hub at Cornell Tech's campus on Roosevelt Island provides a unique opportunity to establish new mechanisms for multi-campus partnerships aimed at solving society's most challenging problems in translational clinical medicine.

Case 2: Advancing understanding of bone metastases

What is the problem or unmet need?

Cancer is the second leading cause of death in the US largely due to the development of therapy-resistant metastatic disease, the late-stage cancer that has spread to a different body part. The skeleton is a particularly frequent site of metastasis, which is especially relevant in breast and prostate cancer patients, where bone metastases dramatically diminish clinical prognosis. How tumors develop and progress in the skeleton is largely unclear.

What is the proposed solution?

Interdisciplinary collaborations are crucial to answering outstanding questions of bone metastasis to improve diagnosis, treatment, and possibly prevention strategies. Below, we highlight three key areas in which collaborations between COE and WCM are revolutionizing the field.

Role of bone materials properties in metastasis: Biomedical engineers and materials scientists in the COE have identified that the unique material properties of bone not only determine the biomechanical integrity of our skeleton but also influence tumor cell behavior. While current models of bone metastasis completely disregard this aspect, COE engineers have developed biofunctional bone models with selectively tunable material properties to mimic differences caused by aging or other conditions. In collaboration with WCM researchers these systems are used to identify why women with decreased bone mineral density have a significantly increased risk of developing breast cancer bone metastasis and to determine why bone metastasis occurs more frequently in the spine relative to long bones.

Imaging of tumor cells in the bone: Very early during disease development tumor cells spread to the skeleton, where they can stay dormant for years or even decades. What re-awakens these cells later in life is extremely difficult to identify as imaging small numbers of cells within the skeleton is challenging. Understanding these connections is critical as reawakened tumor cells form therapy-resistant tumors and dramatically decrease patient survival. COE researchers are experts in developing state-of-the-art cell labeling techniques as well as instrumentation, software, and expertise for high-resolution optical and X-ray imaging analysis of cellular state, bone matrix, and nanoscale cellular properties (**Figure 1**). They apply these technologies in collaboration with WCM researchers to locate small numbers of tumor cells within bone and study their metastatic progression.

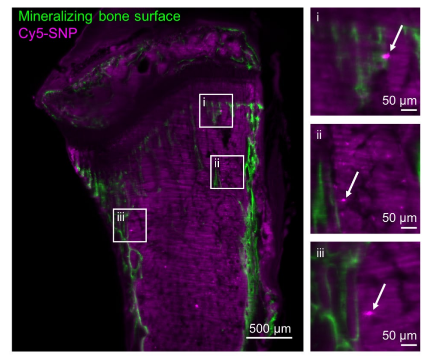

Figure 1. Light sheet microscopy of mouse bones to detect small numbers of tumor cells (purple, Cy5-SNP) interacting with mineralized bone surfaces (green). Tumor cells were fluorescently labeled with ultrabright Cdots (collaboration Fischbach, Wiesner, Estroff, Williams).

Precision medicine approaches for treatment: The cellular composition of tumors is highly complex and varies not only between different patients, but also within a tumor of the same patient. Understanding this complexity will help identify patient-specific treatment options. Precision medicine technologies that depend on the integration of microfabrication strategies, imaging, and analysis of large data sets allow dissection of this complexity. COE engineers are developing massively parallel, single-cell RNA-sequencing strategies and combining them with spatial transcriptomics and computational modeling to identify tumor heterogeneity and predict patient outcome. When combined with access to patient samples, collaborations between COE engineers and researchers at WCM (particularly the Englander Institute of Precision Medicine) are identifying new strategies enabling more efficacious therapeutic intervention in a patient-specific manner.

What is the expected impact and "why Cornell?"

Integrating expertise across disciplinary boundaries will revolutionize the mechanistic understanding of bone metastasis. This interaction enables improved diagnostic and therapeutic options for early-stage bone metastatic cancer and provides novel precision medicine approaches to improve clinical outcomes in patients with advanced disease.

Cornell is uniquely positioned to address outstanding questions of bone metastasis by leveraging the clinical expertise at WCM with technological innovations provided through the COE. In particular, the COE's cross-cutting research excellence in nano- and microfabrication, molecular/cellular/tissue engineering, materials science, advanced imaging approaches, and data science as well as its world-leading research facilities including the Cornell Center for Materials Research (CCMR) and the Cornell NanoScale Science and Technology Facility (CNF) is critical to the efforts above. In combination with the cutting-edge translational research and clinical care at Weill, and resources available at the EIPM and the Clinical and Translational Science Center (CTSC), it will become possible to rapidly assess the utility of newly discovered specific therapeutic targets in disease-relevant contexts.

Case 3: Advancing the frontier of clinical informatics

What is the problem or unmet need?

Continuous progress in the omics fields — including genomics, transcriptomics, and proteomics — provides access to large amounts of data about patient disease status. In many cases, this data comes from real-time imaging and spectroscopic analysis. For example, the relative ease with which single-cell sequencing information can now be obtained through next-generation sequencing technologies, such as single-cell RNA sequencing, provides information about gene expression from the mRNA in a cell, also known as its transcriptome. Furthermore, with spatially resolved transcriptomics, crowned by *Nature Methods* as the "Method of the Year 2020," this information is now available with the multi-dimensional positional context of a cell in an actual tissue.

Overlaying these developments with progress in mass and other spectrometry methods that facilitate access to precise information about small-molecule products of transcription, these advances in method development now enable a physician to examine the full spatiotemporal evolution of gene expression associated with an individual patient treatment. This opens-up unprecedented opportunities for precision early diagnosis and treatment of disease, with the potential to revolutionize personalized patient care. However, how to extract useful information from the enormous data generated by such approaches, such that it can usefully educate patient treatment decisions, remains an unsolved challenge. Addressing this challenge requires close and sustained collaboration between a broad range of disciplines across engineering and medicine.

What is the proposed solution?

Under the umbrella of the **Cornell Institute for Engineering Innovations in Medicine** (CEIM) research, education, and clinical care innovations across COE and WCM will be united. CEIM will also leverage expertise and infrastructure of Cornell's world-class College of Veterinary Medicine (CVM) to develop more streamlined approaches for translating technical breakthroughs into treatments that benefit patients. CEIM will develop seed grant programs for early & mid-career faculty, establish a mechanism for faculty rotations between the COE and WCM, and create an organizational structure that supports COE-WCM collaborative research, and for translating research discoveries into technologies that can be deployed in the clinic. CEIM will combine medical expertise in understanding specific diseases with COE technical experts in areas including mRNA sequencing, computational and systems biology, big data analysis, and network to produce roadmaps for usefully translating transcriptomics data sets into patient profiles. The resulting knowledge can be added to more traditional clinical characteristics in a patient's medical record as a basis for forming more precise treatment decisions. Once such an advanced informatics program has been established for a first disease of choice, its blueprint can be evaluated rigorously in animal model studies in collaboration with experts in CVM and generalized to other more complex diseases.

What is the expected impact?

The successful translation of the vast amounts of specific patient omics data and the enhanced ability to convert the analysis into useful and accessible information for clinicians will revolutionize personalized patient care. Furthermore, producing robust and disease-specific maps that quantify the interrelations between genetic expression levels at the cellular level, associated small molecule products, and successful clinical treatment paradigms at the macrolevel has the potential to catapult Cornell into a national and international leadership position for clinical care. Novel insights gained during this process will also have profound implications for other areas of research and development, including molecular therapeutics and nanomedicine developments, to name a few. The close proximity of WCM to the Health Tech Hub at Cornell Tech's campus provides an advantage in realizing CEIM's potential, as do Cornell's traditional strengths in interdisciplinary research extending beyond department and college boundaries.

Case 4: RNA immuno-cancer prevention

What is the problem or unmet need?

Primary cancer prevention is considered as best targeted to individuals with increased cancer risk. Despite the success of checkpoint inhibitor (ICI) immunotherapy, which was recognized with the Nobel Prize in Physiology or Medicine in 2018, and our understanding of the critical role of immune surveillance in primary cancer predisposition, prevention, and advanced cancer immunotherapy, ICI has significant rates of severe adverse events such as autoimmunity-related lung, hepatic, skin, neuro, colon, endocrine, and lymphoma toxicities, some of which are fatal. Also, ICI immunotherapy has no clear dose-response relationship, making "low dose" ICI problematic. Consequently, case reports of ICI for primary cancer prevention, such as in Lynch Syndrome (LS), have demonstrated significant problems with autoimmune side effects in otherwise healthy patients. Thus, while the risk-to-benefit ratio of ICI drugs is acceptable for patients with metastatic tumors and poor prognosis, it is almost certainly unacceptable in the setting of primary cancer prevention, where the tolerance for side effects is very low, and other approaches with lower adverse event rates are needed.

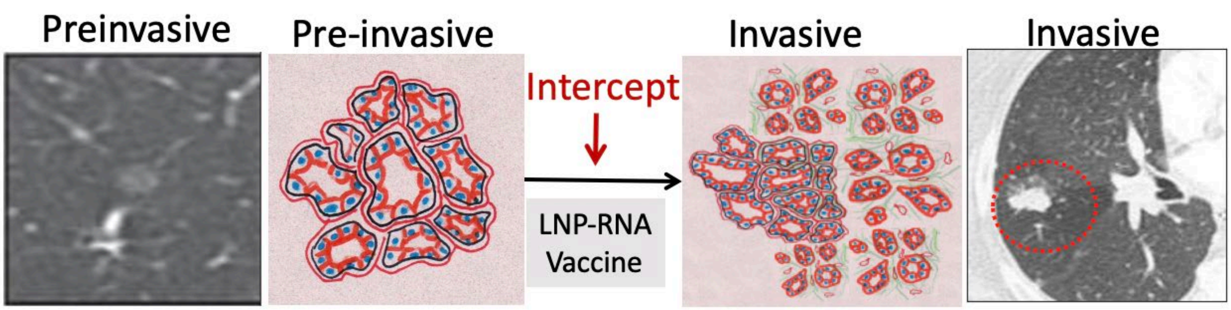

Figure 2. Intercepting progression from pre-invasive to invasive lung cancer by LNP-RNA vaccination against cancer antigens.

What is the proposed solution?

The problems with tolerability of ICI in primary cancer prevention have led to new interest in cancer immune prevention and interception vaccines, which have much milder and fewer adverse events. In 2020, lipid nanoparticle RNA (LNP-RNA) vaccines against COVID-19 demonstrated convincingly that LNP-RNA vaccination is faster, more flexible, and adaptable for variants (both COVID-19 and pre-malignant cancers). They also are cheaper and more immunogenic than any previous vaccine technology. Catalyzed by rapid advances in vaccine science and cancer genomics, opportunities for collaboration between COE and WCM are to discover, formulate, and validate novel LNP-RNA vaccines for effective and safe immune prevention and interception with clinical translation involving pharma/biotech. WCM has strong expertise in cancer prevention, cancer vaccines, and computational cancer genetic tools while COE has strong expertise in drug delivery, biomaterials, and nanotechnology.

What is the expected impact?

Such collaboration will lead to a state-of-the-art, scalable platform pipeline that can develop LNP RNA immune prevention and interception vaccines for different pre-malignancies. The goal is to bring cancer immune prevention and interception LNP-RNA vaccines to the clinic. The success of this collaboration will establish Cornell as a leader in immuno-engineering and cancer immunotherapies.

Case 5: Advanced operating rooms

What is the problem or unmet need?

Human disease is often only detected in advanced and difficult-to-treat stages. Currently, surgeries rely heavily on pre-surgical radiology information derived from imaging techniques — such as MRI, CT, or PET — that are difficult to apply during an operation. This often leaves surgeons with very little real-time analytics data, placing a significant burden on a surgeon's experience and increasing the likelihood of poorly outcomes. The fully engineered healthcare systems of the future will more closely resemble those of a GE jet aircraft engine, which is equipped with more than 5,000 sensors that generate more than one terabyte of diagnostic, state-of-health data in a single trans-Atlantic flight. The insights and analytics provided by these systems have led to improved engine performance and a substantial reduction of in-flight failure. Access to similar real-time information will dramatically enhance a surgeon's decision-making, resulting in shorter surgery times, reduced patient recovery periods, and increased survival rates.

Figure 3. Advanced diagnostics and analytics enabled by data have substantially enhanced the performance of GE jet aircraft engines, left, and will similarly improve patient outcomes in the operating room of the future, right.

What is the proposed solution?

Operating rooms of the future will overcome these limitations using a combination of molecular, particulate, and embedded devices in the patient as well as augmented reality tools in combination with real-time access to surgical databases available during surgery. These advances will enable surgeons to better distinguish diseased tissue form healthy tissue using specifically targeted optical markers, associated imaging methods, and analytical methodologies that are able to use the large amounts of data generated to inform decisions. During an operation, the surgical team will be able to see 3D patient imaging data in holographic form, pre-surgical radiology information superimposed on the patient's anatomy, and real-time comparative information from surgical databases.

What is the expected impact?

Widespread availability of such tools — along with the development of a workforce able to create and use them to enable data-driven decisions during surgery — would transform medicine. Data-driven or data-informed surgical decision making also will improve patient outcomes, including shorter surgery times, shortened patient recovery periods, and improved survival. Medical schools leading this transformation will earn national recognition. Cornell is well positioned to lead in this area due to its world-class programs in optical imaging, molecular spectroscopy, marker and tool developments, data analytics, and AI. As with the previous cases, the close proximity of WCM to the Health Tech Hub at Cornell Tech provides new opportunities for collaborations that span the three campuses with significant real-world impact.

COE-WCM Faculty Task Force Report

SUMMARY

Engineers and physicians educated at the intersection of the two disciplines are the missing element that will drive the innovations needed to revolutionize medicine.

In the operating room, for example, precision tools created by these interdisciplinary pioneers will enable surgeons to better distinguish diseased tissue form healthy tissue using specifically targeted optical markers, associated imaging methods, and analytical methodologies that are able to use the large amounts of data generated to inform decisions. During an operation, the surgical team will be able to see 3D patient imaging data in holographic form, pre-surgical radiology information superimposed on the patient's anatomy, and real-time comparative information from surgical databases.

Currently, surgeries rely heavily on pre-surgical radiology information derived from imaging techniques — such as MRI, CT, or PET — that are difficult to apply during an operation. This often leaves surgeons with very little real-time analytics data, placing a significant burden on a surgeon's experience and increasing the likelihood of poorly outcomes.

The fully engineered healthcare systems of the future will more closely resemble those of a GE jet aircraft engine, which is equipped with more than 5,000 sensors that generate more than one terabyte of diagnostic, state-of-health data in a single trans-Atlantic flight. The insights and analytics provided by these systems have led to improved engine performance and a substantial reduction of in-flight failure. Similarly, augmented reality tools and real-time access to surgical databases — combined with a combination of molecular, particulate, and embedded devices in a patient — will dramatically enhance a surgeon's decision-making, resulting in shorter surgery times, reduced patient recovery periods, and increased survival rates.

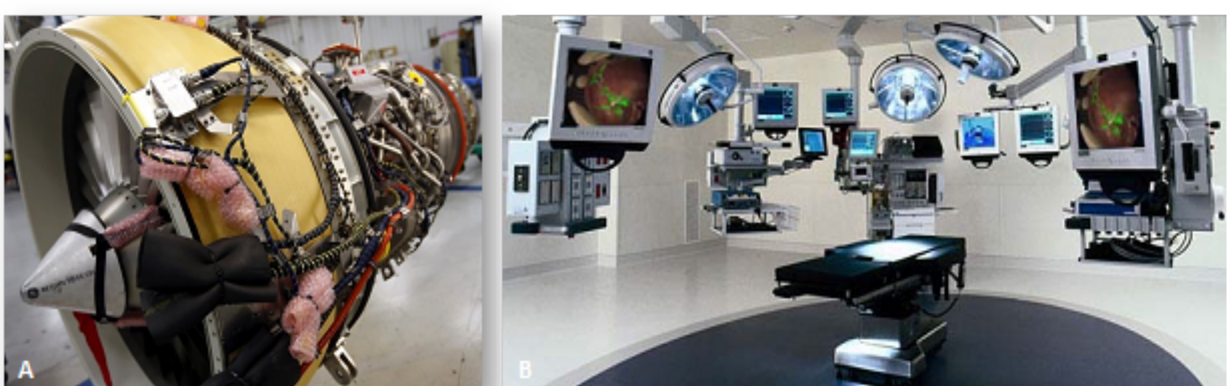

Figure 1. *Advanced diagnostics and analytics enabled by data have substantially enhanced the performance of GE jet aircraft engines, left, and will similarly improve patient outcomes in the operating room of the future, right.*

Nationally, there is a growing awareness that realizing such a vision and finding solutions to complex diseases like Alzheimer's, cancer, and diabetes are interconnected pieces of the same puzzle — they require contributions from an array of disciplines, transcending the boundaries of traditional academic structures. This understanding is evidenced in recent initiatives supported by the National Institutes of Health (NIH), such as the Cancer Moonshot, The BRAIN Initiative and programs in data science, accelerated vaccine development and advanced medical diagnostics, all of which are catalyzing research and education at the confluence of engineering and medicine.

Cornell University has the potential be a national leader in developing the experts and expertise necessary to forge the future of precision medicine. To this end, Lynden A. Archer, the Joseph Silbert Dean of Engineering and the James A. Friend Family Distinguished Professor in Engineering, and Augustine M.K. Choi, the Stephen and Suzanne Weiss Dean of Weill Cornell Medicine (WCM) and the provost for medical affairs for Cornell, established a task force composed of faculty leaders from the College of Engineering (COE) and WCM to determine how the campuses might partner to position the university as a powerhouse in this emergent domain.

The task force was specifically charged with organizing its recommendations as a mix of initiatives that have the potential to establish Cornell as the place of choice for educating future physicians and engineers who thrive at the intersection of engineering and medicine, and as a center of excellence for groundbreaking clinical and translational medical research.

This report summarizes recommendations from the COE-WCM task force. Its key finding is that a Cornell Institute for Engineering Innovations in Medicine (CEIM), focused on uniting research, education, technology innovation and clinical care across its Ithaca and NYC campuses, could cement Cornell as a preeminent university at the forefront of translational clinical medicine research and education that crosscuts engineering and medicine. The task force organized its recommendations in terms of CEIM-hosted education and research activities that could be implemented quickly and with modest investments, as well as other more ambitious opportunities requiring time, fundraising, and investment to launch:

1. **Education:**
   Goal: Create inter-institutional models for educating engineers and physicians of the future.
   Initiatives:
   - **M.D.-M.Eng.:** CEIM will create and host a dual medical degree and master's in engineering program that provides graduates with a competitive edge for problem solving at the intersection of medicine, engineering, and technology.
   - **M.D.-Ph.D. in Biomedical Engineering**: This dual degree program will expand the current MST program at WCM to develop a cohort of WCM-COE educated MDs who also hold engineering doctorate degrees.

- **Intercampus training for *all* students:** CEIM will develop competitive funding, staffing, and housing support mechanisms to facilitate student and faculty immersions at both campuses.
- **Technology Innovation Program:** A new program utilizing the strengths of WCM and the COE will train students to lead technological innovations centered in improving clinical care and health outcomes for patients.

2. **Research:**
   Goal: With the specific aim of seeding multi-investigator COE-WCM institutes and centers that address grand challenge questions in human health, synergize COE's science and technological strengths with WCM's expertise in translational clinical medicine to support impactful cross-campus collaborations in Precision Medicine.
   Initiatives:
   - **Create a world-class community of researchers in existing areas of strength.** CEIM will establish a fund that supports new COE-WCM early & mid-career seed grants, faculty & student rotations, and technology translation programs that enable long-term collaborations in core areas of technical strength, including cancer, imaging, immunology, and neurotechnology.
   - **Develop new partnerships for diagnosing, preventing, and treating disease**. CEIM will leverage the radical collaboration model to recruit faculty and for creating associated infrastructure to build strength in emergent areas, including tissue engineering & organoids, nano-biotechnology, data-driven decisions & machine learning.

Cornell has a head start in leading the transformation of healthcare happening at the confluence of medicine, engineering, and technology. Among the university's advantages are its tradition of interdisciplinary research beyond department and college boundaries and its recognized strength in clinical translational medicine, cancer, neurotechnology, immunology, information science and big data. Connections to the Cornell Tech campus on Roosevelt Island enabled by the Health Tech Hub offer another important advantage. Additionally, COE and WCM faculty have a good record of success working together at the single-investigator scale, and a few examples of leading large, nationally visible multi-investigator efforts in cancer, immunology, and neurotechnology. By putting in place the people, programs, infrastructure, and reliable mechanisms for building and sustaining cross-campus partnership, CEIM will take successful COE-WCM partnerships as a point of departure to both catalyze and sustain development of successful multi-investigator initiatives in research, education, and technology innovation with impacts in existing areas of strength, as well as in emerging domains such as tissue engineering and organoids, imaging, mass spectrometry and omics analytics, and artificial intelligence.

For example, Cornell's Center on the Physics of Cancer Metabolism (PSOC) has brought together leaders in COE and WCM with expertise in biomedical engineering and clinical research to understand how microenvironments impact tumor metabolism and function, as well as clinical outcomes for cancer patients. Research in PSOC leverages WCM clinical expertise in cancer research and treatment and COE expertise in advanced optical imaging and fabricating nano- and microfluidic devices to model the tumor environment in three-dimensions with far greater spatial and temporal resolution than can be achieved with conventional two-dimensional tissue culture models. The work has received over $20 million in support from the NIH and other agencies and has already elucidated the roles played by mechanical forces, chemical cues, and genetic and epigenetic factors in cancer metastasis.

Additionally, the discovery in COE's Department of Materials Science and Engineering that ultra-small nanoscale particles called Cornell Dots (C Dots) can aid in detecting and fighting cancer has led to the creation of another NIH-funded center, the Memorial Sloan Kettering-Cornell Center for Translation of Cancer Nanomedicine (MC^2TCN). Research from this center has spawned a biotechnology company, Elucida Oncology, which earlier this year reported receipts of $44M in series A-1 fundraising and is currently working with WCM on clinical testing. In yet another example of fruitful collaboration across disciplines, a group of COE and WCM scientists, initially brought together by a small Cornell seed grant, combined 3D printing and injectable gels made of living cells to build ear replacements. Over the last 15 years, the team of biomedical engineers and physicians have produced 25 publications and five licensed patents — and they raised their project funding from $50,000 to $2.5 million from state, federal and private sources.

The primary barriers to immediate implementation of CEIM's education initiatives relate to the affordability of inter-institutional instruction for students from diverse socioeconomic groups. Specifically, more attractive student support models are needed to ensure both a seamless transition in financial support and available housing for students matriculating in intercampus arrangements. For the M.D.-M.Eng. and M.D.-Ph.D. students, these barriers can be resolved using some combination of fellowships and scholarships that substantially support the cost of education and housing, while M.D. students are pursuing the M.Eng. or Ph.D. degrees in Ithaca.

For intercampus training, the key barrier is New York City housing for students during their WCM immersion. Here, there are opportunities for leveraging past and future Cornell investments on Roosevelt Island to accommodate COE students participating in short- and long-term research and internship programs at WCM.

The barriers to achieving CEIM goals in research center around insufficient or ineffective mechanisms for sustaining cross-campus research partnerships and for recruiting multidisciplinary faculty that bridge existing strengths of both colleges.

Concrete steps to overcome these obstacles are detailed in the report, and efforts to remove them will allow COE and WCM to build on strengths in established areas — cancer, neurotechnology, and immunology — where joint, world-class projects are already attracting multi-investigator, center-scale grants. These steps will also facilitate robust intercampus partnerships in new areas — data science, AI, and tissue engineering and organoids — where there are many opportunities for Cornell to lead.

In the short-term, investments in staff and infrastructure and the development of a faculty launch committee would provide an important first step to the creation of CEIM. The launch committee would organize cross-campus symposia, workshops and retreats to define CEIM. It would also collaborate with the college and university leadership to define impactful mechanisms and funding sources for supporting the ambitious COE-WCM collaborative research, education, and technology innovation agenda identified by the task force.

These activities will help establish CEIM as the official inter-campus institution supporting all aspects of the COE-WCM partnership and provide straightforward processes for synergizing expertise on the two campuses.

The collaborations engendered by CEIM will propel Cornell to the forefront of a field that we believe will transform precision clinical medicine research, education, and impacts on human health. They will also lead to increased funding through large center grants, industry collaborations, and philanthropy. A formal institute will allow personnel, resources, and other infrastructure to be shared easily and efficiently, circumventing the need to establish parallel entities for individual collaborations. Using a virtual model will initially enable the institute to bring existing collaborators onboard quickly, yet efforts should also be made to identify and invest in research facilities on each campus.

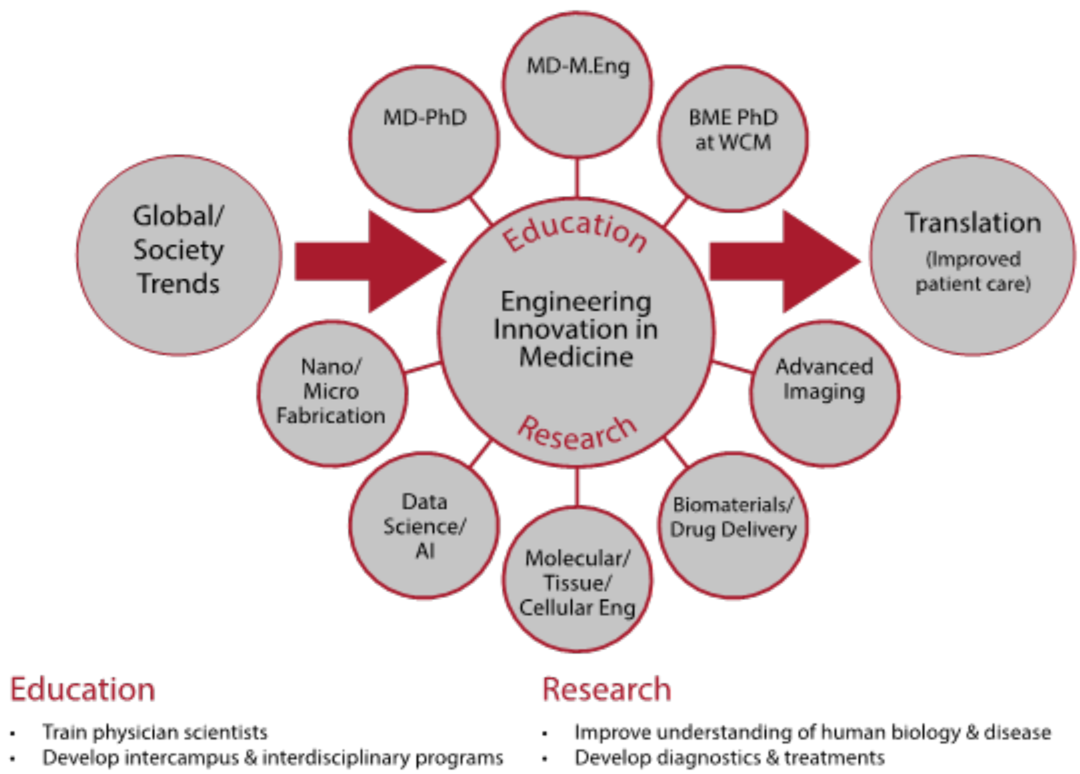

Figure 2. *Modalities for enhancing COE-WCM engagement in education, research, and technology show how engineering innovation in medicine can respond to global societal trends and improve patient care.*

CEIM will support a comprehensive pipeline for both educational training and innovation in translational research, and significant financial investment will accelerate innovation — maximizing the potential to emerge as a national leader in the biomedical engineering field. By emphasizing translational research, COE and WCM will bring more advanced diagnostic and therapeutic tools into the medical industry, driving novel approaches to personalized medicine and advancing healthcare.

Long-term recruitment and retention of diverse and talented trainees and faculty is a high priority for Cornell Engineering. We believe that CEIM's success will allow Cornell to attract diverse talent at all levels in an emerging area that promises to revolutionize medicine. These efforts are essential to training the next generation of diverse engineers, life scientists, and clinicians prepared to work across disciplines and who will diversify engineering and medicine.

Finally, it is understood that the COE-WCM partnership is not only a critical component of advancing the President's "One Cornell" priority, but an important next step in the Provost's "Radical Collaboration" initiative. CEIM will contribute to these important efforts by leveraging expertise from other Cornell partners and programs, including:

- Cornell College of Veterinary Medicine
- Tri-Institutional Therapeutics Discovery Institute
- Center for Technology Licensing at Cornell University
- Engineering Commercialization Fellows
- IGNITE Cornell Research Gap Funding Program

BACKGROUND AND ENABLERS

Cornell Engineering is the highest-ranked engineering school in the Ivy League, and WCM is one of the top academic medical centers in the U.S. Together, they have a longstanding track record of successful intercampus collaborations that have led to the establishment of new academic centers, companies, and clinical trials, and have defined Cornell as a leader in these critical areas.

Cornell Engineering at a glance

Bioengineering and human health is one of the COE's four core strategic research priorities. Ongoing activities in this area span the majority of the COE's 11 associated departments and schools. Consistent with the Provost's "Radical Collaboration" initiative, bioengineering faculty have a track record of leading intra- and intercampus research projects, programs, and centers. These initiatives are funded by a multitude of government agencies, foundations, and industry partners — leading to the establishment of new centers, companies, and clinical trials.

Funding from external sources for bioengineering and human health currently constitutes approximately $10 million of COE annual research expenditures. COE research is at the frontier of the field, enabled by the college's recognized excellence in the development and application of cross-cutting technologies, including nano and microfabrication; molecular, cellular and tissue engineering; materials science; advanced imaging approaches; and data science.

World-leading research facilities and academic programs that have attracted outstanding talent already engaged in accelerating discovery and innovation include:

- Cornell Center for Materials Research
- Cornell NanoScale Science and Technology Facility
- Cornell Institute for Biotechnology
- Cornell High Energy Synchrotron Source

WCM at a glance

With its partner, New York-Presbyterian Hospital, WCM sees more than 1.7 million patients every year. It is internationally recognized for clinical care and research — especially in the areas of oncology, neurology, immunology and translational science. Of particular relevance to the CEIM initiatives are WCM's translational research hub, which uses patient data to enable cutting-edge precision medicine, as well as its robust support for interdisciplinary endeavors and industrial-scale technical support for academic projects. Key research institutes include:

- The Englander Institute for Precision Medicine (EIPM)
- The Clinical and Translational Science Center
- The Tri-Institutional Therapeutics Discovery Institute

TASK FORCE REPORT AND RECOMMENDATIONS

1.0 Education

- *How can Cornell Engineering and Weill Cornell Medicine provide innovative and immersive training for the next generation of physicians and biomedical engineers?*

By developing influential inter-institutional models that define the next era of medical education, the COE-WCM partnership can accelerate the production of future-oriented physicians and engineers capable of regularly incorporating new modalities into practice and keeping pace with the rapid rate of technological development.

Investing in partnerships between COE and WCM that provide robust educational opportunities at the intersection of engineering and medicine will position Cornell alumni as leaders in shaping the interface of technology with individual patient care, with the potential to influence the overall healthcare delivery system. Ithaca-enrolled students will benefit from increased opportunities to perform translational and clinical research, and WCM participants would also gain an advantage through training in biomedical engineering training.

Through the more integrative education in human biology, medicine, and engineering provided as a result of this partnership, the next generation will be uniquely suited to solve critical problems in healthcare.

1.1 M.D.-M.Eng. dual degree program

Leveraging the shared strengths of COE, WCM, and Cornell Tech, the university is uniquely positioned to create a dual M.D.-M.Eng. degree for medical students. This would make WCM the only medical school in New York state to offer a master's degree in an engineering field — allowing it to become a top competitor with other schools across the nation that offer this specialization.

There is interest in launching this program almost immediately, as it is expected to have impact well above the levels of investment needed to get it started. For example, a well-defined pathway to the M.D. degree provides unique opportunities for recruiting highly qualified premedical students, especially those who have prior experience and interest in biomedical engineering. Dual degree graduates would likewise have a competitive edge as they pursue residency training programs. They would also be well prepared to push the boundaries of research and entrepreneurial innovation within the biomedical engineering field.

Efforts to develop an M.D.-M.Eng. degree program can draw on the existing framework from the dual M.D.-MBA program that WCM already offers with Cornell's S.C. Johnson College of Business. After the M.Eng. program component is established for WCM medical students, it could also be expanded to medical residents, fellows, and other students.

Financial investment and structural support need to be established so that WCM students have both funding and housing for the year that they spend on the Ithaca campus, while taking an academic leave from their medical studies. Online resources and other opportunities must also be created to solidify the students' core engineering expertise, including in mathematics, design and entrepreneurship, so that they can capitalize on their experience on the Ithaca campus.

As the program grows, it will create a pipeline of students who can further their engineering experience while still matriculating at WCM.

1.2 M.D.-Ph.D. dual degree program in biomedical engineering

There is a great need to develop a dual M.D.-Ph.D. program in the field of biomedical engineering. One possibility to explore is partnering with the WCM Medical Scientist Training Program (MSTP) and adding 12-15 Ithaca-based biomedical engineering labs to the existing MSTP options.

For MSTP students, a straightforward path to a dual M.D.-Ph.D. degree program is to establish a biomedical engineering Ph.D. program directly at WCM. This approach would also support Ithaca's biomedical engineering Ph.D. students and increase research collaborations between

COE and WCM faculty. The program could also be integrated with the WCM Graduate School of Medical Sciences (GSMS). Including biomedical engineering with the other Ph.D. options for WCM MSTP students would create a hybrid program between the WCM and Ithaca graduate schools.

Doing so could allow MSTP students to also explore Ph.D. options in other fields on the Ithaca campus — which would attract more diversely talented and uniquely qualified applicants and would also catalyze opportunities with other colleges for a One Cornell graduate student experience. Further analysis is needed to define the most feasible financial models to jointly manage the program.

Another option to explore, should the MSTP partnership not prove feasible, is a cross-campus M.D.-Ph.D. degree program in which medical studies are completed in New York City and students pursue their Ph.D. through the Nancy E. and Peter C. Meinig School of Biomedical Engineering.

Efforts to support students pursuing this challenging but rewarding degree path should be paramount. Graduate student stipends, housing needs, curricular gaps, and transportation costs (to maximize in-person education) should aim to reduce barriers for pursuing opportunities on both campuses. This work supports the President's priority for creating One Cornell and enhances the overall impact that Cornellians have in the real world. Additionally, it provides straightforward opportunities for philanthropic giving as a component in the university's forthcoming fundraising campaign.

1.3 Intercampus training for all students

Ithaca graduate students in biomedical engineering have been placed in New York City laboratories since the degree was first offered in the early 2000s. Since then, the number of biomedical engineering Ph.D. students working with WCM researchers has continued to grow and interest in rotations/immersions at WCM have increased. There are opportunities for innovating this program to include students at all levels and postdocs from BME and other engineering disciplines where close interactions with clinical practitioners and research provide win-win outcomes for WCM and the COE.

At the undergraduate level, BME is developing a program, with expected launch in 2023, that will require majors to complete a two-week immersion at WCM. The goal is to provide experience in the clinical environment to gain a firsthand view of how hospitals work, observe clinicians in action, and foster ideas in the intersection of biomedical innovation and medical practice. Students will be selected for the two-week program that will be run in the winter session in the middle of the design module. Students will watch procedures, sit in on case discussions, talk with medical residents, follow clinicians, and work on a clinical research project related to their design project. Students will be matched with clinical and research investigators who will help develop students' ability to communicate across discipline boundaries and understand why designs must meet multiple realistic constraints imposed by the clinical environment. Students will benefit by translating their senior design projects from academic exercises to the development of realistic design solutions for the clinical space. This program is in early development and the details of the selection process, recruitment of mentors and collaborators in WCMl, and defining the curricular structure is being developed.

To attract top candidates and provide meaningful research experiences for PhD students, we see opportunities to build on the immersion experience for BME doctoral students and to expand the set of opportunities for graduate students and postdocs to work in faculty labs at WCM. Given the increasing number of WCM GSMS faculty with biomedical engineering appointments, there are many organic situations in which to formalize these relationships and broaden the program to include students and postdocs from other engineering disciplines.

The long-term success of this program will require that research options at WCM are presented to prospective Ph.D. and postdoctoral students in a timely manner. This will require a small support staff to oversee the program and mechanisms for ensuring that Ithaca-enrolled Ph.D. students and postdocs have good access to subsidized housing in New York City, comparable to what is already offered to WCM Ph.D. students. In the future, there are opportunities for leveraging Cornell real estate investments on Roosevelt Island to create the infrastructure and housing arrangements required to support the proposed program.

An important benefit is that it will increase the intellectual diversity of students and postdocs living on the Cornell Tech campus, spawning new opportunities for COE-WCM-Cornell Tech research partnerships that leverage the respective strengths of the three campuses to enhance the outcomes of the original COE-WCM program.

Long-term efforts to develop this new program to its full potential should focus on equalizing the difference in funding models between Ithaca and WCM institutions so that faculty are better prepared to support graduate students who are primarily enrolled at a partner campus.

1.4 Technology innovation program for enhancing patient care

Technology innovation is fundamentally a three-step process beginning with ideation, followed research, and then translation to the market. Historical precedent shows that the process works best when there is a free flow of information between each of the steps, with new discoveries in each step providing critical feedback that drives innovations in the others.

There is a significant opportunity for training engineering and clinical students who are prepared to move beyond the first two of these steps to play leadership roles in driving technological innovation that enhances patient care. COE and WCM specifically aim to leverage their respective programmatic strengths to facilitate the flow of knowledge for technological innovation to enable new opportunities for collaboration, growth, and impact.

For example, physicians and trainees are making increasing use of data science, machine learning, augmented and virtual reality tools, as well as AI for decision-making in clinical settings. These approaches provide rich data streams that may be used to provide feedback to earlier stages of the innovation sequence. Virtual reality technologies can also be expanded in simulation education for both teaching and assessing core competencies in medical education. This includes skills in communication and team training, as well as critical thinking — especially as it overlaps with data science. There are rich opportunities for win-win type outcomes for students educated to approach patient-centered technology innovation using these approaches.

To put this concept into action, the goal is to establish a technology advisory group, or think tank, that draws from the cross-disciplinary expertise of COE and WCM faculty, as well as collaborators at Cornell Tech, including professors of practice — individuals that bring significant real-world knowledge to all aspects of the innovation sequence, amplifying the impacts of the proposed program. This organization will also ensure that students from COE, WCM, and Cornell Tech receive beneficial and complementary training with clear real-world application.

The task force recommends seeking to initiate rapid-action mini-innovation grants in target areas that support the development of pilot programs that complement existing curricular work and program components. These grants will require detailed plans and deliverables that can be achieved within one year — although some grants may be eligible for renewal.

More broadly, the initiation of this grant program will facilitate the continuous development of medical education and open up the potential for students and faculty to receive external funding for scholarship and for technology translation efforts that accelerate the pace with which Cornell research impacts patient care.

2.0 Research

- *How can COE's science and technological strengths most effectively combine with WCM’s strengths in clinical medicine — in both new and existing ways — to catalyze research and innovation for healthcare systems?*

Partnerships between COE and WCM offer tremendous potential for creating pipelines between basic research and applied technology that can then transform individual and collective healthcare.

This synergy will yield new knowledge, tools, and models that can then revolutionize existing strategies for both preventing and treating disease. Building on existing strengths in both colleges, it will be critical to invest in the fields of data science, machine learning, AI, and tissue engineering and organoids.

Over the past decade, by taking advantage of the synergistic strengths of COE and WCM, Cornell has already established itself as an international leader in engineering approaches to cancer, neurotechnology, and immunology. These three areas highlight how centralized efforts emerging from scientific and administrative leadership on both campuses can enable the formation of vibrant collaborations that advance Cornell's overall status as a premier research institution.

By creating mechanisms for all faculty to integrate student education into their research collaborations, COE and WCM are in a prime position to train the next generation of biomedical engineers who will drive innovation in support of public health.

As a first step to formalizing COE-WCM partnerships, the colleges should commit to providing the necessary administrative support for incentivizing established cross-campus projects and for encouraging new investigators to initiate similar work. These efforts will enable people to connect more readily with each other and with resources. By introducing a more structured framework for these types of biomedical collaborations, it will incentivize researchers to seek more innovative opportunities.

In the near future, COE and WCM leadership should develop a faculty steering committee for organizing joint conferences and retreats on relevant topics to help facilitate collaboration. Each research area should also have a campus liaison on the steering committee to support emerging connections and share insight with junior faculty.

The creation of cross-disciplinary immersion programming would advance partnerships between faculty by exposing engineers to the most pressing issues in medical science and by educating physicians on the capabilities of engineering technology and materials. The establishment of seed grants in key biomedical engineering areas would further incentivize and substantiate COE-WCM partnerships, allowing for preliminary data generation that could then be used in subsequent grant applications.

New faculty should also be hired in areas relevant to key COE-WCM partnerships, and recruitment should include cross-campus tours and interviews that showcase the broad range of collaborations. Additionally, developing courses that are co-taught by COE and WCM faculty will foster new educational opportunities.

This overarching model could eventually be used for generating additional intercampus collaborations — ones that could be expanded to other colleges, as well as Cornell Tech. Ultimately, this approach will yield increased funding through multi-investigator grants, center-based grants, industry collaborations and business partnerships, as more emerging technologies are translated into patient care.

Innovation in engineering offers enormous potential to the medical community. By fostering more collaborative research between these two fields, scientists can work together to advance and adapt technologies that allow us to better understand diseases and to provide more personal healthcare to people in need.

2.1 New and developing partnerships

2.1a Data science, machine learning and artificial intelligence

Data science, machine learning, and AI work hand in hand. They show great potential to drive real-world impact, particularly through investments in three strategic areas: AI and computer modeling, personalized medicine, and healthcare logistics.

There is an urgent need to understand how humans can work effectively and efficiently with AI and computer models to enhance patient care. Ideally, the automation of routine tasks should be maximized while leaving critical decisions about individual treatment up to highly specialized experts. As such, personalized medicine stands to gain from additional time and attention dedicated to customizing individual healthcare. AI and computer modeling also play a critical role in maintaining data security and privacy in the management of healthcare logistics.

Both COE and WCM faculty already devote significant energy to the fields of radiology, population genomics, public health emergency logistics, data privacy, environmental and community health, and precision medicine — generally, as well as in the specific areas of infection and immunity.

To motivate additional cross-campus interactions, COE-WCM relationships should revolve around clearly defined outcomes and deliverables. Such work should be incentivized by institutional seed funding and receive support for integrating students into multidisciplinary projects. Additional efforts should be made to recruit joint COE-WCM faculty members.

A dedicated group should evaluate the best opportunities to receive funding from prominent organizations by identifying the priorities of target groups, such as the NIH and the National Science Foundation.

This work can leverage the presidential vision for One Cornell by proposing a university-wide grand challenge or a series of hackathons to tackle specific, unmet needs in this field. From there, the most promising ideas would receive seed funding for continuing research and developing applications.

COE and WCM should also consider establishing a Center for Biomedical Data Science that would house collaborative activities and streamline the management of such interdisciplinary work.

2.1b Tissue engineering and organoids

Through further COE-WCM collaboration, it is paramount to develop the next generation of human organoid models. Using engineered human tissues, these models are key to the future of medical treatment. They can be adapted for high-resolution imaging — for example, to understand how viruses interact with human tissues — and in drug screening, to identify effective therapeutics.

Producing such intricate and realistic models requires strong complementary expertise in many fields, including stem cell biology, immunology, materials science, biomedical engineering, computer science, and nanoengineering.

WCM has already developed a platform for working with vascularized tissues called Organ-On-VascularNet, which has pioneered a method for manufacturing functioning human blood vessels. The discovery will enable better disease modeling, and in the future, may facilitate the production of human transplantable organs. It also has the potential to eventually identify new precision drugs to treat cancer. Working with COE, the team has made additional progress in cardiac tissue engineering, and with support from a cross-campus seed grant, the faculty have taken essential strides to help bring this method for cardiac tissue regeneration into clinical settings.

Such work builds on a deep knowledge of developmental biology and benefits from COE-WCM collaborations that are already studying tissue modeling in chick embryos, zebrafish, mice, and 3D culture platforms. A goal for several of these programs is to bioengineer tissues, limbs, cartilage, and other body materials that may have become damaged by injury, birth defect, or degenerative illness.

Future investment should also be given to cross-campus initiatives that tackle projects like creating organoids through self-assembling stem cells, such that the process mimics natural organ generation in developing embryos. The resulting three-dimensional, bioengineered tissues offer enormous potential to both medical researchers and practitioners. All these efforts would benefit greatly from an overarching COE-WCM partnership to bring together people and resources to catalyze more innovative, solutions-driven projects.

2.2 Established partnerships

2.2a Cancer

Interdisciplinary, collaborative cancer research between COE and WCM is one of the most successful areas of cross-campus collaboration, and it has been funded consistently by large, center-based grants since 2008. This work includes 26 COE faculty from across six departments, and it has the highest amount of annual cancer research expenditures of colleges on the Ithaca campus.

At Cornell, COE has the only two U54 Centers funded by the National Cancer Institute (NCI):

- U54 Physical Science Oncology Center: This $23 million collaboration between COE, the Sandra and Edward Meyer Cancer Center, and WCM's EIPM involves more than 65 investigators and more than 250 trainees of diverse backgrounds, including a 50:50 male-to-female gender ratio. It focuses on cancer metabolism through high-impact translational work and has developed a successful model for community engagement used by the NCI.

- Center for Cancer Nanotechnology Excellence: Only one of six like it in the U.S., this center is supported by seed funding from WCM's Clinical and Translational Science Center. It participates in multi-institutional clinical trials, and it also works on C Dots — the world's first ultra-small optical nanoprobes used to both image and diagnose cancer cells, target tumors, and even induce cell death — for which the FDA granted an investigational new drug approval. This project inspired the biomedical company Elucida Oncology, which has raised more than $70 million to apply C Dots in therapeutic settings.

2.2b Neurotechnology

COE's work in neurotechnology is advancing understanding of mental health and degenerative diseases, including Alzheimer's, schizophrenia, and depression. Accounting for $3.4 million in annual research expenditures, this work benefits from collaborations between 14 faculty across Cornell Neurotech in Ithaca, the Meinig School of Biomedical Engineering, the Department of Neurosurgery at WCM, and the Feil Family Brain and Mind Research Institute.

Notably, collaborations with WCM's Department of Radiology received seed funding to image immune cells in lymph nodes.

Cornell has given an additional seed grant to a cross-college team with faculty in Biomedical Engineering, the Department of Biochemistry, the Helen and Robert Appel Alzheimer's Disease Research Institute and the Feil Brain and Mind Research Institute.

2.2c Immunology

As a subset of immunology, immunoengineering is one of the fastest growing areas of research in COE — experiencing a 13-fold increase in annual research expenditures over the past five years. Immunoengineering uses engineering tools and techniques to regulate and alter the immune system, making it critically important in human health and disease treatment. This field is poised to revolutionize medical strategies for preventing, diagnosing and treating illnesses such as cancer, diabetes, infectious diseases and autoimmune diseases.

COVID-19 vaccines are an excellent example of successful immunoengineering. This approach has great potential for developing other vaccines that could protect against infectious diseases, and it could also help identify the most common causes of cancer.

Immunology at COE covers diverse topics such as the microbiome, infectious disease, virology, immune microenvironment, transplant rejection and immune-modulatory therapies. With key collaborators at WCM and Cornell's College of Veterinary Medicine, new partnerships are also delving deeper into virology and coronaviruses.

Cornell has already made significant investments in this area of research by leveraging the expertise of both COE and WCM. The work benefits greatly from the new Cornell Center for Immunology, which further integrates the research efforts of faculty across the university. WCM also has excellent facilities for this research, including the Ellen and Gary Davis Human Immune Monitoring Core, as well as two pharmaceutical manufacturing facilities that are already slated for upgrades.

Within COE, several programs have been funded by federal agencies and foundations — notably an NIH immunoengineering training grant. Other multi-PI efforts already receive funding from federal agencies and foundations, including the Bill & Melinda Gates Foundation.

Moving forward, to strengthen these efforts and to advance the dual partnerships, COE and WCM should work with the greater university to invest in personnel and infrastructure that catalyze progress in existing and emerging areas of strength.

CONCLUDING THOUGHTS

As COE-WCM partnerships take shape under the umbrella of the CEIM, they must prioritize research that aligns with real-world needs. When defining priorities, an emphasis should be placed on supporting demographic, technology, and healthcare needs at local, national and international levels.

It is essential that CEIM efforts improve the current understanding of human biology and disease, while also developing more advanced diagnostic tools and treatment methods. Efforts should be responsive to changing dynamics and also factor in the role of social inequalities.

Locally, the CEIM should also work with New York state healthcare systems to provide training opportunities for physicians and to help address needs specific to rural communities.

As many COVID-related changes in healthcare become permanent, the need for technological advancement in data science, artificial intelligence, and other robotic automation will increase — especially for remote monitoring and minimally invasive surgeries. Innovation in precision medicine and cell therapy will allow medical professionals to adapt diagnostic and therapeutic approaches to a wider variety of health conditions.

Nationally, the U.S. population is projected to age considerably, so investments should be attuned to medical conditions affecting older adults, such as neurodegenerative, cardiovascular, and musculoskeletal diseases. The American population is also expected to become more racially and ethnically diverse, and both the quality and accessibility of healthcare should strive to overcome the current inequalities that these communities face.

Globally, climate change continues to create unprecedented technological and medical challenges that pose additional risks to human health, in general, and also exacerbate inequalities across national and international communities.

Ultimately, the foundation of the CEIM and the work within the institute are guaranteed to catalyze critical partnerships between COE and WCM, positioning Cornell as a top competitor in the national academic landscape. By integrating education and research programs, the institute will drive research discoveries, technological advancement, and translational efficiency that produce real-world solutions to complex problems and foster the next generation of biomedical engineering and healthcare leaders.