

Strategic Vision of the Department of Biomedical Engineering Pratt School of Engineering Duke University

Executive Summary

In August 2022, the Dean of the Pratt School of Engineering charged each Department in the School to develop a strategic vision comprising “tangible, descriptive, yet broad themes...that will define the future of your discipline.” To accomplish this, the Chair of the Department of Biomedical Engineering (BME) convened a Strategic Visioning Committee (SVC) consisting of BME faculty and staff to collect and distill information from the entire Duke BME community about the state of BME now, and how we should steer our efforts to ensure leadership in our field for the future. Through an extensive series of focus groups, panel discussions, and solicitation of other forms of feedback from all department stakeholders, the SVC proposed and the faculty approved the department’s strategic vision as documented in this report.

The SVC aimed to provide a *vision* for Duke BME, not step-by-step planning. The focus was to properly contextualize BME’s strategic vision within broader societal-scale trends and challenges. This report’s intended audience is broad, from the Duke community, to our intellectual peers, to the next generation of students, faculty, and staff we recruit. It is meant, as well, to clarify who we are and where we are going to the general public, industry, and other interested academic institutions as well as non-academic parties.

Our future builds on our established strengths. Duke BME was founded over 50 years ago, among the first programs of its kind. Our undergraduate program launched in 1967, the PhD program in 1969, and the department in 1971. We became the first ABET-accredited biomedical engineering program in the US in 1972. Our department was created in large part through collaboration with forward-looking individuals in the Duke School of Medicine, and our continuing close relationships with physicians have empowered our research and training. The close proximity of Duke BME to the School of Medicine may be an accident of history but it allows a degree of interchange that is not possible at most other universities. From its origins to the current era, Duke BME has remained a leader in the discoveries and innovations that have driven the field.

This report updates the *Vision and Mission* statements of Duke BME and then provides a critical evaluation of the *Disciplinary Landscape* of the field. Input from our constituents indicated that the core of the discipline is robust in its focus on using engineering to improve human health, but that recent advances, especially in genetics and computing, are causing major shifts. This is coupled with transitions that are occurring in BME education, staff organization, and community both internal to the department (such as prioritizing inclusive excellence) and external (such as increased

outreach efforts). Collectively, re-evaluation of our core and emerging identities led us to define new *Guiding Principles* and the following three *Strategic Directions*:

1. **Enhance core BME research** in the growing areas of:
 - a. *Complex Biologics*, which leverages new discoveries in cell and molecular biology to engineer new medical diagnostics and treatments
 - b. *Computational and Digital Health and Medicine*, which harnesses advances in computing such as artificial intelligence (AI), digital twins, digital biomarkers, and “Big Data” analyses to understand diseases, promote health, and discover therapies and interventions.
 - c. *Health Disparities*, which takes a worldwide approach to improving medical care in all communities regardless of infrastructure or economy
 - d. *Neuroengineering*, which integrates wide-ranging fields from genetics to neurology to turn neuroscience discoveries into clinical treatments
 - e. *Biomedical Imaging*, which provides non-invasive evaluation of health and disease as well as novel image-guided therapies through engineering at the nexus of biology and physics

2. **Re-imagine BME education** to provide the foundations for excelling and leveraging the five research directions identified above. Throughout our undergraduate, Masters programs, and PhD curricula we aspire to enhance:
 - a. Intensive training in *character, ethics, leadership, and professional skills*
 - b. Broad and deep *integration of engineering design and manufacturing*
 - c. Synergies between tried-and-true teaching paradigms and *AI-assisted classroom and lab experiences*,
 - d. Approaches that *acknowledge and benefit from the breadth of our student experiences*
 - e. Concentrations of *industry-focused curricular paths that merit every student’s investment of cost and time*

3. **Strengthen and expand our BME community** to take full advantage of the career-enhancing and outreach opportunities that are uniquely available via active, reciprocal interactions with campus colleagues and broader communities. Our vision is to:
 - a. Build a BME department that prioritizes *inclusive excellence*
 - b. Increase *research collaborations within Duke*
 - c. Enhance *interactions with industry*
 - d. Enhance outreach activities through *partnerships with local schools*
 - e. Expand connections *across the global community*

We conclude by outlining how our five Strategic Directions will guide our *Next Steps*.

Vision and Mission of Duke BME

The faculty of Duke BME arrived at consensus regarding new Vision and Mission statements for our department. The process started with the existing statements, which the SVC updated collaboratively. The statements were then approved by the faculty at the 2023 BME Retreat.

Vision

Through its faculty, staff, students, and alumni, the Duke University Department of Biomedical Engineering creates knowledge and technology in areas of the biological sciences relevant to medicine using engineering approaches. Duke BME aims to improve human health through advances in basic science, preventative medicine, and clinical care.

Mission

The mission of the Department of Biomedical Engineering has its foundation in that of Duke University. Thus, we seek to:

- Prepare our students for lives of skilled and ethical service to their communities by creating an inclusive and open learning environment that fosters their intellectual growth
- Advance the frontiers of scientific inquiry
- Contribute with distinction to the international community of scholarship

As biomedical engineers, our unique mission is to:

- Create new knowledge at the interface between engineering and biomedical science
- Create enabling technologies founded in biological advances for the improvement of human health, well-being, and medical care

We work closely with medical researchers, patients, and the community to identify important problems that impact human health and solve them using our technical expertise. We engage motivated and talented students in the classroom, laboratory, and clinic to prepare them for future careers as effective, knowledgeable, and ethical leaders in public service, industry, and academia.

Disciplinary Landscape

Biomedical engineering uniquely blends the physical and life sciences to address a spectrum of healthcare challenges. It is a rapidly evolving field that bridges the knowledge gap between the microscopic worlds of biology and the macroscopic needs of medicine, using innovative applications of engineering, computing, and physics. Technological innovation in biomedical engineering is steered toward prevention of disease, early diagnosis, minimally invasive interventions, personalized therapeutics, and advancements in regenerative medicine and biofabrication.

The disciplinary landscape of BME is shaped by efforts to tackle a host of grand challenges, some of which include the global burden of disease and aging populations, climate change-induced health risks, pandemics, and health inequities. BME seeks to address these challenges through innovations such as wearable medical devices, biomedical imaging and diagnostic tools, nanomedicine, and AI applications in healthcare, to name a few. Today, one of the prominent trends in biomedical engineering is the integration of AI and machine learning (ML) into scientific discovery and clinical translation. For basic biomedical research, the influences of these computational approaches have already revolutionized protein engineering and genetic analyses. The resulting healthcare impacts will span applications from predictive modeling and precision medicine to neuroprosthetics and drug discovery. These emerging technologies provide potential solutions to improving patient care, mitigating the cost of healthcare, and making the latest medical advances accessible to everyone.

The translational and commercial side of BME continues to grow, with startups and established enterprises alike striving to create groundbreaking solutions. Challenges continue to arise as well, such as higher expectations that innovations provide not only better outcomes but also lower total costs to the healthcare system. Nevertheless, the field continues to be financially lucrative, driven by market demands for personalized medicine, healthcare accessibility, and patient-centric care. The increasing incorporation of digital health technologies, remote healthcare, and telemedicine are reshaping the business landscape and creating opportunities for public-private partnerships. These developments have heightened the importance of data privacy, security, and ethics, hence attracting regulatory scrutiny and policy implications.

From a social perspective, BME plays a crucial role in addressing health inequities, enabling affordable and accessible healthcare, and advancing precision and personalized medicine. There is a growing emphasis on incorporating social and ethical considerations into the design and implementation of biomedical technologies, considering their potential impacts on society.

The disciplinary landscape of BME is in a state of transition. Historically rooted in more traditional areas of engineering, it now incorporates a more comprehensive range of

disciplines including computational sciences, materials science, genomics, complex biologics, and neuroscience. This shift is catalyzing a transition from conventional diagnostic and therapeutic techniques toward the newer focus on precision targeted therapies and preventive healthcare paradigms. The field is moving towards a future where integrated, intelligent systems provide real-time, personalized health information and interventions, pushing the boundaries of what is possible in medical science and health provision. The changing landscape underscores the need for biomedical engineers to embrace a holistic, patient-centric approach that considers the broader societal, ethical, and regulatory implications of their work.

Guiding Principles

The process for arriving at a Strategic Vision for Duke BME involved soliciting input from all members of our community including faculty, staff, students at all levels, as well as alumni and industrial/governmental representatives under the overarching guiding principle that *everyone's voice matters* in defining our future. The Strategic Directions then emerged as the dominant visionary themes from all this input, distilled on the basis of specific guiding principles.

First, the Duke BME community values *interdisciplinary innovation*, which is important for our current and future proposed research foci in Complex Biologics, Computational Health and Medicine, Health Disparities, Neuroengineering, and Biomedical Imaging. All these research areas are the synergistic outcome of integrating engineering, biology, computing, and health sciences in different ways. Duke BME's principle of interdisciplinary innovation also aligns with the current disciplinary landscape, in that biomedical engineering is transitioning to encompass an increasingly broader range of disciplines and technologies.

Another guiding principle is to provide *future-ready education*, underscored by our Strategic Direction of re-imagining the Duke BME curriculum. Our departmental culture values fundamental training in science and engineering but also recognizes the need to cultivate holistic capabilities in our students: technical, ethical, leadership, and professional skills, combined with lifelong learning about how we may best serve the public. The principle of future-ready education reflects the need for biomedical engineers to be versatile problem solvers who can adapt to evolving industry demands and social contexts.

Our third specific guiding principle is that *community and collaboration* is critical to our future as leaders of the field. Our Strategic Directions express the intention to strengthen relationships with alumni, industry, and other research groups both within and outside of Duke. This aligns with the current trends in biomedical engineering, where collaboration across academia, industry, and global institutions is crucial for innovation and knowledge transfer.

Fourth, the principle of *translational impact* strongly motivates our vision, reflected in our Strategic Directions that emphasize increased interactions with industry, collaborations for commercialization, and the broadening of cooperative research efforts. This echoes the wider landscape where biomedical engineering is reshaping the business landscape toward more effective, practical, patient-centric healthcare solutions.

Finally, the guiding principle of *inclusive excellence* was highly motivating, both in terms of accelerating social progress and embracing all perspectives to drive innovation. Our Strategic Directions emphasize embedding efforts toward inclusive excellence in our recruitment, career support, and community engagement. This aligns with the broader societal role that biomedical engineering should play in education and training, addressing health inequities, and promoting healthcare for all communities.

Strategic Directions

A major result of synthesizing the input from all the Duke BME constituencies was to identify themes that constitute new Strategic Directions for our community. Although presented as three distinct visionary elements, they are intertwined. As examples, the identification of the most compelling emerging areas of BME research will inform our educational priorities and collaborations across academic and industry; the emphasis on re-imagining BME education will lead to more synergy in faculty-student relations, promoting new, creative directions in research and entrepreneurship; and diligence in tending to our community interactions will resonate at every level of research, teaching, and outreach. These Strategic Directions are as follows:

1. **Enhance core BME research** in five areas that are becoming prominent in the disciplinary landscape. In each of these areas, Duke BME has a core cadre of researchers but envisions continued strengthening of talent and resources to increase its impact on society. Our vision is to emphasize and expand the following BME research directions (in alphabetical order):

- a. **Complex Biologics**

This field of BME encompasses a range of disciplines and opportunities that lie at the intersection of biotechnology, engineering, and healthcare. It involves the study of the genome and other cellular and molecular domains to develop new therapeutics and biopolymers. Advanced drug delivery methods, tissue engineering, gene therapies, and systems-level approaches that range from immunological and microbiome applications to cancer-fighting biotechnologies play crucial roles in our vision. We believe that the future of complex biologics lies in the integration of high-throughput, automated, and computational approaches with clinical,

human-focused engineering. Collaborations with industry partners and the translation of research into startup ventures (especially in the local community) will further augment the impact of complex biologics, both locally and globally. Moreover, social opportunities include creating personalized medicines and addressing factors like race, gender, and socioeconomic disparities. By promoting the integration of biological principles, policies, and ethics within the broader scientific community, and by democratizing biotechnologies, the strategic vision for complex biologics aims to revolutionize healthcare with a range of bioengineered innovations.

To effectively navigate the future of complex biologics, a strategic direction focused on rapid application and translation of newly discovered biological phenomena is vital. This approach emphasizes agility and fast adoption, transforming contemporary biology into practical applications. The challenges in biomolecular engineering lie in merging different disciplines to create new biologics through theranostic and integrated approaches. By incorporating multimodal measurement and actuation techniques, coupled with innovative design principles, novel biologics with enhanced functionality can be engineered. Specific examples include multiplexed experimental designs and new enabling biotechnologies such as biological barcoding with ever-improving readout strategies to track and localize intracellular processes in ultrafine detail.

Duke BME has played important roles in recent paradigm shifts such as genetic editing via CRISPR, and it is critical to nurture the same forward-thinking mindset and dynamic adoption of emerging technologies to stay at the forefront of the field. This strategic direction also recognizes the importance of training the next generation of engineers to approach problems differently and tackle underserved issues. BME faculty play leadership roles in two of the driving forces for biotechnological training and innovation on campus, the Center for Biomolecular and Tissue Engineering (CBTE) and the Center for Advanced Genomic Technologies (CAGT). The collaborative approach of our researchers will accelerate biological insight and shed light on systems level interactions that are needed to design complex biologics with transformative impact.

b. Computational and Digital Health and Medicine

Data is becoming the most valuable, actionable resource to advance and personalize medicine. Duke BME is at the forefront of leveraging chemical, biological, and physiological data to develop the next generation of computational approaches in pharmaceuticals, health, and medicine. We

embrace a paradigm shift that integrates next generation learning, high-fidelity data acquisition, and physics- and physiology-based modeling in order to improve our ability to find, track, and treat disease. Our researchers draw from their strengths in fundamental engineering to integrate these disparate data types in a secure and scalable manner to build resilient systems. We see computational approaches, including machine learning and AI methods, as tools that can be leveraged to preserve health, develop new therapeutic approaches, personalize treatments with techniques like digital twins that allow for remote monitoring, provide more options for aging in place, and identify novel and longitudinal digital biomarkers for disease detection and monitoring. Digital data streams combined with AI and multi-scale modeling will lay the foundation for innovation and discovery, particularly when it comes to frontline applications in health and medicine. For example, our department is already developing digital biomarkers to detect pre- and asymptomatic infection and cardiovascular abnormalities before catastrophic events like pandemics and life-threatening cardiac events occur. We are also focused on discovering novel drugs, formulations, and therapeutics to enable the safer and more effective treatment of diseases. We expect that automating biomedical research processes will maximize efficiency and broaden our universe of discovery to identify more optimal solutions. To strengthen and expedite advancement in this direction, we have recently hired new faculty whose expertise bolsters these efforts in computational and digital health. Our vision is for these innovative research programs to accelerate, optimize, de-risk, and de-bias the diagnosis and treatment of diseases and, more broadly, improve lifespan and quality of life.

Achieving this vision requires tight integration between the newest methods of data acquisition/generation and data analysis. This integration enables our researchers to create automated, closed-loop learning systems which can adaptively refine online/real-time and longitudinal models, enhance diagnoses, develop therapeutics, support health and clinical decision-making, and improve health outcomes. Next generation technology like artificial intelligence and extended reality for intuitive interaction and immersion in the data will play a major role in improving health information ingestion, virtual treatment planning, and data interaction. Duke BME differentiates itself from peers through its emphasis on blending innovative technologies, from innovative biomaterials and nanoparticles to digital biomarkers and digital twins to high fidelity wearables to virtual reality and spatial computing, all driven by machine learning, to address key hurdles to improve both human health and healthcare practices. The ultimate goal is to precisely deploy such systems on a large scale, for example through telemedicine, and make

them adaptable to function well in underserved communities including low-resource settings.

Duke BME is able to accomplish all this through vibrant collaborations between our faculty and many partner organizations. Positioned at the interface between the Pratt School of Engineering, the Duke School of Medicine, and the Duke University Health System, we enjoy a critical mass of expertise in multi-modal sensing, imaging, multi-scale modeling, diagnostic devices, drug discovery, drug delivery, and AI that makes all these integrated solutions possible. Beyond Duke, we leverage our unique access to data from local, national, and global sources, our alumni networks, and our strong industry connections, thus enhancing our ability to understand the context of the data. We aim to expand all these collaborations to maintain a robust foundation for our continuing intellectual advances.

c. Health Disparities

As an important application area for many of the technologies being developed in Duke BME, local and global health disparities present an urgent societal need. Duke BME is uniquely positioned to lead in this area through its experience working in and with lower-middle income countries (LMICs) and underserved areas of the US. The efforts, however, face serious challenges. We envision systematic, cooperative strategies to overcome those barriers and expand access to BME technologies across society.

One major challenge is the limited computing, internet, and medical infrastructure in LMICs and many areas of the US, especially rural regions. To address this, we aim to focus more on technologies that are economical, flexible, portable, and aware of downstream constraints grounded in the needs of the setting. New systems engineering approaches, along with data-based predictive modeling and integration of solutions that leverage the near-ubiquity of smartphones, would aid in distribution of medical advances. Feedback on the practical utility of these advances, especially in communities with crises of medical staffing, is essential. This can be provided by closer research-oriented collaborations with the Duke School of Nursing. Our research and teaching efforts should emphasize the improvement of models of resource allocation and inventory control in highly constrained environments.

The design of BME technologies for underserved areas must acknowledge two other challenges, as well: inadequate numbers of

trained personnel and limited access to medical data. Turnkey technologies that require general knowledge instead of specialized training, coupled with AI and personal, remote consultations, need to be integrated into our plans. Robotics for remotely controlled procedures would leverage Duke BME's growing expertise in surgical technology. While some LMICs are rapidly adopting electronic health records that are novel, efficient, and often smartphone-based, we need to find ways to use the data more wisely to guide our BME technological innovations and distribution strategies.

The most challenging barriers, however, are sociopolitical. Biomedical engineers are adept at finding solutions to specialized needs, but the tasks of manufacturing products, running clinical studies, or deploying new solutions in many LMICs remain arduous but imperative to enact lasting impact. Networking with policymakers is essential but complex, and new technologies can become stalled in a pilot-only model, bogged down in regulatory procedures, or diverted to European or US agencies for expensive, time-consuming clearance. All of this requires administrative support, resources, and time beyond what is available. Because Duke BME cannot do this alone, we envision closer networking ties with partners such as the Sanford School of Public Policy, the Duke Global Health Institute, the Duke-Margolis Institute for Health Policy, and external foundations. We see tremendous opportunities for such partnerships in getting our tech to more underserved communities, with greater efficiency, safety, and cost-effectiveness.

Duke BME therefore envisions an expansion of our efforts to meet health disparities with technologies that are continuously re-imagined, redesigned, and retested to operate in specific resource-limited environments. These challenges create opportunities for us to lead and innovate with partners who share that vision. In parallel with the research arm of this effort, educational initiatives are critical, including training of faculty in emerging markets. These endeavors will broaden the impact of our departmental mission to serve society.

d. Neuroengineering

The current state of recording technologies for studying the human nervous system is limited, as they primarily capture macro-scale and mesoscale analyses. The field still lacks the ability to directly examine fine-scale neural activity using routine, safe approaches in patients. This is particularly true for clinical neurotechnology development, but related issues limit basic research on non-human primates, the closest lab animal

model for humans. From lab to clinic there is an urgent need for direct measurement of neural activity that targets specific cells and circuits using the latest advances in genetics and proteomics. Additionally, the field of computational modeling has not kept pace with understanding large-scale circuits and their interactions across micro, meso, and macro scales. A major visionary goal of neuroengineering research in Duke BME is to meet those needs. This will require closer collaborations with materials scientists, geneticists, and the computer science community. In particular, advances in AI and large neural network models may play central roles in the conceptual alignment of biological and artificial neural networks.

Directing our neural-related discoveries and inventions to users beyond Duke is essential. The medical landscape of neuroengineering has undergone significant transformation, with numerous brain interface companies emerging. However, there is limited commercial translation and viability, making it essential to explore approaches that align with the pharmaceutical industry's success in developing and delivering neuromedicine. Given the diversity of neural disorders, generalized solutions are needed, but the delivery process of neuromedicine is more complicated than traditional pills. Therefore, finding innovative ways to create accessible neuromedicine for patients in the US and globally, such as over-the-counter neuropills, becomes crucial.

To address these challenges and advance the field of neuroengineering, it is vital to build a more cohesive and tighter community at Duke. This involves fostering a collaborative environment where researchers are more aware of each other's work and expertise, enabling multidisciplinary research training. At the translational level, we need to continue to leverage our direct access to clinician-scientists in Neurology, Neurosurgery, and Psychiatry to adapt our engineering developments into viable therapies. Increased investment by the federal government in the neuroengineering space provides high potential for attracting more grant funding to Duke. To seize these opportunities, it is essential to expand the expertise and attract top talent in the field. This could be accomplished by offering a well-integrated postdoctoral training experience through initiatives like the "Duke Neuroengineering Fellowship" to help attract and retain high-caliber postdocs and consolidation of faculty expertise in a Center for Neuroengineering. By creating a more integrated and collaborative research ecosystem, Duke can position itself more firmly as a leader in neuroengineering, driving progress in neuroscience and the translation of discoveries into tangible benefits for human health.

e. Biomedical Imaging

For over half a century, Duke BME has led the field of biomedical imaging, pioneering the development of impactful clinical technologies. Examples include phased array ultrasound and optical coherence tomography, now in routine use for cardiology and ophthalmology, respectively. Duke BME continues to advance the frontiers of biomedical imaging science by exploring new imaging physics, creating novel instruments, developing advanced sensors and biomarkers, pioneering computational imaging techniques, and bridging information across scales and modalities to allow for deeper mechanistic studies of biology and disease.

Duke BME leverages its close proximity to the Duke Medical Center to translate its cutting-edge imaging technologies from bench to bedside, yielding rapid and widespread impacts to medical care. Duke BME is committed to leading the development of advanced imaging hardware, image analysis software, and the rapidly evolving landscape of ML and AI methods for both the design and interpretation of image data.

Duke BME's focus on biomedical imaging also encompasses high resolution imaging of cells, 3D multicellular systems such as organoids, and *in vivo* and *in situ* imaging tools for small animal models to enhance biomedical insights and to reveal disease progression and pathways. We see a continuing need to create innovative imaging tools for research laboratories, spanning microscopic, mesoscopic, and macroscopic scales and extending from fundamental scientific discovery to clinical applications. Key challenges include the development of faster imaging methods that extend over larger volumes and offer multimodal measurements (e.g., spectroscopic, biochemical, biomechanical, multi-ohmic), along with complementary technologies of high-speed image data management, sharing, and rapid analysis software.

In addition to high-impact research, Duke BME is also contributing to a major push towards democratization of imaging technologies for health monitoring, particularly low-cost screening technologies, wearable imaging devices, and automated (i.e., robotic) and semi-automated imaging methods for community-based services, home use, and low-resource settings. We are developing new image-guided interventions and therapies, such as combining real-time imaging capabilities with novel visualization tools and robotics for applications in surgery, minimally invasive procedures, lab automation, and home health care. Duke BME has a vision to continue its excellence in this field by creating and co-optimizing imaging hardware, software, and related image-guided therapy

technologies to meet these new and exciting application spaces of the future.

Biomedical imaging is well-suited to translation by working with our clinical and basic science collaborators but also via commercialization, through faculty-initiated start-ups and partnerships with industry. This aspect of the field offers unique opportunities to train students within the undergraduate imaging curriculum, the Masters certificate in photonics, and graduate education in topics including optics, ultrasound, MR, CT, data science and the emerging imaging modalities of the future.

Duke BME will reinforce its position as a leader in biomedical imaging by staying committed to training the next generation of imaging scientists and engineers in a vital research environment. Further, we must invest the resources to support our education and research goals in this field, including (a) seeking new tenure track hires to maintain our position in existing thrusts while also establishing efforts in new developing fields, (b) providing curricular support to ensure our students are afforded the training needed to be leaders in biomedical imaging and (c) supporting outreach efforts to promote our department work at the national and international level.

2. **Re-imagine BME education.** While maintaining our current high standards of education with active learning and experiential learning, we envision an improved program that acknowledges the changing priorities of our students, academia, and industry. Our vision is to prepare our undergraduate, Masters, and PhD students to thrive, whether they choose to stay in academia or pursue opportunities in industry including medical devices, biotechnology, and computational applications. To meet these goals, we aspire to enhance:

- a. **Intensive training in *character, ethics, leadership, and professional skills***

When biomedical engineers conduct research, invent devices or systems, and launch entrepreneurial efforts, the results directly affect people; this is a particularly intimate impact that we are honored and humbled to provide. Our department is committed to educating students to serve as leaders in academia, industry, and society. Leadership is informed by high standards of character (e.g., honesty, practical wisdom) and ethics in decision making. Professional skills such as teamwork, communication, and project planning are also necessary attributes of successful leaders. Graduates must be adaptable and responsive to new challenges and have the character to shun shortcuts that increase risk to the public. Experiences to

develop these skills are transmitted in the classroom and through informal and formal mentoring. Supported by learning outcomes in every class, we aim to produce alumni with highly developed professional skills, leadership potential, and ethical judgment.

b. Broad and deep *integration of engineering design and manufacturing*

As a framework for creating solutions to complex, relevant problems, students must deftly integrate both theoretical knowledge and creative, rigorous, practical applications. We envision training that extends seamlessly from design, to prototyping, to fabrication. Our department will integrate engineering design and contextualized problem-based learning at all levels of our undergraduate and graduate curriculum. We recognize that clinical observation, hands-on prototyping, and rigorous testing are key differentiators of our curriculum. Duke BME will continue to hire faculty with expertise in engineering design and manufacturing to establish a vertically integrated program that consists of dedicated course sequences and projects embedded in most courses.

c. Synergies between tried-and-true teaching paradigms and *AI-assisted classroom and lab experiences*

Emerging AI technologies have swiftly changed the landscape of learning. The new tools are disruptive but here to stay, and we envision constructive integration of conventional pedagogy with AI-assisted learning experiences. Particularly impactful for education are Large Language Models (LLMs), which make access to knowledge from a breadth of sources nearly instantaneously available. Moreover, they can make tasks such as analytic math, coding, and solving many textbook-based problems relatively easy. Adapting to this new reality is a work in progress, but Duke BME recognizes the need to reflect on the technical content covered in courses and reshape its teaching strategies, assignments, and evaluation methods accordingly to achieve three goals: (a) synergize with LLMs and next-generation AI tools to take full advantage of the power they offer for learning; (b) prepare students for the “outside world” which will expect facility with the tools; and (c) ingrain in students the scholarly foundation and engineering mindset that is the signature benefit of a university education.

d. Approaches that *acknowledge and benefit from the breadth of our student experiences*

Student perspectives are shaped by a range of prior academic and social experiences before arriving and while at Duke, which motivates us to evolve toward providing a more personalized learning experience. In order to support all students, we need to learn about, acknowledge, and be sensitive to our students' widely varying backgrounds. We aspire to take these individual differences into account when setting prerequisites for classes; developing our syllabi, lectures, courses, and graduate-level certificate tracks; and in personal and professional mentoring of our students.

e. Concentrations of *industry-focused curricular paths that merit every student's investment of cost and time*

Increasingly, industry opportunities are in medical devices, biotechnology, computational domains, and other emerging domains. This commitment to industry-focused curricular paths and research thrusts underscores our mission to prepare our students to thrive in diverse post-graduation career paths. Staying nimble will ensure that our students are readily employable as thought leaders. This vision extends from the undergraduate through the graduate levels, with a particular emphasis on our Masters programs. We aspire to provide ever-evolving certificate programs for our Master of Science student cohort, as well as sustaining a world-class Master of Engineering curriculum with special emphasis on design and entrepreneurship.

We also recognize that the cost of higher education continues to rise and represents a major investment for all our students. Lower-cost or free alternatives spurred by AI and other transformative approaches, along with several competitive programs that have recently launched, will become increasingly attractive. Continuous re-assessment and updating of our degree programs, rooted to the constant of personalized, in-depth training from our faculty and staff, will set us apart in terms of quality of education. To complement that, we also aim to increase financial aid options and improve our job placement rate to further justify the return on investment for our Masters students.

3. **Strengthen and expand our BME community.** It is central to our mission that all members of our Duke community can grow and thrive, as well as contribute their unique perspectives and experiences to enrich our research, administrative, and teaching efforts. We intend to enhance our collaborations within and outside

our existing community to support research, education, service and professional development.

a. **Build a BME department that prioritizes *inclusive excellence***

Our vision is to adopt a deliberative approach that incorporates inclusive excellence as a foundational part of our identity. The principle that career options, resources, and training are equally available to all constituents will be a departmental priority, contributing to policies and decision-making at every stage of employment and every level of our organization.

- i. **Attain a faculty body that *broadens our perspectives as a department***: Effective faculty governance requires a variety of viewpoints that challenge and hone priorities for research, teaching, and service. We envision growing our faculty both in numbers and in their range of ideas, a quality influenced by one's scholarly and personal background. Broadening the Duke BME faculty requires renewed commitment to advertising job opportunities widely, evaluating candidates equally, and assessing them holistically to appreciate the unique ways they could benefit our community. One example of such a benefit is providing a relatable role model for our students, who themselves come from broad backgrounds. Re-alignment of hiring priorities to ensure more openness would apply to both tenure-track and teaching-focused faculty. Strategies for mentoring new faculty, and efforts to keep promotion policies uniformly rigorous and fair, may also need to be re-evaluated to sustain the improvements to faculty breadth.
- ii. **Ensure *enhanced training and promotion opportunities for BME staff***: The Duke BME staff contribute substantially to the regulatory, financial, teaching, research, and administrative infrastructure that makes our enterprise function. We envision improved, robust, continual training programs to gain skills in multiple dimensions beyond their immediate task sets and to provide resilience for the department. Our vision includes the creation of an environment where every staff member has a path to advancement and where their unique contributions are acknowledged and valued. Improvements in cross training would also support another goal: multilayered administrative organization that redefines critical roles that have been traditionally performed by single staff members can now be distributed across a pool of trained personnel.

- iii. **Provide a *supportive community experience* for all members of the Duke BME community:** Duke BME should be a true community; our department is not just a place of work or study, but a community where everyone feels valued and supported. We envision ongoing conversations with all students, staff, and faculty by offering safe venues to voice concerns, share ideas, and influence decision-making. We also aim to improve the physical space of our department, which was impacted by the COVID-19 pandemic. Lastly, we aspire to strengthen social bonds by hosting more regular informal and formal gatherings of everyone in our community.

b. Increase research collaborations within Duke

In the face of rapid technological advancements and the increasing complexity of biomedical research, Duke BME is committed to leveraging the breadth of ideas, approaches, skills, and expertise across all our community. We envision Duke BME to be well connected through active interdisciplinary collaborations to other members within our department, other departments at Duke, Duke Medical and Nursing Schools, and Duke Hospital to promote convergent scientific exploration, engineering inventiveness, and commercial translation. For those teams that tackle clinical problems, further benefit include the many resources affiliated with the School of Medicine (e.g., local patient populations) and the Medical Scientist Training Program.

c. Enhance interactions with *industry*

We have existing interactions with alumni and industry, but these relationships need to be more fully leveraged for mutual benefit. While we gain from hearing about the “real world” employment and entrepreneurial experiences of our alumni and industry partners, they get the opportunity to learn from us and help shape new generations of research products, commercial endeavors, and workforce personnel.

- i. **Partnership to enhance research portfolio:** We envision a future where Duke BME serves as a hub for academic-industry collaborations to pioneer and commercialize novel biomedical engineering solutions. By forming partnerships with industry, we can enrich our research portfolio, better embrace industry needs and trends, and more efficiently and quickly help society with innovative products and services.

- ii. **Entrepreneurship and licensing as means to commercialize:** Our vision is to be a leading department where innovative research ideas find their way from the laboratory to the marketplace. To this end, we are committed to fostering a culture of entrepreneurial thinking among our faculty, complemented by increased support for licensing of innovations, to ease the way for commercialization.
- iii. **Teaching to expand applications:** Duke BME envisions a future where our teaching integrates the wisdom of industry practitioners at all levels of our curriculum. Integrating their insights helps make our curriculum robust to evolving industry landscape and professional career trajectories. This approach would encourage real-world problem-solving and train students to be adept in managing practical challenges.
- iv. **Professional development:** Drawing on the unique skill sets, experiences, and insights of our alumni and industry partners, we envision forward-thinking career development program, especially for graduate students and long-term teaching and research staff. The current mentoring model for graduate students could be improved by increasing interactions with industry, which could support securing jobs. Research and teaching staff members could expand their knowledge of techniques common in industry.

d. Enhance outreach activities through partnerships with local schools

We envision establishing a solid, lasting relationship with local HBCUs to provide select STEM students with research training and mentorship. An existing student-initiated mentoring program has connected Duke BME faculty with NC A&T students, and could serve as a template for more comprehensive, multi-faceted outreach programs. Through existing programs, a small number of local middle school and high school students come to campus. But these and similar programs are generally limited in scope, separate from each other, dependent on external funding, and reliant on leadership from only a few faculty. We envision that the integrated programs, with steady support, strong continuity and growth, and robust grounding in Duke BME's education best practices, will lead to an ever-increasing impact on local K-12 students. They will provide educational and mentorship opportunities that are open to all, including schools and communities with fewer connections to higher education or careers in science and engineering.

e. **Expand connections across *the global community***

We envision Duke BME as a global player in biomedical engineering, fostering collaborations with scientific and engineering institutions worldwide. Through international collaborations we aspire to partner with peers in countries with fewer resources to broaden our perspectives, increase our research and design practice, and deepen our impact. As part of this effort, we aim to contribute to capacity building through knowledge-sharing programs, co-learning, and co-developing curricula to facilitate a two-way pathway for innovation. This recognizes the notion that novel technological development happens everywhere. The connections we make through international collaborations and Duke's Global Health Institute will enable us to confront health disparities effectively. The connections have more direct societal and economic impacts, as well, facilitating the training of biomedical engineers within disparate parts of the world who are uniquely attuned to the needs of their communities.

Leading the Way – Next Steps

As a Strategic Vision rather than a more conventional Strategic Plan, the intent of this document was to stimulate long-term thinking and discussion regarding the future of the department rather than a detailed proposal and schedule for specific initiatives. However, we fully expect the results of this effort to inform and direct our planning efforts over the next several years. To boost the personnel and resources needed to realize our plans, we envision launching three sets of initiatives to help realize our three strategic directions.

1. Reinforce our five core research areas with the people and resources they require. Our recent and current faculty searches are well aligned with the five research directions representing our consensus on the future of biomedical engineering, and our proposals for future faculty searches will also concentrate on these areas. Additionally, we have BME faculty groups currently proposing major initiatives leading to potential Center proposals in Neural Engineering and Computational Medicine. We anticipate that these activities will lead directly to increased department-wide resources and activities through new faculty start-up packages, increased research proposals, and increased graduate student/post-doc/research staff recruitment in these areas. But some resources common to all our research thrusts may need to be provided at the institutional level, for example expanded computational capabilities. Such capabilities could include cloud platform integrations that allow us to (a) deploy data analysis and modeling systems at larger scales and (b) leverage the large AI models that are released on these cloud platforms and are quickly accelerating in their power and utility for computational bioengineering.

2. Empower teaching in BME to always stay current, inspiring, and inventive. Our recent and planned faculty hiring priorities also aim to bolster our already discipline-leading, teaching-focused faculty contingent with broad and deep teaching capabilities. In recent years we have rolled out major curricular updates to keep our courses aligned with the fast-paced realm of biotechnology. In all areas of our undergraduate and graduate curriculum, we have taken a concerted effort to increase problem- and project-based learning. To ensure that the biomedical engineers we train are not only smart and skilled, but also thoughtful about the impacts of the technology, we have initiated an “ethics everywhere” approach across all levels of our curriculum. Re-imagining BME education is a goal of the nascent Center proposals in Neural Engineering and Computational Medicine, as well. Through Center-sponsored training grants, we intend to fund additional student recruiting and consolidation of our curricular offerings in these fields.

3. Nurture an expanded BME community in which research, education, and quality of life thrive. The elements of our vision will be realized by an ever-growing community of people who work with, learn from, and support each other. A major goal is to shift our attention outward to establish a more extended Duke BME family. One way to do that is through our re-invigorated BME Department Seminar series, which will invite speakers from industry and our ranks of alumni. A highlight in recent years was a very popular alumni panel held during reunion weekend, which we plan to make an annual event. Second, each of the new proposed Center activities, as well as all our pre-existing Centers headquartered in BME, have a specific focus on increasing collaborations between and across departments at Duke as well as externally. Finally, we have changed the very structure of our department to work toward a more welcoming, supportive home for all. New leadership roles and committees formalized in our Bylaws are actively ensuring that inclusive excellence is a priority in all departmental activities.

We are determined to realize all the elements of our strategic vision. Along with our colleagues across the nation, however, we are recently facing new challenges. Federal funding has been thrown into turmoil and Duke has begun to take prudent cost-cutting steps in response. Duke BME may need to assess how to achieve its goals with a reduced workforce, student population, and perhaps even faculty base. Research funding may need to diversify more than ever and collaborations may need to expand further than we have imagined. Financial stressors to the US economy may undermine the job prospects of our trainees. We need to be prepared to emphasize the value of biomedical research and translation in our student recruitment and to follow up with increased support of job placement when they graduate. It will be critical to amplify our outreach to the public to explain why BME is vital, but now at risk, to energize societal support for the discipline. Given all of this context, our strategic vision document is especially valuable. It can serve as a compass to help us navigate the coming years. As

a final vision statement added in postscript, we aim to endure by cultivating more adaptability, cooperation, and ingenuity than has ever before been asked of us.

Appendix: Strategic Visioning Committee Membership

Co-Chairs:

Ann Saterbak, *Professor of the Practice*

Marc Sommer, *Professor*

Members:

Matt Brown, *BME Teaching Laboratory Manager*

Jessilyn Dunn, *Associate Professor*

Danielle Giles, *BME Assistant Director of Graduate Studies*

Michaela Martinez, *BME Senior Communications Specialist*

Amanda Randles, *Associate Professor*

Eric Richardson, *Professor of the Practice*

Jonathan Viventi, *Hawkins Family Associate Professor*

Junjie Yao, *Jeffrey N. Vinik Associate Professor*

Lingchong You, *James L. Meriam Distinguished Professor*

Ex officio:

Joseph Izatt, *Former BME Chair and Michael J. Fitzpatrick Distinguished Professor*

Sharon Gerecht, *BME Chair and Paul M. Gross Distinguished Professor*

Administrative Assistance:

Cynthia Meade, *BME Staff Specialist, Undergraduate Program*