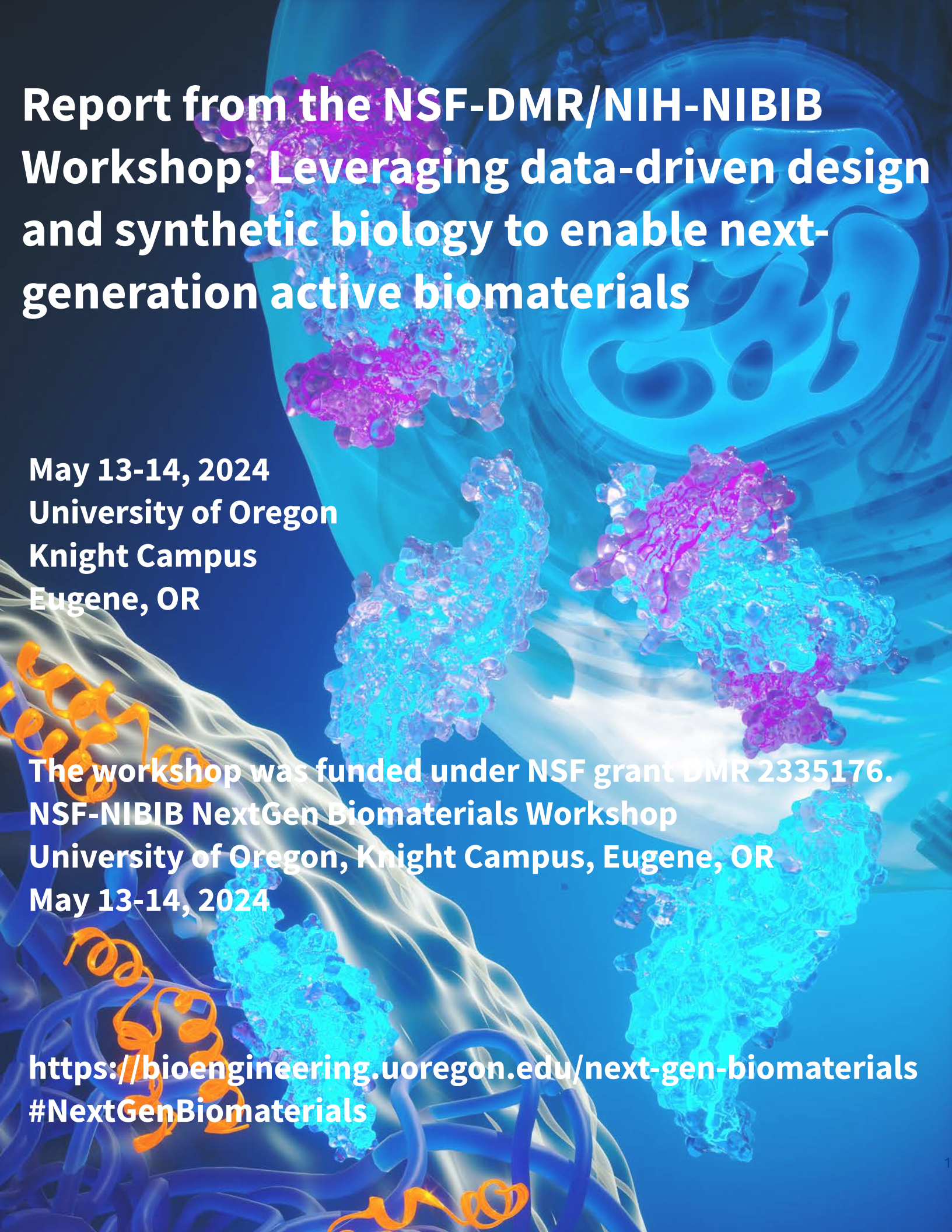
Report from the NSF-DMR/NIH-NIBIB Workshop: Leveraging data-driven design and synthetic biology to enable next-generation active biomaterials



May 13-14, 2024
University of Oregon
Knight Campus
Eugene, OR

The workshop was funded under NSF grant DMR 2335176.

NSF-NIBIB NextGen Biomaterials Workshop
University of Oregon, Knight Campus, Eugene, OR
May 13-14, 2024

https://bioengineering.uoregon.edu/next-gen-biomaterials
#NextGenBiomaterials

Executive Summary

The workshop, “Leveraging data-driven design and synthetic biology to enable next-generation active biomaterials” was hosted by the University of Oregon Knight Campus, Departments of Bioengineering and Chemistry and Biochemistry, and Materials Science Institute on May 13-14, 2024, as part of a new collaboration between the National Science Foundation’s Division of Materials Research (DMR) and the National Institute of Biomedical Imaging and Bioengineering (NIBIB).

Biomaterials have evolved from implanted ‘off the shelf’ materials to rationally designed materials that interact with and instruct biological systems to achieve desired biological outcomes. This “next generation” of biomaterials is currently being developed to meet the growing demand for materials with tailored and tunable properties for numerous biological applications, including tissue engineering, integrative biology, biosensing, and drug delivery. These scientific contributions have shown great promise in advancing numerous biomaterials-based applications. However, a major gap exists in converting these exciting advances in materials science to feasible approaches that can solve pressing biomedical problems, including achieving robust tissue regeneration after injury/disease, tuning localized and on-demand drug delivery, and enabling real-time biosensing.

The workshop explored recent developments in the field and facilitated the development of a multidisciplinary plan to bridge the gap in clinical translation. To facilitate the workshop, 4 integrated Science Drivers were identified as integral to developing and translating next-generation biomaterials: data-driven methods for biomaterials design, synthetic biology-enabled biomaterials, smart/responsive biomaterials, and biofabrication and biointerfaces. As part of the workshop, 51 highly accomplished and innovative experts in these four Science Drivers were recruited from across the US, with representation from academia, industry, government labs, and scientific publishing, to provide insight for hastening the translation of biomaterials. Through virtual pre-work brainstorming sessions and in-person workshop activities, we discussed state-of-the-art in each Science Driver topic to facilitate a dialogue between polymer scientists, chemists, bioengineers, and biologists, and broaden the scope of applications of translational biomaterials to match the diversity of patient populations (ethnicity, gender, etc.). We recruited a broad diversity of participants, especially from historically marginalized groups, to drive creative and unique approaches. Ultimately, we identified key 2-, 5-, and 10-year goals, priorities, and strategies for funding and integrating the Science Drivers.

The major outcomes of the workshop highlight many strengths that position the biomaterials field for a watershed of translatable technologies to impact human health. Integrating synthetic biology, AI, and ML in biomaterials research is creating significant momentum, which is expected to accelerate the development of novel materials and methods. A growing pool of talented researchers is being trained in these interdisciplinary fields, further enhancing their potential impact. Responsive materials and biofabrication technologies are well-established, with foundational techniques advancing and becoming more accessible, leading to a steady pipeline of products under development.

The overarching goal is to revolutionize medical treatments by transforming single-input/single-output systems into multiplexed systems, leading to more complex and effective diagnostics and therapies. Key aspirations include improving disease detection using real-time biosensing, developing advanced topical applications and implantable technologies, achieving societal acceptance, reducing costs, and increasing efficiencies to enhance innovative biomaterials' clinical translation. Training programs and public education aim to prepare the next generation of innovators and raise public awareness and adoption of these new biomaterial technologies.

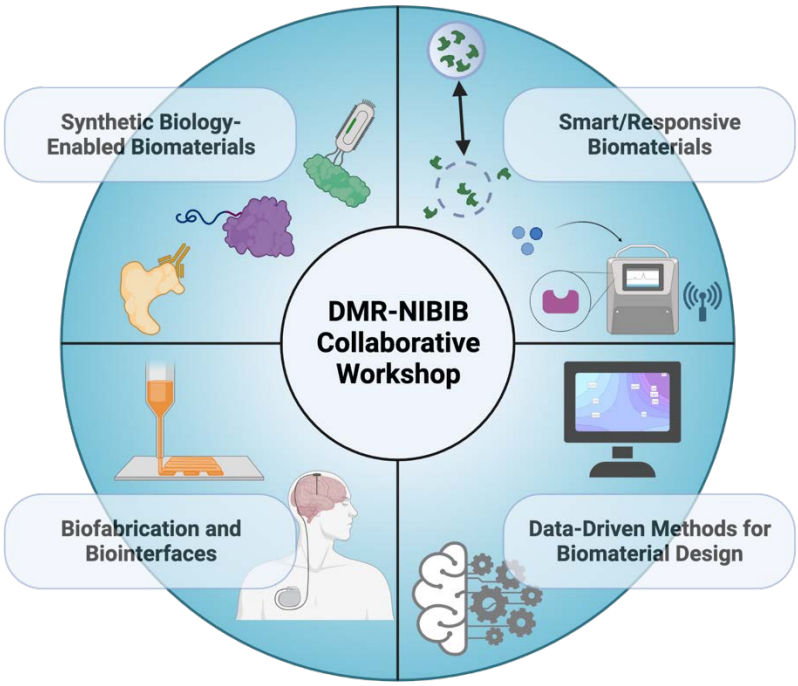
Opportunities lie in developing appropriate funding opportunities to ensure the time and costs of biomedical device development are supported, building highly engaging collaborations across the translational stakeholders, modernizing ISO10993 standards for biomaterials synthesis and characterization, and developing an accessible database for biomaterials. There is potential for creating consortiums, developing training materials, and leveraging existing infrastructure for collaborative efforts. Stakeholders aim to expand the types of materials used, integrate data science routinely, implement

standards that streamline the collection and categorization of biomaterials data, and develop autonomous production methods for biomaterials.

Anticipated outcomes include forging a path to successful FDA approval for multiple biomaterial products, open-source initiatives for data repositories with standardization of methods, data collection, and standard characterization parameters, and routinely incorporating data science tools in biomaterials development. These efforts aim to enhance accessibility and usability and facilitate the reproducible use and development of biomaterials. In the long term, advancements in remote control capabilities of in vivo materials, increased FDA approvals, and improved public awareness and communication strategies are expected.

Introduction

The field of biomaterials has evolved tremendously over the past decade to enable 'programmability' via the incorporation of active and responsive chemistries. These advances leverage highly controlled chemistries and functionalities to enable unprecedented tunability and user-directed or environmentally responsive behaviors. For example, bio-orthogonal or photochemical chemistries have been applied to provide greater control over mechanical and biochemical properties as well as modular tuning of biomaterial properties, while dynamic and reversible chemistries enabled through supramolecular interactions and dynamic covalent bonds have been exploited to develop viscoelastic materials. Advances in manufacturing, processing, printing, and assembly have also provided access to unique hierarchical and complex structural features for materials spanning the nanoscale to the macroscale. Furthermore, tangential advances in synthetic biology and data science have expanded the possibilities in protein- and DNA-based biomaterials and the generation and investigation of large libraries of biomaterials for tunable properties.



To continue along the incredible trajectory of materials advancement and translate these next-generation active biomaterials requires materials chemistry expertise spanning from molecular design to macroscale fabrication techniques and expertise in specific biological applications. These complex systems need to be understood independently, and their interdependency of behaviors in complex systems need to be rigorously characterized. Therefore, the symposium focused on four integrated Science Drivers related to the translation of next-generation biomaterials:

1. Synthetic Biology Enabled Biomaterials
   Beyond traditional chemistry-based efforts to design biomaterials, an approach that shows great promise is using synthetic biology to incorporate active and dynamic materials or engineered cells into a biological system or to integrate active synthetic materials more seamlessly with biological components. These can include protein- and DNA-based biomaterials that leverage unique protein-protein, protein-nucleotide, and other macromolecular interactions. Both cell-free systems and engineered cells can be designed to control complex biological processes within biomaterials. Combining advances in synthetic biology with complementary advances in chemical biology will advance the capabilities of new biomaterials. For example, advances in bioconjugation can enable the precise addition of proteins and other biomolecules to biomaterials.
2. Smart, Responsive Biomaterials
   As the field has moved away from biomaterials that passively interact with their surroundings towards biomaterials that actively integrate with and instruct their environments, the need for smart,

responsive biomaterials that can fulfill this role has increased. The ability to program numerous functions using biomaterials has widened the capabilities of the field. These include biomaterials that trigger temporal immune response activation, present or shield specific protein or cell signals with spatiotemporal control, provide on-demand/triggered drug delivery, and biomaterials that respond to environmental or externally applied stimuli by changing physicochemical properties, releasing cargo, and/or triggering a cascade of cell signaling events.

3. Biofabrication and Biointerfaces
   Traditional implants have been developed to be space-filling with minimal ability to stimulate regeneration of lost tissue and respond to host biological and mechanical inputs. However, more recently developed biomaterials that actively integrate with their surroundings have enormous potential to both fill tissue defects and facilitate the remodeling of the biomaterial into healthy, functional tissue. Research in volumetric 3D printing, bioprinting, tissue-material interactions, and biointerfaces is necessary to develop biomaterials that can fulfill the roles of engineered tissues and actively participate in tissue regeneration.
4. Data-driven Methods for Biomaterials Design
   Considering the tremendous design space available for exploration with current multi-faceted approaches to biomedical problems, the use of data-driven methods, including artificial intelligence (AI), machine learning (ML), and statistical modeling techniques is invaluable in the experimental cycle to focus efforts on the most impactful combinations of variables at the experimenter's disposal. Using data-driven design strategies and large libraries of materials, the process of reaching fundamental understanding is expedited, and the biomaterial can be rapidly optimized and fast-tracked to application-driven stages of development. This methodical experimental exploration is also key to hastening clinical translation and regulatory processes, as the number of new variables is reduced, and iterative design becomes simplified.

Need for the Workshop

Continuing advances in synthetic and chemical biology and the quantitative understanding of biomacromolecular and cellular behavior have created exceptional opportunities for the rational design of biomaterials. Novel biomaterials are being designed using a bottom-up approach to control their structure, rheology, epitope presentation, tailored protein sequestration or repulsion, and transient properties, such as erosion. However, bridging the gap between these exciting advances in materials science and tailoring these approaches toward biomedical problems poses a multidisciplinary challenge.

The basis for our workshop is to envision the next generation of 'smart' biomaterials and biofabricated scaffolds using new approaches in synthetic biology and data-driven methods (Figure 1). While prior conferences may have covered these topical areas individually, they have not been discussed collectively in a workshop format to envision how these scientific drivers can influence the future of biomaterials together. This workshop will be pivotal in establishing and maintaining collaborative efforts in these areas. Showcasing the advances of interdisciplinary investigators while training young scientists of the next generation is also vital to providing nucleation points for new research avenues and fostering the development of the next generation of pioneers.

The DMR-NIBIB-sponsored Planning Workshop, "Leveraging data-driven design and synthetic biology to enable next-generation active biomaterials" brought together 51 highly accomplished and innovative experts in four Science Drivers from across the US, with representation from academia, industry, government labs, and scientific publishing, to provide insight for hastening the translation of biomaterials. The workshop identified tangible 2-, 5-, and 10-year goals, priorities, and strategies for translational success.

Workshop Findings

The workshop included the 2-day in-person event (May 13-14, 2024) and virtual pre-work scheduled in the weeks leading up to the workshop.

Pre-workshop Sessions

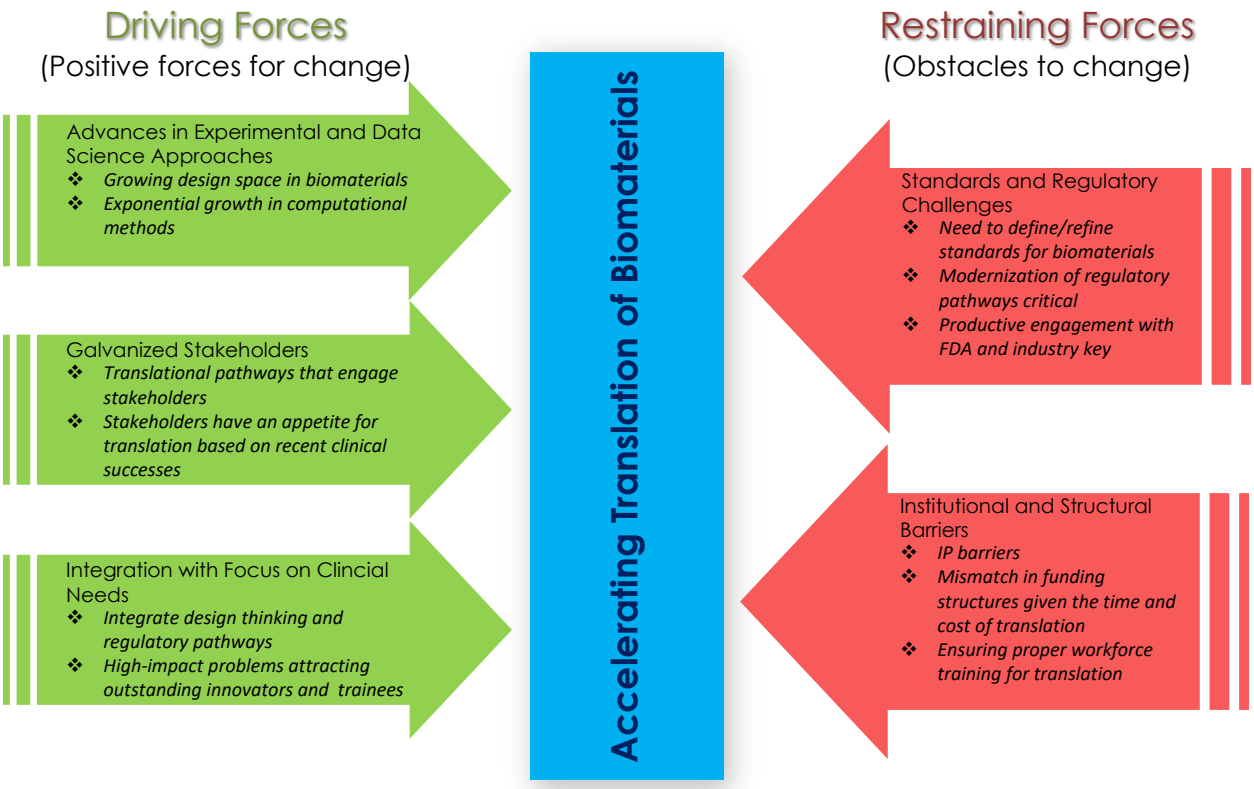
The virtual prework consisted of two 1-hr Zoom sessions organized by the Science Driver Leads to answer the following questions:

- What are the state-of-the-art materials innovations in their Science Driver section?
- What current obstacles are hindering translation of these materials innovations to pressing biomedical problems?
- How can the other Science Drivers be leveraged to overcome translational hurdles?

The pre-work deliverable summarized state-of-the-art, leading-edge, and breakthrough research opportunities in each Science Driver and research connections, techniques/technologies, and barriers to collaboration with the other Science Drivers (see appendix for Science Driver slides). This key pre-work guided our initial in-person discussions.

Workshop Day 1

Based on prework that guided initial discussions on day 1, a force-field analysis was used to investigate bridging biomaterials advances with biomedical applications and accelerating translational research, as summarized below.



Several forces in favor of translation and impact were identified:

Advances in Tools and Approaches

- There is a rapidly growing design space for biomaterials. This momentum in the field is driven by the constant development of new enhanced tools and acknowledgement that these tools have the potential to meet the needs for improved strategies for biomedical applications.

- Data-driven, computational approaches are rapidly being developed and evolving to meet growing demands.

Collaboration and Stakeholder Involvement

- Established translational pathways for biomaterials and historic levels of engagement of clinicians, scientists, and patients further bolster progress.
- Stakeholders (industry, patients, government, physicians, and researchers) have an appetite for translation, shepherded by recent innovations, including the COVID-19 vaccine. This diverse engagement will promote highly collaborative and innovative, translatable developments.

Integration with Focus on Clinical Needs

- Clinical needs are considered upfront, integrating design thinking and defining regulatory pathways.
- Motivating, high-impact problems in the gaps between the bench and the clinic attract trainees to the field.

Several forces hindering translation and impact were identified:

Standards and Regulatory Challenges

- Challenges include the need to define/refine standards for biomaterials development and testing/characterization.
- Regulatory pathways, including biomaterials testing standards and FDA approval pathways, demand modernization to accommodate current innovations.
- Lack of engagement with FDA and industry (manufacturing, licensing) early and often. Communication must be improved between all stakeholders.

Institutional and Structural Barriers

- IP barriers.
- Mismatch in funding structures given the time and cost for bringing products to market.
- Ensuring the future workforce (undergraduate and graduate students) receives proper training to have high impact on translation, including communication, with all stakeholders.

In summary, while substantial forces drive the goal of integrating biomaterials advances into biomedical applications, significant barriers must be addressed to achieve successful translational outcomes in biomaterials.

Day 1 discussions ultimately outlined ambitious 2, 5, and 10-year goals and focus areas in the four Science Drivers.

Synthetic Biology-Enabled Biomaterials:

- **2 Year Goals:** A significant variety of tools exist that span synthetic biology, chemical biology, and biomaterials exist, but these tools may not be known and accessible to all researchers in this multidisciplinary area. Emphasis should be placed on developing standards and toolkits for biomaterials. Stakeholder engagement, including collaboration with machine learning (ML) and artificial intelligence (AI) experts, is pivotal for advancing these goals. The aim is to define key properties, establish repositories of biomaterial components, and integrate these into multiplexable systems leading toward clinical applications.
- **5 Year Goals:** Focus on standardizing data collection and measurement methodologies, potentially collaborating with organizations like NIST for broader adoption. High-throughput methods and educational initiatives for bioengineers become priorities to accelerate biomaterials integration in clinical settings. Outreach initiatives to engage the public and improve public perception and acceptance of clinical biomaterials that contain synthetic biology components.
- **10 Year Goals:** Implementation of standardized practices across all biomaterial studies and applications is envisioned. This includes applying modular biomaterial components to complex systems and advancing toward widespread clinical use. Ultimately, the goal is to create advanced

"living" biomaterials, such as those that can report on and respond to injury and disease environments in real-time, by integrating a variety of synthetic biology tools with biomaterials science.

Data-driven Methods for Biomaterials Design:

- **2 Year Goals:** Establishing metrics and standards while leveraging resources from institutions like NIST and the FDA. Initial phases involve developing foundational projects that could pave the way for future moonshot initiatives.
- **5 Year Goals:** Initiating moonshot projects that demonstrate promising outcomes, focusing on either application-driven or biomaterials-centric approaches. Collaboration across interdisciplinary teams and agencies aims to standardize functional outcomes and test methods.
- **10 Year Goals:** Aspiring to develop AI systems capable of conducting in silico clinical trials for biomaterials. The goal is to create plug-and-play biomaterials that meet specific clinical needs, facilitating scalable manufacturing and adoption.

Smart/Responsive Biomaterials:

- **2 Year Goals:** Establishing databases of previous approaches and outcomes to inform standardization efforts. Identifying critical clinical needs and regulatory discussions are also priorities to guide responsive biomaterial development.
- **5 Year Goals:** Forming stakeholder networks involving researchers, clinicians, and patients to address long-term challenges. Securing funding across multiple agencies supports the development of scenario-responsive biomaterials capable of adapting to environmental changes over time.
- **10 Year Goals:** Achieving scalable manufacturing processes and commercialization pathways for smart/responsive biomaterials and enhancing educational frameworks to integrate these innovations into training programs and establishing standardized in vivo testing methods.

Biofabrication & Biointerfaces:

- **2 Year Goals:** Developing standards and databases amidst current heterogeneity in biomaterials research and exploring high-throughput spatial experiments to better understand and interpret biomaterial performance.
- **5 Year Goals:** Innovating in storage and sterilization techniques for biomaterials. Advancing hybrid multiscale fabrication methods and enhancing bio interfaces with AI-driven manufacturing processes are envisioned to improve temporal control of immune responses.
- **10 Year Goals:** Aspiring to achieve FDA approval for at least one therapy using biofabrication. Developing sentinel and self-adaptive biomaterials representing milestones in enhancing long-term translational success.

In summary, Day 1 ended with outlined goals highlighting a strategic approach to advancing biomaterials science through interdisciplinary collaboration, standardized methodologies, and innovative technologies over defined timeframes. These efforts aim to realize transformative impacts in healthcare, from fundamental research to clinical application and commercialization.

Workshop Day 2

Day 2 focused on integrating strategic goals/approaches into strengths, aspirations, opportunities, and results.

Synthetic Biology-Enabled Biomaterials:

Strengths: There is a notable momentum and increasing interest in integrating synthetic biology with biomaterials research. This convergence has the potential to leverage existing components for developing novel materials. Moreover, a growing pool of talented young scientists is currently being trained in this interdisciplinary field. Synthetic biology techniques are becoming more applicable to a broader range of materials and systems, which enhances their versatility and potential impact.

Aspirations: The primary goal is transforming treatment methodologies from single-input/single-output systems to multiplexed systems, resulting in “living materials” that can report on and respond to injury and disease states in real-time. This approach could revolutionize medical treatments by enabling more complex and effective therapies. Specific aspirations include developing topical applications as a gateway to more complex implantable technologies, such as living bandages, that contain synthetic biology components, and implantable pharmacies, that generate necessary cocktails of drugs on demand. Achieving societal acceptance of these advanced biomaterials is also a key aspiration.

Opportunities: There is an opportunity to establish a consortium or advisory council that would focus on creating standards for data and pathways to commercialization and funding. This collaborative effort could facilitate the development of best practices and standardized methods, ensuring consistency and reliability in biomaterials research. Additionally, centers of excellence, such as core facilities, could be established to promote standardization and serve as hubs for collecting and analyzing data. Developing training materials, kits, and systems incorporating data processing, analysis, and automation is another opportunity to advance the field. Autonomous production of biomaterials could further streamline the development and deployment of these technologies.

Results: The anticipated outcomes include achieving FDA approval for multiple products on topical and implantable sides. There is ongoing progress in tool development and reporting on disease states, such as sepsis in diabetic wounds. It's emphasized that funding initiatives are crucial for research and infrastructure and standardized methods for measuring material properties and responsiveness. This standardization is essential for normalizing reporting practices and providing reliable inputs for training AI and ML systems. Funding opportunities should encourage moonshot projects and training the next generation of scientists and engineers in this growing interdisciplinary area.

<u>Data-Driven Methods for Biomaterials Design:</u>
Strengths: The field benefits from widespread excitement and shared agreement on goals related to AI and ML potential in biomaterials design. A wealth of data is anticipated to be generated, contributing significantly to literature and research. Recent successes in therapeutic biomaterials, such as those developed during the COVID-19 pandemic, have bolstered confidence and engagement in these approaches.

Aspirations: The overarching aspiration is to reduce costs and increase biomaterial design efficiencies while enhancing innovative biomaterials' clinical translation. This involves leveraging AI and ML to optimize design processes and improve outcomes. Strengthening training programs and emphasizing the value of data science in biomaterials research are also key aspirations. Highlighting these values aims to attract and prepare the next generation of trainees effectively.

Opportunities: Similar to synthetic biology-enabled biomaterials, there is an opportunity to establish a consortium or advisory council focused on developing standards and pathways to commercialization and funding. Centers of excellence could be pivotal in standardizing methods and collecting data for future research efforts. Another significant opportunity is developing training materials and systems incorporating data processing, analysis, and automation. The goal is to move towards autonomous production of biomaterials, which would streamline development processes and increase accessibility and reproducibility.

Results: Expected outcomes include the establishment of open-source initiatives and the FDA approval of exemplary biomaterials-based technologies. Routine incorporation of data science tools in biomaterials development is anticipated, enhancing the accessibility and usability of biomaterials. The ultimate aim is to facilitate off-the-shelf distribution of biomaterials and potentially recognize significant achievements in biomaterials design through awards like the Biomaterials Turing Prize.

<u>Smart/Responsive Biomaterials:</u>
Aspirations: Over a 2-year timeframe, there is a focus on enhancing stakeholder engagement through annual meetings and adapting to the rapidly evolving field. Goals for the next 5 years include developing standards for characterization and reporting, sharing best practices, and establishing databases or

standards that labs can utilize. Over the next 10 years, the aim is to increase the number of approved biomaterials that exhibit smart and responsive capabilities, expanding their application in complex systems.

Strengths: Currently, numerous responsive materials are documented in literature and implemented in clinical settings, such as dental and controlled-release applications. This existing foundation presents opportunities for further utilization and exploration. Additionally, investments in characterization centers can be leveraged to expand datasets and ensure robust development in the field. There is widespread excitement and sustained interest in smart and responsive biomaterials, suggesting longevity and growth in this area.

Opportunities: In the near term, there is an opportunity to establish standards for responsive and self-reporting materials. Over the next 5 years, the focus should shift towards developing scenario-responsive materials capable of multiple inputs and outputs, enhancing adaptability in dynamic environments. Looking ahead 10 years, there is potential to integrate non-invasive monitoring technologies with remote-controlled responsive materials, advancing both material science and biomaterial applications.

Results: Expected outcomes include increased access to open-source technologies, advancements in 2D cell knowledge, and progress toward achieving spatial resolution in 3D printing technologies. Over the longer term, there is anticipation of developing smart and responsive tissues and integrating a broader range of materials and cell types.

Biofabrication & Biointerfaces:

Aspirations: In the short term (2 years), goals include training a skilled workforce in biofabrication and establishing standards for the field. Over the next 5 years, aspirations focus on improving storage and transportation of biofabricated materials, public education and adoption, and achieving FDA approval for biotherapies. Looking ahead 10 years, aspirations expand to include AI-driven biofabrication and development of artificial living systems.

Strengths: Biofabrication technologies are well-established, with foundational printing and fabrication techniques already in place. These technologies are advancing, with printers capable of maintaining high cell viability and becoming more accessible across various laboratory settings. Products based on these technologies are already in development pipelines, indicating continued interest and investment.

Opportunities: Over the next 2 years, an opportunity exists to integrate a broader range of materials into biofabrication techniques, including electronically activated materials. This period also presents a chance to connect stakeholders and establish collaborations that enhance the diversity and application of biofabricated materials. Looking forward 5 years, challenges such as transportation and sterilization of biofabricated materials will be addressed, alongside advancements in self-adaptive or sentinel biomaterials and bio-hybrid brain interfaces. Over 10 years, the focus will expand to include achieving additional FDA approvals for smart materials and improving public awareness and acceptance of these technologies.

Results: In the near term, efforts will focus on identifying clear clinical needs and applications where smart materials can significantly impact. Anticipated outcomes include advancements in remote control capabilities of in vivo materials and increased FDA approvals for smart materials. Over the longer term, there is an expectation of refining communication strategies to better articulate the benefits of smart materials already approved for use.

Appendix

Workshop Organizers and Participants

Workshop Facilitator

Kate Petcosky-Kulkarni - kpetcos2@uoregon.edu
Assistant Vice President, Strategic Research Initiatives, Research and Innovation, University of Oregon

Kate Petcosky-Kulkarni is the Assistant Vice President of Strategic Research Initiatives at the University of Oregon. In this role, she oversees Research Development Services (RDS), which supports faculty in increasing their externally funded research activity by identifying funding opportunities and providing writing and editing support to help researchers craft competitive grant proposals. In addition, RDS offers training to researchers, coordinates internal seed funding programs, and assists faculty in managing proposal development for complex, multi-project proposals.
Prior to joining UO, Kate was the Director of the Office of Proposal Development at Boston University School of Medicine.
Kate received her B.S. from Boston University and obtained an MA in food studies from New York University and an MPH, with an emphasis on global health, from Boston University. In 2016, she was selected as a Global Health Storytelling Fellow with the Pulitzer Center on Crisis Reporting to travel to India to explore and report on experiences of individuals living with disabilities, the intersection between poverty and disability, and cultural attitudes toward disability. Her work was published by NPR and Johns Hopkins.

Workshop Science Driver Leaders

Marian Hettiaratchi - mhettiar@uoregon.edu
Assistant Professor, Department of Bioengineering, Knight Campus, University of Oregon
Marian Hettiaratchi officially joined the Knight Campus in January 2020. Prior to that, she was a post-doctoral fellow at the University of Toronto where her research focused on combining chemical and biomedical engineering approaches to create effective biomaterials that can precisely deliver proteins for tissue repair. She holds a bachelor's degree in chemical engineering with a biomedical specialization from University of Calgary and a doctorate in biomedical engineering jointly from Georgia Tech and Emory University. Her work involves developing protein delivery vehicles for regenerative medicine by integrating cutting-edge techniques in protein engineering, polymer chemistry, and computational modeling to design versatile, clinically-relevant biomaterials. As an educator, Hettiaratchi said she enjoys bridging the gap between fundamental and translational knowledge to develop innovative healthcare technologies and educating the next generation of engineers and scientists to do the same. She is committed to developing initiatives to make science, engineering and math more accessible to students from underrepresented groups, by fostering inclusivity in the classroom and diversity in research. Professor Hettiaratchi has been the recipient of the NSF CAREER Award, Tissue Engineering Regenerative Medicine International Society – Americas (TERMIS-AM) Young Investigator Award, and University of Oregon Early Career Outstanding Research Award.

Mike Pluth - pluth@uoregon.edu
Associate Vice President for Research, Research and Innovation, University of Oregon
Professor, Department of Chemistry and Biochemistry, University of Oregon
Mike received his B.S. in chemistry and applied mathematics from the University of Oregon in 2004, where he conducted undergraduate research with Prof. David Tyler. He earned his PhD in 2008 as an NSF predoctoral fellow under the joint direction of Profs. Robert Bergman and Kenneth Raymond at UC Berkeley, where he investigated supramolecular chemistry and proton-catalyzed reactions in supramolecular hosts. Mike then moved to MIT, joining the research group of Prof. Stephen Lippard as an NIH Pathway to Independence Postdoctoral Fellow, where he investigated methods for biological nitric oxide detection. In 2011, Mike joined the faculty in the Department of Chemistry & Biochemistry at the University of Oregon as an Assistant Professor and was promoted to an Associate Professor in 2016 and Professor in 2020. He is also a Member of the Materials Science Institute, a Faculty Associate of the

Knight Campus for Accelerating Scientific Impact, and an Associate Member of the Institute of Molecular Biology. He has served as an Associate Vice President for Research at the UO since 2018. He is a recipient of the NSF CAREER Award, Alfred P Sloan Fellowship, Camille Dreyfus Teacher Scholar Award, and a fellow of the American Associate for Advancement of Science. His research interests are thematically based on different aspects of molecular recognition at the interface of bioorganic and bioinorganic chemistry. Much of his lab focuses on developing chemical tools for investigating the roles of reactive sulfur species in biological systems.

Ramesh Jasti - rjasti@uoregon.edu
Professor, Department of Chemistry and Biochemistry, and Director of the Materials Science Institute, University of Oregon
Professor Ramesh Jasti was born in Concord, North Carolina (1st generation in the United States) and attended the University of North Carolina-Chapel Hill as an undergraduate. At UNC, Prof. Jasti synthesized and characterized gold nanoparticles in the laboratories of Professor Royce Murray. This early research experience sowed the seeds of his future interests in interdisciplinary research and nanoscience. After graduation in 1998, Professor Jasti worked at a start-up pharmaceutical company for three years in the Research Triangle Park. Having found great interest in organic synthesis, Prof. Jasti conducted his graduate education under the guidance of Professor Scott Rychnovsky at the University of California, Irvine. Prof. Jasti's graduate research led to the unraveling of numerous mechanistic aspects of the Prins cyclization reaction. After obtaining his PhD in 2006, Prof. Jasti started as a postdoctoral fellow with Professor Carolyn Bertozzi at The Molecular Foundry, a brand new nanoscience institute at the Lawrence Berkeley National Laboratory. At Berkeley, he began to explore the concept of attacking problems in nanoscience utilizing organic synthesis as an enabling tool. Having joined Boston University in the summer of 2009, this basic idea continues to be the overarching theme of the Jasti Research Group. Professor Jasti received the NSF CAREER Award, and Alfred P. Sloan Fellowship, as well as a Camille Dreyfus Teacher-Scholar Award. In the summer of 2014, he moved to the University of Oregon where he is currently a Professor in the Department of Chemistry & Biochemistry and Director of the Materials Science Institute.

Danielle Benoit - dbenoit@uoregon.edu
Lorry Lokey Chair of the Department of Bioengineering, Knight Campus, University of Oregon
Danielle Benoit is the Lorry Lokey Chair of the Department of Bioengineering. Her research specializes in the rational design of polymeric materials for regenerative medicine and drug delivery applications. Before joining the Knight Campus, Benoit served as the University of Rochester's William R. Kenan, Jr. Distinguished Professor in the Department of Biomedical Engineering and Director of the Materials Science Program. Her work has provided insights into the translation of tissue engineering strategies for bone allograft repair, development of pH-responsive nanoparticles for nucleic acid and small molecule delivery, and novel targeting strategies for bone-specific delivery of therapeutics. An award-winning researcher, teacher, and mentor, she is an NSF CAREER recipient, Fellow of American Institute of Medical and Biological Engineering, the Biomedical Engineering Society, the National Academy of Inventors, as well as Deputy Editor of the Journal of Biomedical Materials Research Part B and Associate Editor for Science Advances. As chair, Benoit plays an instrumental role in the continued development of the Department of Bioengineering, including shaping and maturing the research and educational portfolio, coordinating fundraising, outreach, and alumni and industry relations, and hiring of approximately 15 new faculty as Phase 2 of the Knight Campus is completed. These efforts are critical to advancing the Knight Campus mission of translating research discoveries into innovations to improve the human condition.

Benoit received her Ph.D. from the University of Colorado and completed her postdoctoral fellowship at the University of Washington in the Department of Bioengineering. She holds a B.S. from the University of Maine, Orono, in Biological Engineering.

Participant List

Science Driver: Data-Driven Methods for Biomaterials Design		
└Danielle	*Benoit*	*University of Oregon*

Anna	Balazs	University of Pittsburgh
Bill	Cresko	University of Oregon
Kaitlin	Fogg	Oregon State University
Adam	Gormley	Rutgers University
Jason	Guo	Stanford University
Parisa	Hosseinzadeh*	University of Oregon
Daniel	Reker	Duke University
Kennth	Sims	Battelle Memorial Institute
Michael	Webb	Princeton University
Science Driver: Synthetic Biology-Enabled Biomaterials		
└Marian	*Hettiaratchi*	*University of Oregon*
Anne	Meyer	University of Rochester
April	Kloxin	University of Delaware
Calin	Plesa	University of Oregon
Cole	DeForest	University of Washington
Danielle	Tullman-Ercek	Northwestern University
Hugh	O'Neill	Oakridge National Labs
Carolyn	Mills	University of California Santa Barbara
Shawn	Owen	University of Utah
Tara	Deans*	Utah/Georgia Tech
Shadi	Mamaghani*	National Science Foundation
Science Driver: Biofabrication and Biointerfaces		
└Ramesh	*Jasti*	*University of Oregon*
Bala	Ambati	University of Oregon
Konane	Bay	University of Colorado, Boulder
Luiz	Bertassoni	Oregon Health Sciences University
Paul	Dalton	University of Oregon
Felix	Deku	University of Oregon
Andres	Garcia*	Georgia Institute of Technology
Tim	Gardner*	University of Oregon
Melissa	Grunlan	Texas A&M University
Bob	Guldberg	University of Oregon
Nathan	Jacobs	University of Oregon
Gabrielle	Lindberg	University of Oregon
Keat Ghee	Ong	University of Oregon
April	Rodd	Wiley
Molly	Shoichet*	University of Toronto

Matthew	Webber	University of Notre Dame
Nick	Willett	University of Oregon
Science Driver: Smart/Responsive Biomaterials		
└*Mike*	*Pluth*	*University of Oregon*
Mark	Blaine	University of Oregon
Simone	Douglas-Green	Georgia Institute of Technology
Tayler	Hebner	Purdue University
Jim	Hutchison*	University of Oregon
Germano	Iannacchione*	National Science Foundation
Abraham	Joy	Northeastern University
Juana	Mendenhall	Morehouse College (HBCU)
Teresa	Rapp	University of Oregon
Daniel	Savin	National Science Foundation
Carolyn	Schutt Ibsen	Oregon Health Sciences University
Anita	Shukla	Brown University
Hadley	Sikes	Massachusetts Institute of Technology
Taylor	Ware	Texas A&M University

**Participated in Pre-Work Sessions Only*
└Science Driver Leads

Workshop Detailed Agenda

Next Generation Biomaterials Workshop Agenda

DAY 1: May 13

8:30-9:30: Registration and Continental Breakfast
Facilitated Introductions

9:30-10:00: Opening Remarks and Welcome (Danielle Benoit)
Shared agreements, Agenda, and Introduce Module 1 (Kate Petcosky-Kulkarni)

10:00-10:30: Session 1 (Force Field Analysis) - Breakout

- ***GOAL***: Identify forces for and against ultimate goal (bridge gap to translation) to help frame overall goals
- ***STRUCTURE*****:**
  - 5 minutes: individual brainstorm (forces for & against change)
  - 10 minutes: paired or small group brainstorm
  - 15 minutes: group

10:30-10:50: Module 1 (Force Field Analysis) - Full Group

- ***GOAL:*** Identify forces for and against ultimate goal (bridge gap to translation) to help frame overall goals
- ***STRUCTURE:***
  - Kate to share full Padlet board
  - Additional grouping
  - Invite questions/responses
  - Encourage participants to have this frame of how to overcome forces against and leverage forces in support as they continue to brainstorm throughout the workshop
  - At conclusion, introduce Session 2

11:00-12:00: Session 2 (Carousel)

- ***GOAL***: Level setting across groups by having them understand outcomes/discussions from other Science Driver pre-workshop sessions
- ***STRUCTURE*****:** Focused conversation design
  - Each Science Driver lead will remain in their driver room
  - Graduate student will time keep and help note take (if needed)
  - 12 minutes per room, 3 min transition time
- Instructions:
  - Science Driver to give brief overview of discussions/share points (Objective Data)
  - Invite reactions/questions from participants (Reactions)
    - *Gut instincts/responses*
    - *Red flags, major gaps?*
  - Invite participants to use post its to add (Synthesis/Analysis)
    - *Research question you could tackle related to this driver*
    - *Scientific breakthrough or outcomes you could envision related to this driver at 2, 5, 10 years*

12:00-100: Lunch

1:00-2:25: Session 3 (Original Science Driver Groups)

- ***GOAL***: Integrate/understand/respond to other drivers; begin translating opportunities to timeline of potential discovery
- ***STRUCTURE:***
    - 1-1:15: Driver lead invites responses/feedback from Module 1
        - What stood out from your walk through?
        - What was surprising?
        - What were reminded of?
        - What shifts for us?
        - What are the implications for how we initially thought of this driver?
    - 1:15-1:45: Transition to Timeline
        - 5 minutes: individual brainstorm (using handouts)
        - 10 minutes: Pair or small group (write on post its)
            - What are key research milestones we could see in these areas in 2, 5, 10 years
        - 15 minutes:
            - Groups report out and post on timeline
                - Driver facilitates Q&A as groups clarify/adjust potential timing/etc.
    - 1:45-2:30: What is needed to GET us here?
        - Driver facilitates discussion (grad student or facilitator note takes) on key gaps, major questions to pose to full group
        - Clarify major items to share in report back to group

2:30-3:30: Session 4 (Report Back & Discussion)

- ***GOAL***: Share outcomes from each discussion, identify shared priorities/discoveries, clarify/questions among groups
- ***STRUCTURE*:**
    - 8-10 minute "report back" from each driver on
        - Research milestones for 2, 5, 10 years
        - Key barriers or research questions needed to enable those discoveries
        - Big questions to pose to full group
    - After each Science Driver, 5 minutes for appreciations/suggestions/additions
        - If audience unresponsive, pivot to talk to neighbor and then ask for large group report back
    - Q&A discussion

3:30-4:30: UO Tours/Break

4:30-5:30: Posters Session

5:30: Dinner

DAY 2: May 14

8:30-9:00: Continental Breakfast

9:00-9:15: Welcome and Agenda

- Overview of Agenda for Day (Kate)
- Introduction for Module 2 (Kate)

9:15-10:15: Session 1 (Carousel)

- ***GOAL***: Identifying opportunities for to accelerate progress to research milestones through collaboration

- ***STRUCTURE*****:** Focused conversation design
    - Each Science Driver lead will remain in their driver room
    - 12 minutes per room, 3 min transition time
- Instructions:
    - Report backs allowed for sharing of "objective data"
    - Driver invites questions/clarification
        - What concerns do you have? What are opportunities? What is exciting?
    - Driver invites participants to add to timeline
        - Identify research collaborations or opportunities that could accelerate achievement of milestones
        - Pose solutions/strategies to address barriers

10:30-11:30: Session 2 (Original Science Drivers)

- ***GOAL:*** Streamline/coalesce ideas generated from prior discussions (integrate feedback from carousel) to coalesce around opportunities for investment
- ***STRUCTURE***
    - ***SOAR analysis: 2, 5, and 10 years***
        - Strengths (Assets, Areas to strengthen)
        - Opportunities (Specifically brainstorm NIH/NSF investment)
        - Aspirations (impact on field/society)
        - Results (What do we want to achieve)
    - 5 minutes: introduction to activity
    - 5 minutes: individual brainstorming (using worksheet)
    - 10 minutes: paired or group brainstorming
    - 20 minutes:
        - Circulate in 4 groups and circle 3 key ideas
        - Discuss/prioritize ideas from each 4 quadrant (SOAR) that will be shared back with group

11:45-12:30: Session 3 (Report Back & Discussion)

- ***GOAL***: Share outcomes from each discussion, identify shared priorities/discoveries, clarify/questions among groups
- ***STRUCTURE*****:** All attendees in Beetham, Kate to facilitate
    - 8-10 minute "report back" from each driver on SOAR discussion
    - After each Science Driver, 5 minutes Q&A discussion
    - Final concluding remarks (Kate and/or Danielle?)

12:30-1:30: Lunch

1:30-6:00: Free Time Activities

6:00: Dinner Off Site

Science Driver Pre-workshop Slides