Outcomes of Workshop Series on Using the Rules of Life to Address Societal Challenges

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Working Group on Using the Rules of Life to Address Societal Challenges

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Facilitated by
Knowinnovation

Events in the Series

Town Hall

Workshop Orientation

Workshops:

1 - Stewarding an Integrated Biodiversity-Climate System

2 - Achieving a Sustainable Future

3 - Harnessing Microbiomes for Societal Benefit

4 - Leveraging AI and Data Science for Predicting Mechanisms

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Workshop Process

Events

This series consisted of six virtual events. A 4-hour Town Hall, held on March 15, 2022, was open to all who registered. This was followed by five workshop events for which attendance required application and subsequent invitation. A 1.5-hour Workshop Orientation was held for all invited workshop participants on April 12, 2022. Four 6-hour Workshops were held on April 14, 19, 21, and 26, 2022. Approximately 100 participants were invited to each Workshop. A list of participants is included in this document.

Defining the Workshop Topics

Registrants for the Town Hall meeting were asked to provide societal challenge ideas. These were clustered by the workshop organizers and presented at the Town Hall for participants to further cluster. Approximately 80 initial topics fell into nine clusters, five of which overlapped with recent NSF-sponsored workshop and thus were deemed of lower interest. The remaining four topics were selected as the themes of this workshop series: Stewarding an Integrated Biodiversity-Climate System; Achieving a Sustainable Future; Harnessing Microbiomes for Societal Benefit; and Leveraging AI and Data Science for Predicting Mechanisms. The community was invited to apply to participate in the workshops.

Scoping the Societal Challenges

At the Orientation Workshop held on Tuesday April 12, participants were invited to identify what they considered to be the most important challenges related to the overall themes of the workshops they would be attending. These challenges were reviewed by the organizing team and presented as starting points for discussion at each of the workshops.

Defining Science Questions

Each workshop was one day long. At the beginning of each workshop, participants first broke out into small interdisciplinary groups and generated a long list of Science Questions that might need to be addressed if we are to tackle the societal challenges. Each breakout group then converged on what they considered to be the most compelling question in their group, creating for each Workshop a short list of Science Questions to pursue further.

Generating Research Questions and Exploring as Project Ideas

Participants selected one Science Question drawn from the shorter list to develop in more detail all the way from Societal Challenge to Science Question to Research Question to Project Idea, considering how Rules of Life could be applied. Outlines of research proposals included defining multidisciplinary expertise required, specific aims, potential training activities, and descriptions of what impacts on society might accrue. As the Workshops progressed, two ideas that emerged included the benefits of more explicitly emphasizing societal impact of the research as a broader impact consideration and including elements of diversity, equity, inclusion, and access in developing the research itself.

Outcomes

Representative outcomes of the four workshops are presented below in Tables 1-4.

Table 1. Outcomes of Workshop 1 - Stewarding an Integrated Biodiversity-Climate System

Representative societal challenges and corresponding science questions and research questions developed by workshop participants

Societal Challenge	Science Question	Research Question
How might we address the biodiversity-climate challenges through the use of concepts of feedbacks and tipping points?	How might we develop and use new tools to assess and identify feedbacks and tipping points? can machine learning, new statistical and hypothesis-building approaches using large databases globally available move forward integrative thinking about systems and systems thinking?	When are tipping points at different scales of coupled biodiversity-climate systems detectable from early warning signals, in which subcomponents of the system do these signals manifest, and how do we identify them (mechanistic models, ML, AI)?
How might we better predict the impacts of climate change and climate events on biodiversity at different spatial and temporal scales?	How might we quantify the links between social and economic processes and drivers and dimensions of biodiversity that depend on, but also have feedback on, climate?	What are the relationships between biodiversity hotspots in linked aquatic and terrestrial systems and people, how do they change with climate change, and how do they in turn drive social and climate changes? What are the ecosystem cascades, and how do those link with climate and society?
How might we address the interconnected biodiversity-climate system while balancing various tradeoffs, such as short- vs. long-term and/or public vs. private gains?	How might we address the interconnected biodiversity-climate system while balancing various tradeoffs, such as short vs. long term and/or public vs. private gains?	How do interactions among global change drivers (climate-disturbance-disease-invasions-eutrophication) and processes operating across biological scales generate rapid change or tipping points in ecosystems?
How might we account for, or mitigate, the disruptive effects of unexpected global or local events (e.g., global pandemics or geopolitical conflicts, or localized disasters like wildfire and flooding) in stewarding the biodiversity-climate system?	How do we put stochasticity of events into predictive models and policy choices?	Develop a generalized model for prediction of risk for (rare) random catastrophic event in foundational/keystone species, and its consequences to biodiversity (incl. humans). To choose an ecosystem-based extinction/extirpation-level event as an example to fit into the generalized model to work backward & forward to identify causes & consequences (e.g., a validation exercise).
How might we incorporate understanding of the past (climate, anthropology, ecosystems, geology, sea level rise) to devise strategies for stewarding the biodiversity-climate system?	How might we learn from past biological species explosions to be able to facilitate biodiversity increase rather than focusing on stopping the decrease. Could be speciation, genetic manipulation, rewilding…	By understanding the genomic basis of biocomplexity, how can we plan for successions that bridge ecosystem functions from carbon sources to carbon sinks in agro-intensive systems?

Societal Challenge	Science Question	Research Question
How might we apply modeling and AI analyses of biodiversity and climate data to help us predict beneficial changes?	How do we engage with frontline communities to create modeling scenarios that are informed by 1) challenges in communities, and 2) solutions that have explicit benefit to these communities?	How can we incorporate local knowledge of cultural, behavioral, and socio-economic processes into bio-geophysical modeling while empowering frontline communities?
How might we address biodiversity loss and climate change mitigation at different scales, e.g., geographic, temporal, and spatial?	How might we create, support, and sustain interdisciplinary teams to integrate seemingly disparate datasets and facilitate larger ecosystem perspectives?	What are the characteristics of successful interdisciplinary teams that address biodiversity loss and climate change mitigation at different scales?
How might we address biodiversity-climate challenges in stages to avoid the tendency for 'perfect to become the enemy of good'?	What are the climate-biodiversity hotspots at the confluence of ecosystem carbon sequestration, ecosystem function maintenance, human impacts, and feasibility of solutions?	How can we characterize and map multifunctional biodiversity-climate hotspots that integrate knowledge and values across disciplines and communities to maximize global conservation and climate-change mitigation?
How can we characterize and map multifunctional biodiversity-climate hotspots that integrate knowledge and values across disciplines and communities to maximize global conservation and climate-change mitigation?	How might we utilize models of the dynamic world to better collectively define a successful (or, less painful) future and design equitable and forward-looking initiatives towards this goal?	No research questions were developed from this question.
How might we leverage the experience and knowledge of indigenous populations to tackle local biodiversity-climate challenges and apply the lessons learned broadly for the benefit of the local community and beyond?	How might we: ● Elicit, engage with, and curate (perhaps via a database) people's experiential and traditional knowledge of the natural world and biodiversity resilience ● Center natural history as a basis for understanding the natural world ● Integrate "science" ways of knowing with local knowledge ● Motivate dialogue to synthesize ways of knowing	How can we integrate diverse sources of knowledge (including Indigenous Knowledge, local community knowledge, and Western science) in documenting and predicting temporal changes in ecological processes and biodiversity to empower stewardship by local communities?
How might we discover which elements of the biodiversity-climate system most effectively resonate with broad, diverse public interests and thus most effectively stimulate public involvement and action?	How might we collaborate with social scientists to establish a multidisciplinary group to investigate what most effectively works with a diverse public (leveraging technology, community groups, etc.). How might we engage a broader range of stakeholders, who might occupy disparate/competing societal domains?	How can we develop a model of co-production that centers the needs of the diverse public/frontline communities and directly includes their perspectives and values in biodiversity and climate change research?
How might we use education and training opportunities to excite a diverse, next generation of scientists to pursue research	How might we reconcile the internationality of the problem of biodiversity loss and the inherent	How do we optimize and integrate policies from local to global governance landscapes (private, public, etc.) to co-

Societal Challenge	Science Question	Research Question
related to biodiversity-climate challenges?	localization of science education and training opportunities? ● We know that biodiversity is distributed unequally, but so are the resources to handle the problem of loss. ● We need to include all voices in articulating the problem and use cultural and traditional information in the solution.	create and co-implement climate-biodiversity research across borders?

Table 2. Outcomes of Workshop 2 - Achieving a Sustainable Future

Representative societal challenges and corresponding science questions and research questions developed by workshop participants

Societal Challenge	Science Question	Research Question
How might we more effectively improve public trust in science and commitment to sustainability?	How might we develop the educational and social communication strategies needed to generate generations of a logic-capable and engaged public?	The team would develop a participatory game that would help communities draw out their cultural perspectives on the Rules of life and develop knowledge about the fundamentals of the Rules of Life.
How might we make food production sufficient, equitable and more sustainable?	How can we make food production a closed loop (Social and economic dimensions as well as the technical)?	Use a large university food system as a model for polyculture and food waste reuse.
How might we make water, as a resource, more sustainable?	How can we balance the increasingly frequent fluctuations between scarcity and excess of water (i.e. droughts and flooding), and through an understanding of the complexity of the system, be able to effectively manage, store and equitably distribute the water resources?	How do we identify economically feasible approaches to promote water resiliency in the natural, built, and agricultural environments, while recognizing the need to take into account predicted changes in water distribution patterns?
How might we learn from natural systems to better achieve sustainability?	Can we prove or disprove the idea of the "maximum power principle" (evolution favors organisms that extract resources faster than others, since this better enables reproduction) within ecosystems and economies/societies?	Can we determine proper simulations (agent-based, AI, etc.) and serious games to explore necessary ideas that can be used to validate the Maximum Power Principle (MPP) computationally (considering multiple time and spatial scales)? Can we even make "good enough" real-world experiments (that are flexible and long-term enough to explore the relevant time scale for MPP) that can be co-validated computationally?
How might we harmonize diverse perspectives on sustainability to find a common way forward?	How might we promote the emergence of harmonized perspectives in societies while balancing the desire to harmonize and maintain diversity to adapt goals over time?	What is the optimal optionality-preserving policy for synchronizing the perspectives of interacting agents with stochastic traits to achieve a short-term goal and survive long-term shocks in random environments?
How might we predict the effects of complexity on our forecasts for natural systems?	How can we use the past to understand and predict the future?	How do evolutionary dynamics and principles underlined by spatio-temporal connectivity and diversity help us increase predictive accuracy of the future?
How might we transition to a less wasteful society?	How might we internalize the externality of waste - how can we shift the burden of the cost of the waste to the people who produce the waste (fairly and equitably)?	What are the spatial and temporal scales at which internalizing the externality of waste in natural systems becomes sustainable, and to what extent are those systems reflected in

Societal Challenge	Science Question	Research Question
		the current design of anthropogenic waste systems?
How might we use a system-of-systems approach to achieve sustainability?	How might we identify and mitigate subsystems that are impediments to achieving sustainability, so that they can be linked back together to have predictive power?	The team merged with another team and stopped developing their project.
How might we use biological strategies to transition from reliance on fossil fuels to renewable carbon resources?	How might we leverage ecological principles of resource cycling (element or limiting nutrient) to improve efficiency and reduce energy use and redefine 'waste' in a manner that is likely to be societally adopted?	Can we build bio- or biohybrid technologies that are more efficient at scale than their natural biological or technological approaches alone? (e.g., carbon capture and sequestration technology)?
How might we balance the tradeoff of (bio)technological vs. natural solutions to achieve sustainability, considering benefits, risks, and social and ethical concerns?	What are the tradeoffs between biotechnological and natural solutions? • In what ways can biotechnological and natural solutions work together (be integrated and used synergistically) to offer benefits? • How to overcome tradeoffs?	Develop a model system that integrates "bioengineered" and “natural” components with predictable emergent traits (like carbon sequestration, iron oxidation, nitrogen fixation…).
How might we more effectively use collaboration to develop scientific strategies for achieving sustainability?	How do we model and design a decentralized, collaborative process such that we can allow for diversity and scientific pluralism with polycentric community collaboration for sustainability?	Investigate organic attempts at sustainability, at the level of community. Understand the factors that provoked success. To what degree have they embraced engaged scholarship, broad participation, and collaboration?
How might we mitigate plastics pollution?	How might we mitigate/prevent future plastic pollution? how can we produce green plastics, at scale?	Waste plastics as food for microbes: How can we divert waste plastics towards food for microbes to create biological products that are thermodynamically favorable, predictable, reproducible at scale?

Table 3. Outcomes of Workshop 3 - Harnessing Microbiomes for Societal Benefit

Representative societal challenges and corresponding science questions and research questions developed by workshop participants

Societal Challenge	Science Question	Research Question
How might we achieve better population health in humans, accounting for health inequities (race, gender, sexual identity, socioeconomic status) that undermine healthy microbiome function by engineering microbiomes?	How might we improve immune system development and modulation in all people equitably using the microbiome?	We want to follow individuals from birth to adulthood and characterize their gut microbiomes, immune function, and overall health.
How might we develop synthetic microbiomes for novel uses by modelling rules of organization and communication that apply broadly across microbiomes?	How do we integrate multiple types and scales of models to engineer a synthetic microbiome that's versatile and adaptable (e.g., scientists use microbes to clean our water)?	Development of a set of integration tools/methods that can make use of models of different scales and different types and be used to derive universal/fundamental rules governing the organization and evolution of various microbial communities.
How might we prevent the spread of infectious disease (from host-to-host or vector-to-host) by using microbiomes?	How might we promote existing beneficial microbes, or introduce new beneficial (engineered) microbes to keep out harmful ones?	Can we determine the mechanisms of stasis and change in host-microbiome effects on hosts over time in order to design long-lasting microbiome improvement?
How might we develop complex, microbial communities with beneficial uses by using experimental evolution?	How might we combine classical approaches of single species experimental evolution with complex co-evolution in communities to use complex natural microbiomes?	Can we engineer/evolve a transmissible C. elegans bacterial microbiome that provides host resilience to environmental perturbation (behavior--chemotaxis in response to predator or social cues)? What evolutionary or ecological attributes of the microbiome or host are associated with resilience?
How might we synthesize novel compounds for feedstocks in biomanufacturing by harnessing existing or creating new microbiomes?	How might we best screen, enrich, and engineer microbial communities for complex processes, such as specific bio-manufacturing processes?	How to encourage selection for chemical processes that are not obviously beneficial for a given microbial community? I.e., how to select for a multi-step pathway that requires input of energy?
How might we break down unwanted byproducts of human activity, e.g., toxic substances, waste, pollutants, plastics, etc., by harnessing existing or creating new microbiomes?	How might we establish and implement new synthetic microbiomes to deploy broad toxin monitoring systems and identify solution-based approaches for remediation? How can we design strategies to sense, detect, and quantify the presence of microbes and relevant biomolecules in the engineered microbiome?	Understand the rules that govern the stability of engineered microbial communities under perturbed conditions for targeted bioremediation capabilities
How might we improve sustainable agriculture by	How can the scale of interactions among the plant-microbe-mycorrhiza rhizosphere members be productively	Develop a predictive model and manipulate plant health as modulated by plant and AMF genotype and

Societal Challenge	Science Question	Research Question
leveraging rhizosphere microbiomes?	manipulated, for example, to defend the plant from specific pathogens or fungi?	microbiomes, using tomato as a model system.
How might we make arable land from non-arable land, and increase the productivity of arable land by engineering microbiomes?	How might we select a community of microbes (instead of single bacteria) for remediation of non-arable land across many axes of challenges that won't harm the existing ecosystem function, e.g., water decontamination, or carbon retention in soil?	We will test the development of a universal soil microbiome mix that can respond to a variety of adverse conditions (heat, diminished water availability, toxic materials) Ensuring we all have enough food - consider the environment that we are working in, leveraging our knowledge of drought/salt/other-tolerant microbes and plants and combining with traditional, local knowledge - wastewater/biogas? Crop irrigation? Reintroducing microbes. Aim for a microbiome that can remediate Martian/Atacama desert soil.
How might we produce biofuels in an environmentally friendly manner by engineering microbiomes?	How might we predict the metabolic capability of a community, perhaps based on the genome of each organism, so that community makeup can be maximized for the purpose of biofuel participation? How might we predict the metabolic capability of a community so that community makeup can be maximized for the purpose of biofuel participation?	What are the basic principles needed to create a fermentative bioreactor community for cellulose breakdown?
How might we improve human and animal nutrition by engineering microbiomes?	How might we identify which nutrition engineering goal is most important and what the tradeoffs might be - these might vary among species and among human populations, diet types, etc.?	What are the keystone species and metabolites that are associated, and how are they causatively linked, with certain diets/nutrients consumed by different human populations?
How might we mitigate the negative effects of climate change on plants and animals by leveraging the roles played by their microbiomes, e.g., in food production or ecosystem health?	How might we design microbiome communities to positively influence ecosystem resilience?	Which aspects of microbiome diversity (species vs functional, keystone vs core assemblage) are related to ecosystem resilience?
How might we develop interventions that prevent the occurrence of disease in humans, animals, or plants by manipulating microbiomes?	How can we understand what a "healthy microbiome" is in a wide variety of human and animals and the impact of microbiome fluctuations and intrinsic heterogeneity over time and space?	What are the specific interactions/parts of the microbiome that affect its behavior? How does the microbiome influence neurotransmitters, mental health, and host behavior? Start with a nematode model, develop a mathematical model of this one-host, one-microbe system with few neurons and simple behaviors, generalize to a more complex microbial community (combine organs-on-a-chip) and higher-

Societal Challenge	Science Question	Research Question
		order animals (e.g., fish, cattle, humans) with more complex neurobiology.
How might we sense, respond to or mitigate unwanted effects of environmental perturbations by harnessing the ability of microbiomes (natural or engineered)?	How might we use ecological interaction models to leverage heterogeneity in natural microbiome communities to engineer synthetic communities capable of mitigating negative effects of environmental perturbation?	How do systematic perturbations impact tipping points within a synthetic community, and can we use models to validate and predict microbial community collapse caused by perturbations?
How might we enhance the health of animals and humans in the household by using ecological or modeling approaches to predict modifying microbiomes in built environments?	How might we integrate microbiomes more holistically into the design (architecture, construction materials, aesthetics, etc.) of built environments?	How can microbiome science be used in the built environment to monitor signs of disequilibrium or system function?

Table 4. Outcomes of Workshop 4 - Leveraging AI and Data Science for Predicting Mechanisms

Representative societal challenges and corresponding science questions and research questions developed by workshop participants

Societal Challenge	Science Question	Research Question
How might we address health and health care disparity among races and ethnic groups by leveraging AI and Data Science?	How might we help build public trust in AI by identifying sources of uncertainty, limitations, and biases?	How might we build human-in-the-loop AI workflows to identify sources of uncertainty, limitations, and biases?
How might we create equity in the water system across the country using AI and Data Science?	How might we gain an understanding of how much water is available for use in various places across the country without negatively impacting ecosystems?	How can we compare continental-scale process-based (physics-based starting from precipitation) hydrologic models (e.g., ParFlow-CONUS) with aggregated water district-scale models focused on human usable water?
How might we ensure that generalizations drawn by AI from training data (e.g., facial recognition, contextual image algorithms, human gut microbiome etc.) are validated sufficiently before being applied to new datasets?	How might we understand the generalizability of diverse feature representations and their suitability for different kinds of problems?	Understanding the generalizability across fields and scales and their suitability for different kinds of problems.
How might we enhance the transition from reliance on fossil fuels to renewable carbon resources using AI and Data Science?	How might we use AI to develop models that predict the effect of changes that we can make now to decrease our reliance on fossil fuels?	How can we develop AI models to predict the optimal operation of future energy grid with different renewable energy sources?
How might we achieve fair and equitable distribution of retraining and employment, as more jobs become automated, by leveraging AI and Data Science?	How might we model the complexity of employment (job skills, education, opportunities) through better understanding of careers and their data, and how can AI optimize such modelling?	Adaptive and inclusive data collection for matching people to careers.
How might we predict future infectious diseases, and help prevent the spread of existing ones, by using AI and Data Science to help?	How might we improve public trust in the science/ medical community to allow us to achieve better equity and more reliable quality data across broad populations?	Enhancing trust and equity in infectious disease response using AI and data science methods.
How might we improve food production, distribution, safety, waste and consumption by applying AI and Data Science?	How might we use data (soil contents, microbiome, GMO needs) and climate prediction (rainfall, changing weather patterns, heat, drought) to improve food growing/production?	How to combine very different data modality into a trainable AI construct that can predict genetic-environment interactions? And collect data to validate?
How might we address the increase in resistance to antibiotics and pesticides more strategically by using AI and Data Science?	How might we identify mechanisms underlying resistance to antibiotics/pesticides using AI/Data Science, given that geographic and population representation in the data are unequal?	Collecting and analyzing global data to elucidate the evolution and spread of antimicrobial resistance as a function of changes across genetic, organism, and environmental levels.

Societal Challenge	Science Question	Research Question
How might we address urban challenges, such as transportation, pollution, water, and energy consumption, etc., by using AI and Data Science?	How might we design low-cost data collection mechanisms to monitor the dynamics in transportation, pollution, water, and to turn those into actionable insights for urban residents.	Large urban/metropolitan areas can be considered as complex systems that involve engineered components (e.g., transportation infrastructure, EV and power-grid infrastructure), natural components (air quality and weather), and human components (i.e., how people use and impact these components). We plan to develop integrated models that allow for understanding the interactions between all these components (i.e., RoL), assess the robustness of such systems in response to external stress (e.g., due to climate change), and allow for introducing novel control strategies to optimize overall performance of the complex system given some target global multi-criteria objective functions (e.g., one that considers traffic congestion, air quality, and economy of EV operation at the same time).
How might we increase the sustainability of agricultural systems by using AI and Data Science?	How might we use AI and data science tools to map species interaction networks (like plant-pollinator, or microbe-plant networks) that are relevant to agricultural systems?	Points of failure in detecting meaningful differences in prediction of dynamic networks in agriculture: testing plant-microbe metabolic networks across scales.
How might we design better engineered biotechnologies by more effectively learning from natural systems using AI and Data Science?	How might we model all of the scales involved in a biological process to evolve biotechnologies (or other technologies) in the same way that living systems evolve?	How can we quickly and efficiently develop models of complex multi-scale systems and networks and evaluate them? How do components form into a network across scales (from gene network to ecological interactions)? What tools are needed to model this? How does life compute?
How might we model predictively the ways systems at different scales, from molecules to biospheres, will respond to environmental change by using AI and Data Science?	How might we use AI/Data Science to cope with missing data when we try to relate biological functions at different scales to changes in the environment?	How can we use prior knowledge and existing data to build, train, and test machine learning and mathematical models in an iterative manner to: • Predict dynamics, characteristics, and relationship of components within, between, and across biological scales of organization and across the tree of life? • Infer, interpret, and generalize top-down and bottom-up causal relationships • Understand systems-wide responses to changing environments

Participants: Workshop 1 - Stewarding an Integrated Biodiversity-Climate System

First	Last	University/Organizational Affiliation	Scientific Expertise
Subodh	Adhikari	University of Idaho	Biological science
Peter	Adler	Utah State University	Biological science
Barbara	Ambrose	New York Botanical Garden	Biological science
Ana	Carnaval	City College of CUNY	Biological science
Karen	Castillioni	University of Minnesota	Biological science; Mathematics
Lorenzo	Ciannelli	Oregon State University	Biological science, Geoscience
Jacob	Cram	University of Maryland Center for Environmental Science	Biological science, Geoscience
Kyla	Dahlin	Michigan State University	Biological science
Michael	Dawson	University of California, Merced	Biological science
Julie	Dinasquet	University of California, San Diego	Biological science, Geoscience
Emmett	Duffy	Smithsonian Institution	Biological science
Andrea	Durant	Rosenstiel School of Marine and Atmospheric Science, University of Miami	Biological science
Richard	Emlet	Oregon Institute of Marine Biology	Biological science
Tafesse	Estifanos	University of Vermont	Geoscience
Oxzem	Garibay	University of Central Florida	Computer science
Katherine	Glover	University of Maine	Biological science, Geoscience, Education and Human Resources
Helga	Gomes	Lamont Doherty Earth Observatory at Columbia Univ, NY	Biological science
Tamar	Goulet	University of Mississippi	Biological science
Abdel	Halloway	University of Illinois at Urbana-Champaign	Biological science, Mathematics
Jill	Hamilton	Pennsylvania State University	Biological science
Tracy	Heath	Iowa State University	Biological science
Erika	Hersch-Green	Michigan Technological University	Biological science
J. Aaron	Hogan	University of Florida	Biological science, Mathematics
Tingyu	Hou	Purdue University	Biological science, Geoscience
Christine	Johnson	American Museum of Natural History	Other
Michael	Kahn	Washington State University	Biological science
Janet	Kubler	California State University, Northridge	Biological science
Shannon	LaDeau	Cary Institute of Ecosystem Studies	Biological science
Zachary	Lippman	Cold Spring Harbor Laboratory, HHMI	Biological science
Isabel	Loza	The Morton Arboretum	Biological science
Travis	Marsico	Arkansas State University	Biological science
Jenny	McGuire	Georgia Tech	Biological science, Geoscience
Monica	Medina	Penn State University	Biological science, Geoscience
Richard	Meisel	University of Houston	Biological science
Neha	Mohan Babu	University of Minnesota	Biological science, Mathematics
Frank	Muller-Karger	University of South Florida	Biological science, Geoscience
Jasmine	Nirody	Rockefeller University / University of Oxford	Biological science, Chemical/physical science
Lauren	Norman	University of Kansas	Social, behavioral, and/or economic sciences
Ljuba (Lyuba)	Novi	Georgia Tech University	Biological science, Engineering, Physics, Mathematics
Felicia	Nutter	Tufts University	Biological science
Amanda	Oehlert	University of Miami, RSMAS	Chemical/Physical science, Geoscience
Olabisi	Ojo	Albany State University	Biological science
Alessandro	Ossola	University of California Davis	Biological science

Hamil	Pearsall	Temple University	Social, behavioral, and/or economic sciences
William	Petry	North Carolina State University	Biological science
Erin	Rankin	University of California Riverside	Biological science
Andrew	Ridgwell	University of California, Riverside	Geoscience
Leslie	Ries	Georgetown University	Biological science
Alejandro	Rojas	University of Arkansas	Biological science
Jocelyn	Rose	Cornell University	Biological science
Michael	Roswell	University of Maryland, College Park	Biological science
Oswald	Schmitz	Yale University	Biological science
Rachel	Short	Texas A&M University / Georgia Tech University	Biological science, Geoscience, Education and human resources
Katherine	Siegel	NOAA/ University of Colorado-Boulder	Biological sciences
Rachel	Simons	University of California, Santa Barbara	Geoscience
Bao-Hua	Song	University of North Carolina Charlotte	Biological science
Kaitlin	Stack Whitney	Rochester Institute of Technology	Biological science
Beckett	Sterner	Arizona State University	Biological science, Social, behavioral, and/or economic sciences
Bradley	Strickland	Virginia Institute of Marine Science	Biological science, Mathematics
Lynette	Strickland	University of Memphis	Biological science
Anshuman	Swain	Harvard University and University of Maryland	Biological science
Ed	Tekwa	University of British Columbia / Rutgers University	Biological science, Engineering, Mathematics
Alec	Tewsley-Booth	University of Kentucky, Lexington	Biological science, Mathematics, Physical science
Elisa	Van Cleemput	University of Colorado	Biological science, Geoscience, Mathematics
Roger	Wang	Rutgers University New Brunswick	Engineering, Geoscience
Judith	Weis	Rutgers University	Biological science
Nan	Woodman	Biominga	Biological science
Xiaofeng	Xu	San Diego State University	Biological science, Geoscience
Ce	Yang	University of Minnesota	Engineering
May	Yuan	The University of Texas at Dallas	Social, behavioral, and/or economic sciences
Lu	Zhai	Oklahoma State University	Biological science, Mathematics

Participants: Workshop 2 - Achieving a Sustainable Future

First	Last	University / Organization Affiliation	Scientific Expertise
Tri Dev	Acharya	University of California, Davis	Geoscience
Gladys	Alexandre	University of Tennessee	Biological science
Sanjay	Antony-Babu	Texas A&M University	Biological science
Mostafa	Ardakani	University of Utah	Engineering, Social, behavioral, and/or economic sciences
Joshua	Atkinson	University of Southern California	Biological science, Engineering, Physical science
Jacopo	baggio	University of Central Florida	Social, behavioral, and/or economic sciences
Bhavik	Bakshi	The Ohio State University	Engineering
Jocelyn	Behm	Temple University	Biological science
Matthew	Berens	University of Minnesota Duluth	Chemistry, Geoscience
Patrick	Biber	University of Southern Mississippi	Biological science
Sharon	Billings	University of Kansas	Biological science
Israel	Borokini	University of California, Berkeley	Biological sciences
Nicole	Buan	University of Nebraska-Lincoln	Biological science
Robbie	Burger	University of Kentucky	Biological science
Caitlyn	Butler	University of Massachusetts Amherst	Engineering
Elizabeth	Carlen	Washington University	Biological sciences
Prakash	Chakraborty	University of Michigan	Mathematics, Social, behavioral, and/or economic sciences
Diana	Chin	University of Florida	Biological science, Geoscience
Erome	Daniel Hankore	University of Kentucky	Biological science, Chemistry
Peter	Davenport	University of New Mexico	Biological science, Engineering
Lauren	Drakopulos	Cornelle University	Geoscience, Social science
Pilar	Fernandez	Washington State University	Biological science
Lara	Figueroa	University of Massachussetts, Amherst	Biological science
Kelsey	Fisher	Iowa State University	Biological science
Philippe	Foret	University of Basel	Geoscience
Jacob	Freeman	Utah State University	Biological science, Geoscience, Social, behavioral, and/or economic sciences
Aroussiak	Gabrielian	University of Southern California	Other
Chris	Gough	Virginia Commonwealth University	Biological science, Geoscience, Education and Human Resources
Christy	Grettenberger	University of California Davis	Biological science, Geoscience
Wenyu	Gu	Stanford University	Engineering
Fardad	Haghpanah	One Health Trust / Center for Disease Dynamics, Economics & Policy	Engineering, Mathematics, Public Health
Qiang	He	University of Tennessee, Knoxville	Engineering
James	Henriksen	Colorado State University	Biological science, Computer science
Andrew	Hess	University of Nevada, Reno	Biological science
Rachael	Heuer	University of Miami	Biological science
Cailin	Huyck Orr	Carleton College	Education and Human Resources
Jim	Junker	Michigan Technological University/ Louisiana Universities Marine Consortium	Biological science, Geoscience
Carey	King	University of Texas at Austin	Social, behavioral, and/or economic sciences
Manish	Kumar	University of Texas at Austin	Biological science, Engineering

Robert	Last	Michigan State University	Biological science
Manuel	Lerdau	University of Virginia	Biological science
John	Little	Virginia Tech	Engineering
Gabriel	Lopez	University of New Mexico	Engineering
Rohan	Maddamsetti	Duke University	Biological science
Cresten	Mansfeldt	University of Colorado Boulder	Engineering
Erica	McKenzie	Temple University	Engineering, Geoscience
Tae Seok	Moon	Washington University in St. Louis	Biological science, Engineering
Orit	Peleg	University of Colorado Boulder	Biological science, Engineering, Mathematics, Chemical/Physical science, Computer science
Alberto	Perez-Huerta	The University of Alabama	Geoscience
April	Roggio	SUNY at Albany	Social, behavioral, and/or economic sciences
Michelle	Salgado	University of Michigan	Education, Social science
Adriana	San Miguel	North Carolina State University	Biological science, Engineering
Sergiu	Sanielevici	Carnegie Mellon University	Chemical/Physical science
Saba	Siddiki	Syracuse University	Social, behavioral, and/or economic sciences
Olga	Smirnova	East Carolina University	Social, behavioral, and/or economic sciences
Amanda	Spivak	University of Georgia	Geoscience
Bilinda	Straight	Western Michigan University	Social, behavioral, and/or economic sciences
Tricia	Thibodeau	University of Rhode Island	Biological sciences, Geoscience, Mathematics
Kristina	Thorsell	University-Industry Demonstration Partnership (UIDP)	Chemical/Physical science
Bryan	Travis	Planetary Science Institute	Mathematics
leanne	ussher	Bard College	Social, behavioral, and/or economic sciences
Stephen	Uzzo	New York Hall of Science	Social, behavioral, and/or economic sciences, Education and Human Resources
Andreas	Vasdekis	University of Idaho	Biological science, Chemical/Physical science
Wim	Vermaas	Arizona State University	Biological science
Peter	Vikesland	Virginia Tech	Biological science, Engineering, Chemical/Physical science
John	Voiklis	Knology	Social, behavioral, and/or economic sciences
Rory	Waterman	University of Vermont	Chemical/Physical science
Joaquine	Yus	University of Illinois at Urbana-Champaign	Chemistry/Physical science
Helen	Zha	Rensselaer Polytechnic Institute	Chemical/Physical science
Kuang	Zhu	University of Michigan	Engineering

Participants: Workshop 3 - Harnessing Microbiomes for Societal Benefit

First	Last	University/Organizational Affiliation	Scientific Expertise
Katherine	Amato	Northwestern University	Social, behavioral, and/or economic sciences
Adrien	Assie	Baylor College of Medicine	Biological science
Robert	Austin	Princeton University	Chemical/Physical science
Mentewab	Ayalew	Spelman College	Biological science
Lisa	Belden	Virginia Tech	Biological science
Yehuda	Ben-Shahar	Washington University in St. Louis	Biological science
Abhinav	Bhushan	Illinois Institute of Technology	Engineering
Paul	Bogdan	N/A	Engineering, Mathematics, Computer science
Chequita	Brooks	Appalachian State University	Biological science, Geoscience
Giancarlo	Bruni-Saldaña	University of California Los Angeles	Biological science
Tessa	Burch-Smith	Donald Danforth Plant Science Center	Biological science
Posy	Busby	Oregon State University	Biological science
Barbara	Campbell	Clemson University	Biological science
Jennifer	Carinci	University-Industry Demonstration Partnership (UIDP)	Education and Human Resources
James	Chappell	Rice University	Biological science
Aisha	Chilcoat	University of North Carolina - Chapel Hill	Biological science, Engineering
Jackie	Collier	Stony Brook University	Biological science, Geoscience
Jonathan	Conway	Princeton University	Biological science, Engineering
Sambeeta	Das	University of Delaware	Biological science, Engineering, Chemical/Physical science
Sujit	Datta	Princeton University	Biological science, Engineering, Chemical/Physical science
Anca	Delgado	Arizona State University	Biological science, Engineering
Joe	Edwards	University of Tennessee Knoxville	Biological science
Vincenzo	Ellis	University of Delaware	Biological science
Natalie	Farny	Worcester Polytechnic Institute	Biological science
Ronaldo P.	Ferraris	Rutgers University	Biological science
Ramana	Gadhamshetty	South Dakota School of Mines and Technology	Engineering
Cody	Garrison	Stony Brook Universtiy	Biological science, Geoscience
J.P.	Gerdt	Indiana University	Chemistry
Gene	Godbold	Signature Science	Biological science
Anuradha	Goswami	University of Alabama at Birmingham	Biological science
Heidi	Gough	University of Washington	Engineering
Jennifer	Heppert	University of Tennessee Knoxville	Biological science
Catherine	Hermandez	Yale University	Biological science
Jay	Lennon	Indiana University	Biological science
Herbert	Levine	Northeastern Univ.	Chemical/Physical science
Maggie	Lewis	Ohio State University	Biological science
Nikhil	Malvankar	Yale University	Biological science
Megan	McClean	University of Wisconsin-Madison	Biological science, Engineering
Ali	McCully	Stanford University	Biological science, Engineering
Katherine	McMahon	University of Wisconsin Madison	Engineering
Katherine (Trina)	McMahon	University of Wisconsin	Biological science
Melissa	Melby	U of Delaware/ CIFAR Humans & the Microbiome	Biological science, Social, behavioral, and/or economic sciences

Babak	Momeni	Boston College	Biological science, Engineering
Ulrich	Mueller	Univerity of Texas at Austin	Biological science
Carly	Muletz Wolz	Smithsonian	Biological science
TM	Murali	Virginia Polytechnic Institute and State University	Computer science
David	Murrugarra	University of Kentucky	Biological science, Mathematics
Theodore	Muth	CUNY Brooklyn College	Biological science
Roger	Narayan	North Carolina State University at Raleigh	Biological science, Engineering, Chemical/Physical science
Mohammad	Nooranidoost	Florida State University	Engineering, Mathematics
Mike	Nute	Rice University	Biological science, Computer science, Mathematics
Anna	O'Brien	University of New Hampshire	Biological science
Jose	Onuchic	Rice University	Biological science, Chemical/Physical science
Ryan	Pace	University of Idaho	Biological science
Sherlynette	Perez Castro	Marine Biological Laboratory	Biological Science
Stephanie	Porter	Washington State University, Vancouver	Biological science
Ami	Radunskaya	Pomona College	Mathematics
Jason	Rothman	University of California, Irvine	Biological science
Jennifer	Salerno	George Mason University	Biological science
Daniel	Schachtman	University of Nebraska - Lincoln	Biological science
Andrew	Schuler	University of New Mexico	Engineering
Marilou	Sison-Mangus	University of California – Santa Cruz	Biological science
Davida	Smyth	Texas A&M San Antonio	Biological science, Education and Human Resources
Ranjan	Srivastava	University of Connecticut	Biological science, Engineering
Wesley	Swingley	Northern Illinois University	Biological science, Computer science
Erika	Szymanski	Colorado State University	Social, behavioral, and/or economic sciences
Stephen	Techtmann	Michigan Technological University	Biological science
Michael	Travisano	University of Minnesota	Biological science
Todd	Treangen	Rice University	Biological science, Computer science
Joe	Vallino	Marine Biological Laboratory	Biological science, Engineering, Geoscience
Mohit	Verma	Purdue University	Engineering
Marina	Walther-Antonio	Mayo Clinic	Biological science
Naomi	Ward	University of Wyoming	Biological science
Roland	Wilhelm	Purdue University	Biological science
Jessica	Winter	Ohio State University	Engineering
Yuzhen	Ye	Indiana University	Computer science
Yanbin	Yin	University of Nebraska - Lincoln	Biological science

Participants: Workshop 4 - Leveraging AI and Data Science for Predicting Mechanisms

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Viktoriia	Babicheva	University of New Mexico	Engineering, Chemical/Physical science
Farnoush	Banaei-Kashani	University of Colorado Denver	Computer science
Richard	Booth	Pennsylvania State University	Chemical/Physical science
Ian	Breckheimer	Rocky Mountain Biological Laboratory	Biological science, Geoscience
Huyen	Bui	Montana State University	Biological science
William	Burke	University of Nevada Reno	Geoscience
Rossie	Clark-Cotton	Stanford University / Duke University	Biological science
Vinicius	Contessoto	Rice University	Biological science, Physics
Kristin	Crouse	University of Minnesota	Biological science, Computer science, Behavioral, social, and/or economic science
Kelly	Diamond	Seattle Children's Research Institute	Biological science
Minh	Do	University of Illinois at Urbana-Champaign	Engineering, Computer science
Joyonna	Gamble-George	New York University	Biological science, Behavioral, social, and/or economic science
Jie	Gao	Rutgers University	Computer science
Rebecca	Garabed	The Ohio State University, College of Veterinary Medicine	Biological science
Diane	Genereux	Broad Institute	Biological science
Agustin	Guerra	University of Florida	Engineering
Tom	Hartvigsen	Massachussetts Institute of Technology	Computer science
Pengyu	Hong	Brandeis University	Computer science
Niyomi	House	University of Nevada, Reno	Biological science, Other
Bruna	Jacobson	University of New Mexico	Chemical/Physical science, Computer science
Constance	Jeffery	University of Illinois at Chicago	Biological science
Libusha	Kelly	Albert Einstein College of Medicine	Biological science
David	Kramer	Michigan State Univerisity	Biological science
Arjun	Krishnan	Michigan State University	Biological science, Engineering, Computer science
Tze	Lai	Stanford University	Mathematics
Hilmar	Lapp	Duke University	Biological science
Marc	Libault	University of Nebraska Lincoln	Biological science
Maren	Loe	National Academies of Sciences, Engineering, and Medicine	Biological science, Engineering, Mathematics
Eduardo	Lopez	George Mason University	Mathematics, Chemical/Physical science, Social, behavioral, and/or economic sciences
WOLFGANG	LOSERT	University of Maryland College Park	Chemical/Physical science
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Marcelo C.R.	Melo	Auburn University	Biological science
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Sheida	Nabavi	University of Connecticut	Engineering, Computer science
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Todd	Oakley	UC Santa Barbara	Biological science
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Elif	Oral	California Institute of Technology	Engineering, Geoscience
Chongle	Pan	University of Oklahoma	Biological science, Computer science
Pratishtha	Poudel	Oklahoma State University	Biological science, Mathematics
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Nidhi	Rastogi	Rochester Institute of Technology	Computer science
Jeffrey	Regier	University of Michigan	Mathematics, Computer science
Nicole	Riddle	University of Alabama at Birmingham	Biological science
Brenda	Rubenstein	Brown University	Biological science, Chemical/Physical science
Rogini	Runghen	Northeastern University	Biological science, Mathematics
Howard	Salis	Pennsylvania State University	Engineering
Mindy	Shi	Temple University	Biological science, Computer science
Shin-Han	Shiu	Michigan State University	Biological science, Computer science
Shabnam	Sodagari	California State University – Long Beach	Engineering, Computer science
Manal	Tabbaa	University of Southern California	Biological science
Wei	Wang	University of California – Los Angeles	Computer science
Stephen	Welch	Kansas State University	Other
Zhaohui	Xu	Bowling Green State University	Biological science
Tai	Young-Taft	Bard College	Social, behavioral, and/or economic sciences
Hao	Zhang	Purdue University	Mathematics
Ying	Zhang	University of Rhode Island	Biological science, Computer science
Wangda	Zuo	Penn State University	Engineering

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