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Conference Report

Designing the Microbes and Social Equity Symposium: A Novel Interdisciplinary Virtual Research Conference Based on Achieving Group-Directed Outputs

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Abstract: The Microbes and Social Equity working group was formed in 2020 to foster conversations on research, education, and policy related to how microorganisms connect to personal, societal, and environmental health, and to provide space and guidance for action. In 2021, we designed our first virtual symposium to convene researchers already working in these areas for more guided discussions. The symposium organizing team had never planned a research event of this scale or style, and this perspective piece details that process and our reflections. The goals were to (1) convene interdisciplinary audiences around topics involving microbiomes and health, (2) stimulate conversation around a selected list of paramount research topics, and (3) leverage the disciplinary and professional diversity of the group to create meaningful agendas and actionable items for attendees to continue to engage with after the meeting. Sixteen co-written documents were created during the symposium which contained ideas and resources, or identified barriers and solutions to creating equity in ways which would promote beneficial microbial interactions. The most remarked-upon aspect was the working time in the breakout rooms built into the schedule. MSE members agreed that in future symposia, providing interactive workshops, training, or collaborative working time would provide useful content, a novel conference activity, and allow attendees to accomplish other work-oriented goals simultaneously.

Keywords: multi-disciplinary; social equity; microbiome; workshop; co-working activities; collaborative meeting notes; virtual conference

1. Introduction

The Microbes and Social Equity (MSE) working group [1–3] was formed in 2020 to foster conversations on research, education, and policy related to how microorganisms connect to personal, societal, and environmental health; as well as to coalesce interest groups including those who were already working on these topics. In 2021, MSE organized and hosted our inaugural symposium to foster these conversations and provide space and guidance for action [4]. The planning committee was composed of researchers from a wide range of intersecting disciplines, such as host-associated microbiology, architecture, health, biopolitics, nutrition, geography, and psychology, and we chose five broad topics encompassing major themes that had been consistently of interest to the MSE group since its inception [1,3].

The committee featured researchers from different career stages, from graduate students to tenured professors, which enabled us to design the symposium to foster inclusion. For example, using breakout rooms for discussion, limiting room occupancy and including students as notetakers and discussion facilitators was based on personal and published experiences confirming that small-scale, structured, and student-led conversations remove the barrier of career hierarchies and allow for more direct contact between students/trainees and experts [5,6]. Fostering student engagement, especially in challenging virtual environments, is also well-documented to improve learning outcomes and achievement in a typical academic setting [7,8]. We also made specific efforts to reach out to speakers from historically excluded social groups and highlight their work as discipline experts [9], not just advocates for outreach, which is a critical aspect of inclusion practices [10].

The goals of the MSE virtual symposium were to (1) curate interdisciplinary audiences around topics which involve microbiomes and health, (2) stimulate conversation around a selected list of paramount research topics, and (3) leverage the interdisciplinarity and diversity of professional experience of the group to create meaningful agendas or actionable items for attendees to continue to engage with after the meeting. As microorganisms connect to societies and ecosystems in myriad ways, the planning committee drafted a prospectus to narrow the scope of the meeting, which was later used in publicity materials [4]. As the term 'microbes and social equity' is nascent, and as the broad audience we wished to reach may not be familiar with microbiomes, the prospectus included a short description of the term and listed some examples (e.g., diet), as well as described the

relevance to the SARS-CoV2 (COVID-19) pandemic and the role of inequity in exposure and treatment options. For example: "The collective microbial community, our microbiome, can be impacted by the details of our lifestyle, including diet, hygiene, health status, and more, but many are driven by social, economic, medical, or political constraints that restrict available choices that may impact our health" [4]. The prospectus also included a summary of the intended symposium program, including a description of the speaker talks, the breakout room discussions, and the outcome goals for each. For example, "Ideally, meeting attendees will gain knowledge, collaborators and connections, and a path forward for turning their research into evidence-based policy to support public health" [4].

2. Coordinating Planning, Content, and Event Activities

The symposium dates were chosen to avoid time conflicts with other related conferences, and set for 14–18 June 2021, from 12:00–16:30 Eastern Daylight Time (EDT). We used the Google Suite of online applications to share and store publicity documents and data files, including co-written scope documents, images and fliers and a spreadsheet to coordinate speaker invitations and progress of the sessions asynchronously, and coordinate the event from multiple time zones over a 6-month period.

One thematic section was scheduled per day, featuring 90 min of plenary-style talks, followed by 90 min of discussion in breakout rooms to facilitate conversations. We aimed to confirm one biological/microbiological researcher, one social science researcher, and one practitioner or other professional per symposium session. Potential speakers were invited with details on MSE, the goals of the symposium, how the virtual format would be managed, and why their expertise would be relevant, as some potential speakers were not in research, academia, or areas overtly related to microbiome science. Confirmed speakers (~50% success rate of invitations) were each asked to prepare a 30-min plenary-style presentation that provided an overview of their work which would appeal to a research audience who had some level of familiarity with the topic.

The committee coordinated the scope of presentations in advance by setting up short virtual meetings for each session featuring the three speakers for that session and the committee. This allowed speakers to meet, discuss their research, and coordinate the three plenary talks, as well as discuss pertinent research questions, social policy concerns, pedagogical concepts, or other topics on which they wanted to lead a group discussion in a breakout room. Discussion group participants (~10 per room) would be encouraged to "problem solve" a suggested topic or one of their own choosing. The goal was to create meaningful action items, such as ideas for curricula development, identifying research needs or best practices, suggestions for engaging research in policy, and more. Notetakers were matched to a speaker/room, and were most often students in Dr. Ishaq's lab, including one student participating through the Research Experience for Undergraduates (REU) program through the UMaine One Health and the Environment Initiative, who were interested in these research concepts and in the organization of the conference. During the symposium, attendees were instructed on the goal of the breakout rooms and the topics in each, and were asked to self-select the room(s) to attend. Once in a room, designated notetakers shared links to premade documents on Google, featuring the topic ideas speakers had written down to seed conversations, enabling all room participants to co-write notes for the discussion.

3. Inviting Diverse Audiences

The goal for the symposium was to spark conversation on broad, seemingly intractable topics which spanned biological, microbiological, ecological, and sociopolitical spheres. To do this, we invited diverse audience participants. For the event, we defined diversity to include profession, area of study, career stage, geographic location, as well as demographics/background. We specifically invited and publicized the event to historically excluded groups via direct email and social media interaction with advocacy groups, including university-based, profession-based, and regional groups. While all parameters were impor-

tant to adding new perspectives to the symposium, especially to giving community-specific and relevant contexts, diversity of profession and area of study were of particular importance to our goal of facilitating conversation leading to actionable items. Thus, our goal was to bring researchers, practitioners, educators, designers and legislators together to engender actions and solutions in addition to conceptual advances. We chose a virtual format for our symposium to facilitate attendances from far-reaching geographic locations and those who were unable to travel in summer 2021 due to SARS-CoV-2. To create a more comfortable environment for participants to voice their perspective, the committee decided not to make any audiovisual recordings of the event. The decision was not made lightly, as choosing not to record content made the talks inaccessible to those with work or caregiving responsibilities, and anyone several time zones away.

We presumed that each themed session might attract different audiences, and that audience members might not attend all sessions. To help us better understand topic popularity and audience demographics, registration was required for each session independently. One session was held per day to provide more time for audiences to consider each topic. Registration links to Zoom meetings [11] were made available online through the MSE webpage [4], the UMaine Institute of Medicine, and promoted through posts to multiple social media platforms where the planning committee members had existing professional profile accounts. In addition, an invitation to the symposium was emailed to interest groups in the state of Maine based on publicly-available email addresses, including several hundred health researchers and practitioners who are part of the UMaine Institute of Medicine network; UMaine faculty and students in STEM, agriculture, nutrition, and food science, pedagogy, or equity; UMaine Cooperative Extension in agriculture or food security; University of Illinois Microbial Systems Initiative; local food security non-profit organizations; state-wide food production non-profit organizations; Maine's state legislators; and the MSE working group which contained ~100 members at the time of the symposium.

All publicity materials indicated that registration was free and open to the public. Several months prior to the symposium, 'save the date' email and social media posts were circulated, followed by posts, fliers, and emails (from the committee and speakers) listing the session dates and names along with a link to full program details and registration links. Additional fliers were created for each symposium topic session/day featuring the session title, a brief description of the scope, the speakers' photos, names, and institutional affiliation, and a link to registration for that session.

Upon registration, participants had the option to answer, "Which topic most interests you for a breakout room discussion?" out of nine areas (Table 1, University of Maine IRB, Application # 2022-05-02). The responses were used to organize rooms, notetakers, and expertise. Of those registrants who did not respond, many were speakers, organizations, notetakers, or MSE members. That list also included other registrants who were signed up for multiple sessions, and may have been disinclined to answer this question for multiple registrations.

Table 1. Registrants Indicated "Which Topic Most Interests You for a Breakout Room Discussion?", By Session.

Interests	Day 1: Biopolitics and the Human Microbiome	Day 2: Nutrition and the Gut Microbiome	Day 3: Natural Resources and Access to Environmental Microbes	Day 4: Social and Environmental Stress	Day 5: Access to Healthcare and the Microbiome
Learn more about the microbiome	15 (16.67%)	20 (20.53%)	14 (14.29%)	13 (12.15%)	13 (15.12%)
Creating integrated curricula and education	8 (8.89%)	6 (7.06%)	7 (7.14%)	5 (4.67%)	5 (5.81%)
Bringing science into policy	8 (8.89%)	9 (10.59%)	6 (6.12%)	12 (11.21%)	9 (10.47%)
Connections with social equity	23 (25.56%)	16 (18.82%)	20 (20.21%)	16 (14.95%)	8 (9.30%)
Engaging with this on social media	1 (1.11%)	0 (0.00%)	1 (1.02%)	0 (0.00%)	3 (3.49%)
Engaging the community into research	6 (6.67%)	3 (3.53%)	4 (4.08%)	6 (5.61%)	1 (1.16%)
Evaluating research through the lens of social equity	11 (12.22%)	1 (1.18%)	3 (3.06%)	5 (4.67%)	3 (3.49%)
Identifying future research on this topic	5 (5.56%)	8 (9.41%)	7 (7.14%)	9 (8.41%)	4 (4.65%)
Mobilizing university resources on this topic	2 (2.22%)	1 (1.18%)	1 (1.02%)	0 (0.00%)	0 (0.00%)
No response	11 (12.22%)	20 (23.53%)	30 (30.61%)	37 (34.58%)	37 (43.02%)
Total registrants	90	85	98	107	86

Registrants received a confirmation email, and reminder emails prior to the sessions which included a curated list of links to related recorded seminars from the spring 2021 MSE speaker series [12]. All session recordings from the speaker series were freely available online, and were intended to provide additional background information which would stimulate thought prior to the symposium, with the intention of focusing symposium time on goal-oriented group activities.

There were 467 total registrants across all 5 days, which included 210 total unique attendees registering for multiple days (Table 2, Figure 1), with 85–107 unique registrants per session. Some people registered 6 times, even though there were only 5 sessions, and we attributed this to losing links for the event; however, most people registered for only one session. Registrations were from 22 countries of origin: Antigua and Barbuda, Canada, Chile, Costa Rica, Denmark, Germany, Ghana, Greece, India, Indonesia, Malaysia, Morocco, Nigeria, Norway, Pakistan, Puerto Rico, South Africa, Spain, Sweden, United Kingdom, United States, and Uruguay.

Table 2. Registration And Attendance Counts Per Session.

Session	Registered	Attended
Day 1 (Monday): Biopolitics and the human microbiome	109	59 (54%)
Day 2 (Tuesday): Nutrition and the gut microbiome	113	67 (59%)
Day 3 (Wednesday): Natural resources and access to environmental microbes	99	46 (46%)
Day 4 (Thursday): Social and environmental stress	107	44 (41%)
Day 5 (Friday): Access to healthcare and the microbiome	86	36 (42%)
Total	514	252 (49%)

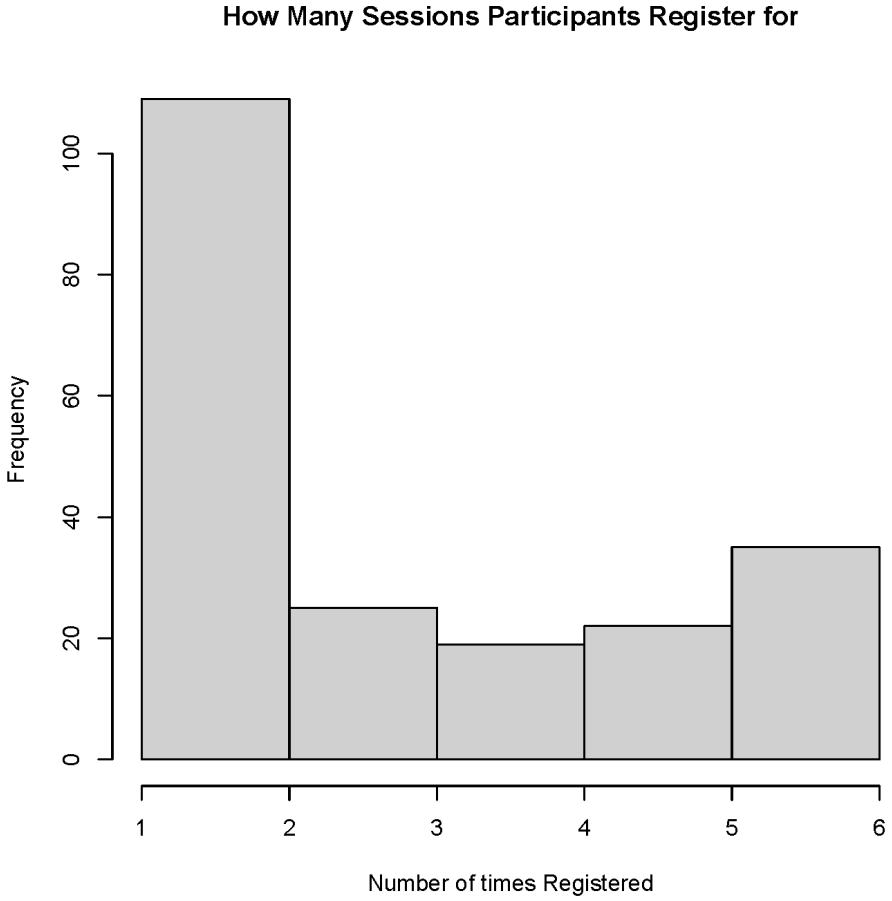


Figure 1. Session Registrations Per Attendee.

Registration was much higher than attendance, which ranged from 36–67 unique attendees per session and totaled 254 non-unique attendees (Table 2). The percentage of attendance decreased as the week progressed (Table 2), which may have been due to conference-fatigue rather than disinterest in the topic. Registrants were more likely to attend the event if they had registered for it recently, and most attendees registered the same day as the event (Figure 2).

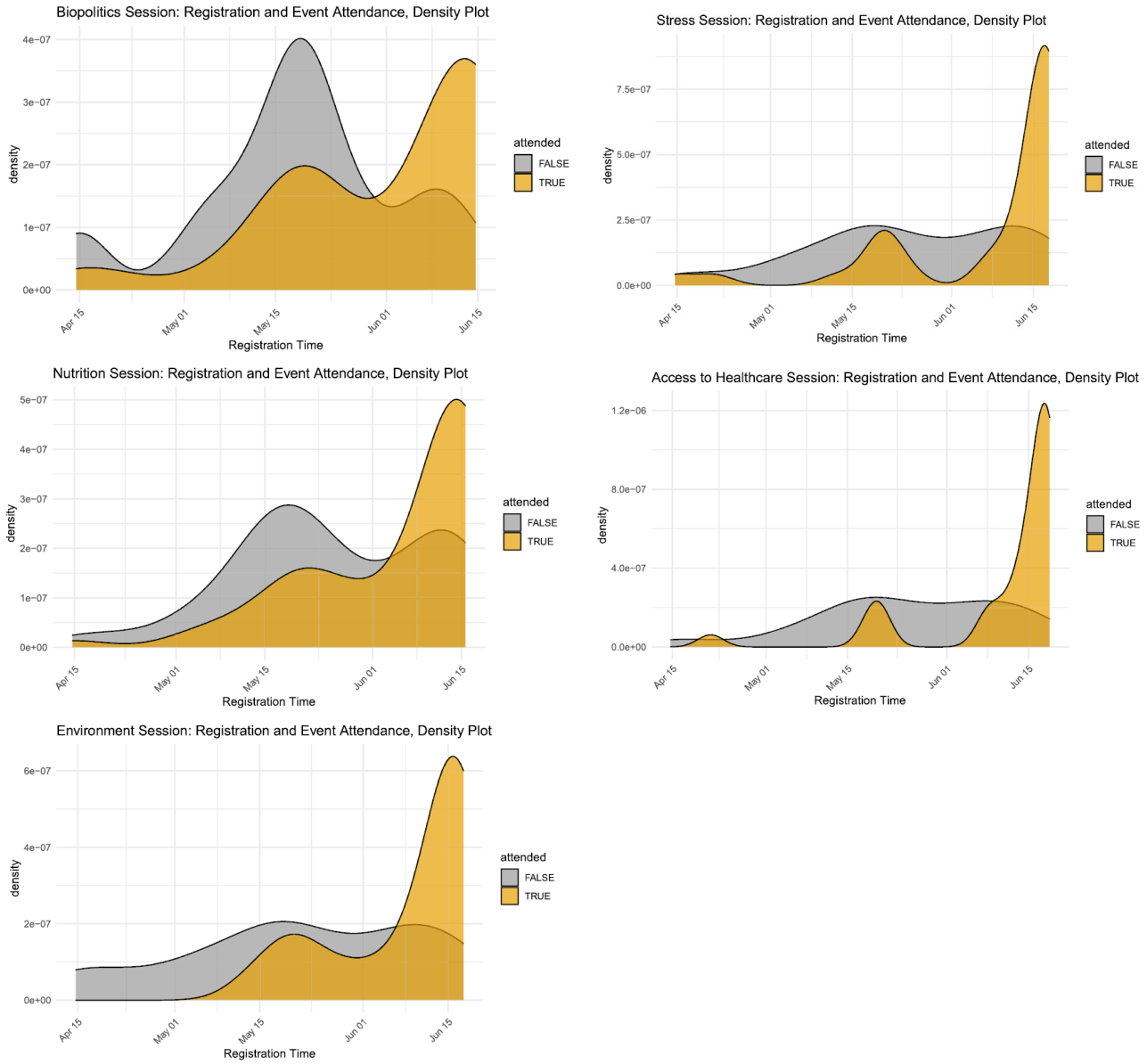


Figure 2. A Comparison of Registrants Who Did or Did Not Attend The Live Event By Date Of Registration.

To summarize the planning priorities:

- Ensure the planning committee is organized and delegates responsibilities clearly;
- Coordinate content with speaker groups prior to the event for more cohesive presentations;
- Publicizing events to diverse audiences requires diverse formats and venues.

4. Meeting Program and Session Achievements

4.1. Session 1: Biopolitics and the Human Microbiome

The first day of the symposium, as anticipated, drew a range of experienced and emerging scholars and practitioners, the highest attendance, and the most curiosity about the working-group format and what would be expected of the audience. The goal of this session was to introduce broad concepts about the impact of social and political constructs on how we access resources and interact with microbes [13,14]. We hoped that this "training day" would empower repeat attendees to engage on later topics in a more actionable way. Topic summary: "The human microbiota is a mediator between social determinants of health and health outcomes. Social determinants, such as racism, sexism, and social

class position are power relations that shape human microbial communities by providing access and exposure to varying biological factors. In turn, shifts in such communities are associated with distinct health outcomes. This opening session will introduce the concept of microbes and social equity, and open the discussion on how to create change".

In a coordination meeting prior to the symposium featuring Day 1 session speakers and planning committee members, we discussed possible breakout room discussion topics so that speakers could prepare resources or plan for how best to guide their discussion. This included defining terms related to equity and how these would integrate into microbiome research, and the discussion prompts: Which social determinants influence health and environmental inequities? What does feminist anti-racist and anti-colonial research practice look like, and how do we make science open to reflection? How do we incorporate lack of access (to care, food, housing) into experimental interpretation? What tools exist for examining spatial justice? How do we incorporate biopolitics in curricula, and how do scientists control their own biases? At what steps are people being excluded from participation in microbiome studies, and how can we address this? How can we ethically include indigenous populations in microbiome/genomics research, so they benefit from microbiome research? Should participation in microbiome/genomics research always entitle participants to direct benefits?

This session opened with an introduction to symposium schedule and goals, to the MSE group, and the UMaine Land Acknowledgement, provided by Dr. Sue Ishaq, MSE founder. An introduction to the topic of biopolitics and the microbiome, as well as introductions for each speaker, was provided by the session leader, Dr. Michael Friedman. Plenary speakers included those with expertise in public health, healthy equity research, and geography-based health research (Box 1).

Box 1. Speaker Information for Session 1.

"Advocating for COVID Equity by Addressing Misinformation, Mistrust, and Lack of Access during COVID-19". Jessica Otero, Community Health Education Specialist at the Mayo Clinic, focuses on reducing disparities in the communities of color, including by creating culturally relevant education materials and access to healthcare, with a specific focus on COVID-19 disparities in 2020/2021 [15,16].

"Imagining Otherwise? Theory and Practice for Centering Equity in Biomedicine". Dr. Katherine Darling, Ph.D., Assistant Professor of Sociology at University of Maine Augusta, embodies the breadth of health equity research and education, with training in feminist studies of science, medical sociology, bioethics, and molecular environmental biology [17].

"Neighborhood Inequalities: How Where We Live Influences our Health", Dr. Amber Pearson, Ph.D., Associate Professor in the Department of Geography, Environment and Spatial Sciences at Michigan State University and an Adjunct Fellow in the Department of Public Health at the University of Otago, focuses on health geography with a focus on social justice [18].

In one breakout room, we defined biopolitics and links to the microbiome. Biopolitics concerns the way social or political systems define and manage populations and control the biological capacities of individuals [19]. Challenging individual-level mainstream bioethics approaches, critical scholars of biomedicine have called for a "new biopolitics" as a frame for grappling with how emerging biotechnologies and biomedical influence communities and institutions [20]. Social and environmental inequities affect where people live, work, play, go to school, buy food, and access healthcare. By emphasizing social and political dynamics of biomedicine and health, biopolitics also addresses the justice concerns of disproportionate adverse social conditions such as the pollutants, toxic waste, violence, stigma/oppression, discrimination, or logistic burdens that make communities vulnerable. These factors can affect access to food, housing, transportation, mental and physical health, and other resources, and can affect the level of education, collective agency, self-efficacy for improving people's circumstances, and political representation people are able to obtain. For example, disempowerment and resource discrimination leads to stress and exposure

to chronically elevated cortisol, which causes microbiome changes that lead to acute and chronic health problems and inequities [21,22]. Simply put, we must make it possible for all communities to access resources and opportunities, and to be free. Researchers, and universities, can be involved in these efforts by acknowledging and participating in equity-centered work [23,24].

In a discussion on research tools, maps and geospatial data were identified as underutilized means of understanding disparities in resource access or exposure risk in microbiome research. Understanding local conditions of greenspace use was also important, for example, in high-use areas where many different activities are taking place in the same small space and are contributing to microbial transfer. In particular, low-income areas which lack greenspace may have to use the same space for community gardens, parks and playgrounds, but also dog parks, and these may be areas that feral or wild canids frequent. This can contribute to zoonotic transfer of microorganisms from feces via contact with soil [25] or aerosolized particles [26].

When discussing biopolitics in curricula, especially STEM, we discussed the problem of bias present in existing information on historical science which is used to teach the basics of STEM disciplines. The available historical information downplays or excludes contributions of scientists who were female or non-white, and while there are many efforts to uncover these lost contributions, this information is not commonly found in many textbooks or courses. We discussed the need to situate all STEM curricula in social contexts, as no scientific information exists which is not biased by its human observers. Thus, teaching students to identify human bias is equally as important as teaching them to identify experimental bias. We also identified the tendency of humans towards dualisms or binaries when categorizing concepts, rather than evaluating factors as a continuum or spectrum; for example, 'healthy' versus 'unhealthy', or 'good microbes' versus 'bad microbes'. This extends to the point of enforcing binaries on human populations, such as Western/non-Western diet, urban/rural, male/female, white/non-white, erases research trends by removing fine-scale differences or scaled responses, and can preclude meaningful contextualization of results [14,27].

To summarize the main points of session 1:

- To understand an individual's microbiome, one must understand their environment, and the social contexts which affect their choices and exposures;
- Geography can provide a wealth of environmental data for understanding host microbes;
- We must teach and combine humanities studies with microbiome/STEM studies to preclude siloing or the artificial separation of disciplines.

4.2. Session 2: Nutrition and Gut Microbiome

This session featured well-established research on the importance of a high-quality diet, and access to food resources as critical for physical, microbial, and mental health [1,28,29]. The goal of this session was to create actionable items regarding leveraging university or community-based resources to improve food access. Topic summary: "Access to fresh foods, and especially fruits, vegetables, and other products high in fiber, is well demonstrated to be affected by social inequity. The lack of fiber and nutritious food can dramatically hamper a functional gut microbiome. With the effects of COVID-19 being felt, the loss of income and disruption to our food and transport systems will make it more difficult for many individuals to obtain a nutritious diet and reap the benefit of a healthy gut microbiome. This effect will be disproportionately felt by lower-income individuals. This session explores the effects of diet on the gut microbiome and health, food insecurity, policy to support food access, and how to use existing resources to create community-based food systems".

Similar to Day 1, the Day 2 session speakers and planning committee members generated questions to seed breakout room discussions: How do we bring food insecurity into gut microbiome research? How can diet and microbiome research in wild animal populations be applied to humans? How do we incorporate nutrition and the gut−brain

axis into information for policy makers? What are the barriers to nutrition/health equity? Food insecurity on campus is often higher than in the rest of the state; why isn't this part of the conversation at colleges and universities? What are tools for gut research? Where is the disconnect between demonstrated science and getting it to lawmakers? How do we bridge the lack of awareness about our science?

This session opened with the same introduction to the symposium, followed by an introduction to the topic of nutrition and the gut microbiome and introductions for each speaker provided by the session leader, Dr. Laura Grieneisen. Plenary speaker expertise included food security and outreach, diet and health research, and food security in policy (Box 2).

Box 2. Speaker Information for Session 2.

"University of Maine Cooperative Extension Programs, Resources and Research Relevant to Food Insecurity". Frank Wertheim, M.S., Associate Extension Professor, University of Maine Cooperative Extension, focuses on hunger-related issues, and includes the development of educational and community-resources programs for farming and gardening communities to promote food security [30].

"Dietary Patterns and the Microbiome". Dr. Abigail J Johnson, Ph.D., Assistant Professor, Division of Epidemiology and Community Health at the University of Minnesota, and Associate Director, Nutrition Coordinating Center, performs nutrition research ranging from molecular biology and clinical nutrition to bioinformatics and public health, and explores the relationships between diet and the human gut microbiome in health and disease using novel computational methods for dietary data [31,32].

"USDA Approaches to Alleviating Food Insecurity during the COVID-19 Pandemic". Dr. Leslie Hodges, Ph.D., Research Agricultural Economist, Economic Research Service at the USDA, conducts research to inform evidence-based policymaking on the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) and the Supplemental Nutrition Assistance Program (SNAP) [33].

In one breakout room, we discussed how to tell science apart from 'fads' in trying to understand the role of nutrition in the gut−brain axis. We discussed how microbes play an underappreciated role in processing the food we eat and, in turn, our well-being and cognition. From there, participants asked questions about our sense of self (is the brain the center of everything? What would it mean to be a 'holobiont'?). While these questions are larger than our discussion room could answer, facilitators provided resources for those who expressed interest in reading more about the microbiome in several contexts.

In another room, discussing tools for gut microbiome research, the group noted the general public's lack of knowledge/science literacy, which makes it difficult to identify or to effectively alter food behaviors. We discussed the effectiveness of lifelong nutritional education to provide information, as well as to teach meal and nutritional planning. Community engagement was also mentioned as a valuable research tool, to assist in planning research, understanding individualized barriers to food access, and to creating localized solutions which leverage community resources. More broadly, we cited the need for larger study sizes and the inclusion of diverse geographies, socioeconomic statuses, and food preferences, as many human diet microbiome studies focus on university-adjacent populations. We also discussed the need for more specific food preference and used surveys, as commonly used surveys do not capture barriers to food access when gathering information about food choice, or do not capture high-resolution nutritional content in foods with diverse components, which may require paired proteomics analysis and highly complex computational biology to connect nutritional and microbiological changes.

Finally, we discussed barriers to nutrition and health equity in general, and specifically the often-overlooked food insecurity which exists on university campuses. Barriers to food choice included lack of time, knowledge, kitchen resources, or food storage options; lack of local options and affordable food; and lack of dental or healthcare or housing which may restrict diet choices (e.g., inability to consume or store root vegetables). The group agreed

that better organization of local resources, such as providing kitchen space, food storage, or food sharing options, could dramatically improve timely resource allocation (e.g., [34]). Universities could provide these to students to reduce food insecurity (e.g., food sharing app ShareMeals.org). Making nutritional assessment and planning more accessible, such as in documentaries, at all levels of education including medical schools and community-level programs, could empower more people to find accurate nutritional information and make informed decisions over their lifetime. We stressed that community involvement and cultural importance of food in research and local food systems are critical, and discussed the role of microbiome science in supporting food access policy, and the recently passed legislation in the state of Maine; Resolve to End Hunger in Maine by 2030 [35].

To summarize the main points of session 2:

- Resolving food insecurity is an easy and effective way to improve host−microbial interactions;
- Food insecurity may have nuanced causes but we already have the resources to resolve it, we simply lack logistical organization to allocate them.

4.3. Session 3: Natural Resources and Access to Environmental Microbes

This session highlighted the potential benefits of access to natural environments and their diverse microbial communities [36], and discussed how urban planning and design could be used to increase greenspace in urban settings, improve the quality of those ecosystems by reducing chemical and microbial pollutants, and provide better access by making their distribution across populations more equitable [37,38]. Topic summary: "The relationship between health and greenspace is well-established. There is also a recognized association between social equity and distribution of greenspace in many cities—parks are often larger, higher-quality, and more prevalent in higher-income, upper-class neighborhoods; private yards and gardens are a luxury sometimes inaccessible to lower-income households; even street trees tend to be older, larger, and more numerous in higher income neighborhoods. New evidence shows that exposure to microbial diversity may be an important ecosystem service provided by urban greenspace, as exposure to greater microbial diversity early in life is related to lower prevalence of autoimmune disorders, such as allergies and asthma. This session will explore how environmental justice can be used to resolve health, microbial, and land access disparities".

The Day 3 session speakers and planning committee members generated questions to seed breakout room discussions: What are the rural versus urban differences in accessing natural resources and exposure rates to pollution types? Is ecological restoration and microbiome 'rewilding' an effective means of reducing pollution and improving beneficial microbial exposures? How do we leverage existing datasets to glean more information? How do we integrate disparate datasets to include all aspects of the exposome in microbiome research, especially the more elusive social equity variables? How do we develop science communication and education around good/bad environmental exposures, such as "raw water"? Has the pandemic highlighted/exacerbated inequitable access to beneficial exposures (e.g., greenspace)? Has the pandemic highlighted/exacerbated inequitable access to detrimental exposures (e.g., degraded buildings)?

This session opened with the same introduction to the symposium, followed by an introduction to the topic of exposure to environmental microorganisms and introductions for each speaker provided by the session leader, Dr. Gwynne Mhuireach. Plenary speakers included expertise from civil and environmental engineering, pollution abatement, microbial exposure, and distribution of high-quality versus degraded natural resources (Box 3).

Box 3. Speaker Information for Session 3.

"Living Near Urban Natural Environments and Gut Microbiota Diversity and Composition in Young Infants", was co-presented by Drs. Nielsen and Kozyrskyj. Dr. Charlene Nielsen, Ph.D., Postdoctoral Fellow, School of Public Health, University of Alberta, uses geography and spatial data science to research environmental health solutions for exposome and climate change impacts on at-risk populations [39]. Dr. Anita Kozyrskyj, Ph.D., Professor of Pediatrics at the University of Alberta, Canada, leads the SyMBIOTA research program on environmental shaping of the infant gut microbiome, and development of child overweight, atopic disease and neurodevelopmental disorders in the CHILD Cohort Study [40]. Their research included co-primary author Dr. Mireia Gascon, a microbiome epidemiologist at ISGlobal in Spain (Nielsen, Kozyrskyj, Gascon, unpublished results).

"Biosolids, Beneficial Reuse and Risk—or Why We Need to Consider the Whole System to Avoid Creating New Problems". Dr. Jean MacRae, Ph.D., Associate Professor in the Department of Civil and Environmental Engineering at the University of Maine, researches managing risks associated with a circular food system and management and processing of organic residuals; reducing the impacts of aquaculture, and nutrient recovery from its wastes; biogeochemical cycling of nitrogen and other elements; and microbial community composition and function in environmental systems [41].

"Predicting Environmental Sewage Pollution Persistence and Engaging in Public Scholarship". Dr. Elise McKenna Myers, at the time, was a NASA Future Investigator in Earth and Space Science and a Ph.D. candidate at Columbia University and Lamont Doherty Earth Observatory. Dr. Myers develops methods to predict microbial sewage contamination in urban waters using a combination of models, experiments, and satellite data; and is committed to making her research accessible to the public [42].

The discussion groups for this session were originally designated by speaker expertise: "exposome in datasets", "biosolids reuse", and "education about environmental exposures", as well as "transdisciplinary training" provided by Dr. Erin Eggleston [43]. However, all groups merged into one due to the overlap of interests. One of the primary points of discussion was leveraging existing datasets to combine microbiological, social, economic, and other forms of information, as well as the vast online resources such as ArcGIS [44], USDA Food Desert [45], Statistics Canada [46], The Microsetta Initiative (formerly American Gut Project) [47], the Veteran's Microbiome Project (available by collaboration) [48], Earth Microbiome Project [49], and the Canadian Urban Environmental Health (CANUE) Research Consortium, which combine various data sources [50]. Another theme covered was the need of developing methods of reaching populations who are underrepresented in large studies because they lack time and resources to participate. It was mentioned that methods which utilize existing data from wearable technologies and sampling devices, phone apps, or audiovisual data could allow participation of diverse populations. Finally, we discussed the difficulty of handling diverse datasets when our training in data analysis is typically limited to techniques from our primary research field. Beyond training resources, we agreed that sharing data between researchers and soliciting additional collaborations was the most efficient solution; however, it did require additional time to develop the new collaboration and the new analytical framework.

To summarize the main points of session 3:

- Interactions with the environment are complex and difficult to study, though critical to understanding host microbiomes;
- Creative use of technology can increase data collection on an individual scale;
- Researchers trained to use large-scale environmental and geographic datasets can provide insight to microbiome research without having to collect massive numbers of environmental microbiome samples.

4.4. Session 4: Social and Environmental Stress

This session paired with Day 3, and presented the potential negative aspects of the environment on health and microbial communities, including how pollution and degraded environments, neglected neighborhood infrastructure, and stress due to structural inequal-

ity and discrimination can collectively reduce beneficial microbial exposures while increasing detrimental ones, induce stress-based health problems, and disrupt host−microbial interactions [51–53]. In summary: "While it has been established that human behavior may impact microbiome structure, it has become evident that this is only part of the story. Historically racist housing policies may lead to inequitable exposure of those living in segregated neighborhoods to environmental pollutants. Additionally, life-long exposure to social and environmental stress faced by minority groups within the US may increase risk to disease through the alteration of host and bacterial metabolites. These inequities were compounded during the COVID-19 pandemic, during which neighborhood structural environments led to differing access to healthcare and treatment for the disease. Notably, those with the least access often were subject to higher exposure to the disease due to having "essential" employment. This session will explore the social and environmental factors that can impact human microbiomes, and will discuss measures that investigators should incorporate into research to fully understand microbial mechanisms of disease".

The Day 4 session speakers and planning committee members generated questions to seed breakout room discussions: What is "stress", and/or how is it defined and measured? Has the pandemic highlighted/exacerbated inequitable access to beneficial exposures (e.g., greenspace)? Has the pandemic highlighted/exacerbated inequitable access to detrimental exposures (e.g., degraded buildings)? International responses to the COVID-19 pandemic have been very different. How should the US respond so that it acknowledges and supports the needs of our worldwide community, and how can international organizations create policies that impact the response to disease outbreaks so that they are equitable? As microbiome researchers, how do we account for vastly different lived experiences of study participants and how those affect their microbiome? How do we bring together investigators with differing expertise to tackle quantification of lived experiences in data analysis? How are proposals being written to ask these questions and what organizations are funding these projects? How do we operationalize these ideas to train interdisciplinary scientists that prioritize social and structural barriers to social equity in their microbiome research? What are ways that we can educate the public using evidence-based data particularly in topics related to microbes and social equity?

This session opened with the same introduction to the symposium, followed by an introduction to the topic of exposure to environmental stressors and introductions for each speaker provided by the session leader, Dr. Patricia Wolf. Plenary speaker expertise included epidemiology and host-associated microbiology, cancer risk based on lifestyle and health disparities, and tracking inequality using wastewater (Box 4).

Box 4. Speaker Information for Session 4.

"It's Probably Stress': Towards a Better Understanding of our Microbes, Environment, and Society". Dr. Ariangela Kozik, Ph.D., Postdoctoral Research Fellow, University of Michigan, and the Co-founder and Vice President of the Black Microbiologists Association [54], focuses on host-associated microbial ecology, structural inequalities and discrimination, and how collective stressors affect the microbiome and health [13,51].

"Structural Violence, the Gut Microbiome and Colorectal Cancer Health Disparities". Dr. Lisa Tussing-Humphreys, Ph.D., M.S., R.D., Associate Professor of Kinesiology and Nutrition, University of Illinois at Chicago, and Program Leader, UI Cancer Center's Cancer Prevention and Control Program, focuses on the intersection of microbial communities in the gut, structural inequality, and subsequent health disparities in colorectal cancer risk and outcomes [55,56].

"The Urban Wastewater Microbiome". Dr. Monica Trujillo, Ph.D., Associate Professor of Biology Queensborough Community College, The City University of New York, focuses on microbiology, and more recently, using microbiological testing of wastewater to track SARS-CoV2 by neighborhood in New York City to determine areas which lack resources for disease management [53].

One of the breakout rooms discussed the barriers to equity in science, and considered the effect of discrimination towards scientists as well as the use of science to reinforce

discrimination in society. This includes research institutions where diverse talent might be recruited but not retained, often referred to as a "leaky pipeline", from the burden of having to achieve more to be seen as equally productive, or have to spend more time, energy, and money to access the same institutional support resources which are ostensibly there to ensure their success. Institutions can easily review applicant, candidate, hire, and promotion demographic data to understand employee success [57], but it may be difficult for institutions to identify the source of barriers without forcing former employees to disclose personal or professionally sensitive information which can subject them to further professional backlash. Instead, institutions can find best practices for equity and inclusion through published research and conversations with the relevant scientific community [58–60].

Another common barrier to equity, discussed in the same room, includes the use of ghost variables [14] and undefined broad categories (e.g., race and gender) as if they were fixed biological characteristics [61]. Not only does this obscure trends in data and imply that race is responsible for dictating differences in microbiomes or overall health [62], but it can be used as a fake biological justification for discriminatory legislation or outright genocide [63–65]. Scientific training currently favors reducing biological diversity down to narrow, quantifiable categories, that are presented without interpretation which could be construed as speculation, but we must change our training if we want to prevent this winnowing of context down to one-dimensional factors [23,24,60,66]. Institutions can support this training towards context-aware microbiome research by prioritizing diversity, equity, and inclusion not only as a broader impact outcome but as a primary focus of the experimental design.

This conversation was echoed in a second breakout room that examined current tools used to measure exposure to structural violence and its effect on health [22,67], and other tools needed for inclusive translational research. Overall, obtaining context-aware and high-resolution results requires multiple sources of data beyond just the microbiome and basic survey information. Activity, heart rate, blood pressure, and exposure to microbial or chemical pollutants can be measured using wearable technology [68,69], chronic stress can be measured in hair cortisol and neurosteroids, or in controlled experimental situations using pupil dilation, eye tracking, or electrogastrography (proxy for vagal nerve activity). However, measuring and quantifying structural violence is so nuanced that the best tool is collaboration with sociologists. Adding dimensionality to the research team is just as critical as adding dimensionality to microbiome data, and can improve data collection and interpretation.

Another breakout room discussed the challenges and best practices for developing curricula on topics that meld microbiology and sociology. The primary barrier to developing curricula was a lack of resources, such as computing resources, supplies for training, and time in a semester to develop and build on complex skills such as data analysis. In particular, many classes struggle to teach skills in microbiome, sociology, and integrated data analysis in one semester. We highlighted the importance of integrating social equity aspects into our data analysis and curricula, such as talking about policy in science courses and the effect on people's decision-making process, as well as promoting science literacy skills over memorizing facts.

To summarize the main points of session 4:

- Water systems can be a critical source of detrimental microbial exposure;
- Infrastructure on water systems management, especially wastewater management, is a key target for improving equitable distribution of resources and public health;
- Creative use of technology can increase data collection on an individual-scale.

4.5. Session 5: Access to Healthcare and the Microbiome

The last session centered on the importance of preventative and treatment-based healthcare, of health disparities based on access to healthcare resources, and of the role that reproductive and perinatal health care, especially at birth [70,71], can play in ameliorating

or worsening microbial exposures with longer-term health consequences [39,72,73]. The goal of this session was to highlight these areas of medical care, as they may be considered "niche population health issues" instead of concerns which broadly affect public health, e.g., [74]. Topic summary: "Access to healthcare, including treatment and preventative care, is critical to moderate beneficial host−microbe interactions and mitigate host-pathogen interactions, yet healthcare is inequitably distributed and often curbed by social policy. For instance, maternity care is well-demonstrated to improve health outcomes and facilitate the transfer of beneficial maternal microbes to newborns. Policies which support breastfeeding likewise promote this transfer of maternal microbes. Similarly, newborns and infants with access to care in their first five years of life have better outcomes overall than those with limited access. This difference in care during early life can impact lifelong differences in outcomes, reinforcing inequalities present at birth. This session will cover topics from the vaginal microbiome during pregnancy to the infant gut microbiome after birth, with perspectives from a clinician, public health researchers, and a biological scientist".

The Day 5 session speakers and planning committee members generated questions to seed breakout room discussions: How do we disambiguate the narrow category of "race/ethnicity" from the complex effects of structural inequality, racism, and lifestyle/health consequences which might affect the microbiome? What is race a "proxy measurement" of, and can we measure lived experiences more directly? What does the research say when race is a predictor for participants? Race is a social construct, so why are we talking about the vaginal microbiome in terms of race? How do we support breast feeding by improving access and infrastructure? How do we educate providers to support breastfeeding? How do microbiome scientists impact policy for expanded maternal health care? How do we improve education on healthy vaginal hygiene practices versus what is marketed as "healthy"? How do social barriers to health access affect vaginal microbiome/health?

This session opened with the same introduction to the symposium, followed by an introduction to the topic of maternal health and transfer of microbes, as well as introductions for each speaker provided by the session leader, Emily Wissel. Plenary speaker expertise included nursing, healthcare research, and microbial communities related to reproductive, perinatal, and breastfeeding events (Box 5).

Box 5. Speaker Information for Session 5.

"Sexual Health Disparities: How Social Determinants of Health May Affect the Vaginal Microbiome". Dr. Gaea Daniel, Ph.D., R.N., Postdoctoral Fellow at Nell Hodgson Woodruff School of Nursing at Emory University, focuses on understanding the sociocultural and environmental influences that affect sexual health behaviors and outcomes, and particularly in sexual health outcomes of Black women that present as race-based disparities, from intravaginal practices to sexually transmitted infections [75].

"Place, Race, and the 'Geomicrobiome': How Spatial Mobility and Environment Can Shape Reproductive Health". Dr. Michael Kramer, Ph.D., Professor of Epidemiology and Director of Maternal and Child Health Center of Excellence at Emory University, researches and teaches the exploration of mechanisms by which social and spatial context broadly, and aspects of structural racism specifically, affect the maternal and infant health outcomes, and act to reduce racial, economic, and geographic inequities in health [76].

"How Disparities in Access to Health Care Could Impact the Maternal−Infant Microbiome". Dr. Sharon M Donovan, Ph.D., R.D., Professor, Director of the Personalized Nutrition Initiative, University of Illinois, investigates some of the most pressing health issues facing children and families, including promoting a healthy gut, brain, and microbiome through diet, preventing childhood obesity and picky eating behaviors [77,78].

It is well established that breastfeeding can dramatically benefit the developing infant gut microbiome and immune system, and in one breakout room we discussed common barriers to breastfeeding. Providing mandated and paid family leave, lactation specialist consultations, lactation spaces which have hygiene stations but are not bathrooms, policy which protects the right of people to breastfeed in public [79], and destigmatizing the

decision to breastfeed or not would all help. These barriers and recommendations have been reiterated for several decades without widespread policy action; yet providing perinatal and lactation financial and infrastructure support is one of the easiest ways to support public health and reduce healthcare cost burdens [80].

Another conversation focused on the misuse of racial categorization as an explanatory variable in the vaginal microbiome. Not only does this usage obscure trends in the vaginal microbiome which are related to targeted marketing campaigns [81], discrimination in the health care system [82], and cultural practices, but it also situates certain demographics as having the "standard/best" vaginal microbiome and others as being deviations, which can further lead to discrimination in health care. Some barriers that were identified included the stigma of talking about sexual health, vaginal microbiomes, hygiene practices, and the mythicization of "clean, scent-free vaginas" which has reinforced the stigma of seeking reproductive healthcare care. Further, public policy can massively affect access to sexual health services and information, stigma around vaginal health, and even the ability to talk about sexual health in certain settings. Solutions include improving sexual health education, encouraging conversations about the vaginal microbiome especially in situations where it might be awkward to bring up the topic, and pushing back against marketing which sells the idealization of the microbiome and health.

To summarize the main points of session 5:

- Improving reproductive and peri-natal healthcare access is an easy and effective way to improve host-microbial interactions and health
- Access to and autonomy in reproductive healthcare is critical to human rights and equality
- Breastfeeding is an easy and effective way to improve host−microbial interactions and health, and we already have the resources to make this practice widespread, we simply lack logistical organization to allocate those resources.

5. Future Directions

Based on attendee comments during the conference, on the post-conference survey (University of Maine IRB, Application # 2022-05-02), and in the months since, one of the most fruitful and remarked-upon aspects of the symposium was the working time in the breakout rooms built into the schedule. We built upon work that demonstrates the importance and efficacy of working time in scientific or other informational meetings [83]. MSE members agreed that providing workshop, training, or collaborative working time was essential. It covered useful content, allowed them to accomplish other work-oriented goals simultaneously (i.e., work on writing projects as part of the symposium), and provided an aspect of a conference that was not already being offered by other conference venues. Indeed, providing research content and information was also cited as important but less necessary, as MSE has generated two years' worth of speaker series talk recordings [12,84] and papers [3,14,43,55,85–87], already available to symposium attendees.

We learned that most people registered for only one session, indicating that we needed to advertise to non-overlapping audiences for each session. There were large increases in registration in response to social media and email campaigns, but most people who registered months ahead of the event did not attend. While reminder emails were sent the day of the event to registrants, including the meeting link in this email would likely boost attendance, as would notifying the registrants that these talks would not be recorded.

For future MSE symposia, we intend to put greater focus on skills development and tangible outputs, and to design the schedule around those goals. For the main session topics, instead of research areas as the focus of content, outputs would form the session topics and research areas would be represented by speakers and breakout rooms. For example, a session might focus on curricular development, and speakers from microbiology, education, and curricular development backgrounds would focus on how this is accomplished. The discussion groups would then self-select breakout rooms which reflected the student audience they were most likely to work with, such as "STEM undergraduates", "non-STEM

undergraduates", "medical students", and more. During the discussion time, attendees would share resources, examine draft syllabi, draft assignments, and use their own course materials as case-studies for the group to consult on. We anticipate that networking and forming new collaborations, developing curricula, writing policy briefs, or planning outreach and extension activities, as well as experimental designs and data analyses, will form the main outputs and session topics.

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