
















# Introducing the Microbes and Social Equity Working Group: Considering the Microbial Components of Social, Environmental, and Health Justice

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**ABSTRACT** Humans are inextricably linked to each other and our natural world, and microorganisms lie at the nexus of those interactions. Microorganisms form genetically


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 Introducing the Microbes and Social Equity (MSE) Working Group, which connects microbiology with social equity research, education, policy, and practice to understand the interplay of microorganisms, individuals, societies, and ecosystems.

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flexible, taxonomically diverse, and biochemically rich communities, i.e., microbiomes that are integral to the health and development of macroorganisms, societies, and ecosystems. Yet engagement with beneficial microbiomes is dictated by access to public resources, such as nutritious food, clean water and air, safe shelter, social interactions, and effective medicine. In this way, microbiomes have sociopolitical contexts that must be considered. The Microbes and Social Equity (MSE) Working Group connects microbiology with social equity research, education, policy, and practice to understand the interplay of microorganisms, individuals, societies, and ecosystems. Here, we outline opportunities for integrating microbiology and social equity work through broadening education and training; diversifying research topics, methods, and perspectives; and advocating for evidence-based public policy that supports sustainable, equitable, and microbial wealth for all.

**KEYWORDS** biopolitics, health disparities, social determinants of health, structural determinants of health, integrated research, microbiomes

### MICROCOSMS OF SOCIAL EQUITY

**As an anthropologist, . . . what I love about the microbiome is that it brings together social intimacies of life with our biological selves in ways that show us that those two things are inextricably entangled.**

—Amber Benezra, The Microbes and Social Equity spring 2021 seminar series, virtual, 10 March 2021, [https://video.maine.edu/media/The+Global+MicrobiomeA+microbes+and+public+health+beyond+biology/1\\_nyje1v0b](https://video.maine.edu/media/The+Global+MicrobiomeA+microbes+and+public+health+beyond+biology/1_nyje1v0b)

Humans are inextricably linked to each other and our natural world through social, political, economic, and cultural interactions that have biological or ecological impacts. Microorganisms, including bacteria, archaea, fungi and other microbial eukaryotes (protists), and viruses, lie at the nexus of those relationships. Microbial transmission between individuals or from the environment is inevitable and ongoing; in our lifetimes, we encounter incredible microbial biodiversity, and in this way, microbes are the ties that bind us (1, 2).

Exposures to and long-term interactions with microorganisms are involved in the health, development, and security of individuals (3), societies (4–6), and ecosystems (7, 8). For example, nourishing diets support microbial communities that benefit mental, physical, and immune system function(s) (9–11). However, oppressive social structures result in financial, temporal, geographic, and logistical barriers to accessing healthy diets (12–14) and, thereby, beneficial microbiomes. Exposure to a variety of xenobiotics, including profligately employed antibiotics (15), is associated with depleted and distorted microbial communities (16–20). Access to greenspace promotes microbial exposures (21–24) that benefit physical and mental health (25) but is impacted by a history of environmental racism (26). Moreover, environmental microbiomes offer sustainable solutions to waste remediation, bioenergy production, food production, climate change mitigation, and, indeed, Earth's future (27–29), yet human activities fundamentally alter environmental microbial communities on which humans depend for our physical, social, and economic well-being (8, 30, 31).

Clean water, fresh air, healthy soils, nutritious foods, safe shelter, and the preservation of global biodiversity inherently depend on microbial communities (7, 32), and healthy human microbiomes depend on these resources. Access to these resources is a fundamental human right (33–35); however, neither the resources nor the associated beneficial microbiomes are equitably distributed. Thus, the key to supporting healthy microbiomes (from guts to soils) is rooted in addressing social inequities (Table 1).

**Group Mission Statement.** The Microbes and Social Equity (MSE) Working Group posits that microbial exposures across ecosystems, urban and rural settings, and individuals are sociopolitical. Our purpose is to connect microbiology with social equity research, education, policy, and practice to understand the interplay of microorganisms, individuals, societies, and ecosystems. Collectively, we seek to generate and communicate

**TABLE 1** Glossary of terms

Term	Definition
Biopolitics	The forms of political power concerned with the scientific management of biological processes and population dynamics of human, animal, and microbial life. Biopolitical resources are the processes managed through the scientific and administrative attempts to define, predict, or control human or non-human life, health, productivity, reproduction, and populations. See references 73 and 153.
Environmental justice	Equitable treatment and meaningful involvement of all people with respect to the development and implementation of environmental policies and practices. Equal access to environmental risks and benefits. See reference 145.
Epistemology	The theory of knowledge and the differentiation of belief from opinion.
Exposomics	The study of collective microbial and chemical exposures over time. See reference 100.
Intersectionality	The idea that identities, including, but not limited to, race, gender identity, ability, sexuality, and socioeconomic status, overlap in individuals, an acknowledgement that is required to bring social justice to the microbiome. In addition to referring to overlapping (nonadditive) identities, intersectionality refers to interlocking systems of oppression (e.g., racism, sexism, capitalism, ableism). See references 154, 155, and 162.
Microbial diversity	A diverse community contains more “types” of microorganisms and is analyzed by examining the number of types (i.e., species, strains, or functions) as well as their abundances and distributions in a host population or habitat.
Microbiome	The collection of microorganisms, which may include bacteria, archaea, fungi and other microbial eukaryotes (protists), and viruses, in a given habitat or host and their genomes, which are often used to characterize the collective organismal diversity and functional capacity of that community. See reference 147.
Neoliberalism	A set of political-economical and ideological principles and policies based on the view that every individual is an equal economic and social actor in a society best regulated by the “free” market. Its spread has depended upon a reconstitution of state powers such that privatization, finance, and market processes are emphasized. See reference 148.
Ontogeny	All physiological, developmental, and phenomenological events occurring during the processes underlying biological organization across an agent’s lifetime.
Social equity	The concept that additional barriers exist for certain social groups that restrict access to public resources because of implicit or explicit biases and the active support of social policy, viewpoints, and public infrastructure that promote access to public resources in a way that dismantles these additional barriers. See reference 149.
Social determinants of health	The living, working, and local environmental conditions around a person that affect their health, their risk of harm, and health outcomes following medical interventions. See reference 150.
Social justice	The concept that wealth, economic opportunities, and financial privileges should be equitably distributed or accessible within a society. The practices of legal policy and law that facilitate more equitable distribution of economic opportunity when they are not.
Spatial justice	The concept that socially valued resources, such as natural and built environmental (i.e., infrastructure) resources, are not equitably distributed or accessible within a society. The practices of social and legal policy that facilitate equitable access to important resources. See reference 151.
Sustainability	The state in which a system is able to function with little-to-no additional outside inputs or with little-to-no waste.
Transdisciplinary research	Research that brings together different disciplinary perspectives to forge a new, synthetic field or framework, as opposed to interdisciplinary research, which brings together different disciplinary perspectives while keeping them distinct from one another.

knowledge that will spark evidence-based public policy and practice, supporting equity and sustainability for all.

### MANY INDIVIDUAL CONTRIBUTIONS CREATED A COMMUNITY

What do microbes have to do with social equity? What began as a thought exercise in 2019 became an educational discourse (S. L. Ishaq’s “Microbes and Social Equity” course materials) and an essay (1) and has since grown into an international community of like-minded researchers (The MSE Working Group and S. L. Ishaq). In line with the pivotal role of microbiomes and growing public attention to issues of social inequity and health outcome disparities, the MSE Working Group members represent diverse fields, e.g., anthropology, architecture, bioethics, bioinformatics, data science, ecology, engineering, genetics, medicine, microbiology, nutrition, psychology, and sociology, and exhibit expertise in various hosts, systems, and environments beyond human microbiomes. We are researchers, educators, practitioners, and policymakers spanning the globe and career levels. While the term “microbes and social equity” is novel, this concept has previously entered academic and public discourse (10, 36–43). We gratefully acknowledge these previous efforts to situate natural sciences within sociopolitical contexts.

**A Call to Collaboration.** Connecting diverse demographics, cultures, and geographic regions is an underappreciated opportunity in the microbiologist's domain. This work requires us to develop teams of biological and social scientists and policy experts who engage with affected communities to create solutions for substantial change. This creativity requires research journals to accommodate biological and anthropological data in the same piece, imaginative study endpoints that create meaningful change, and the intellectual freedom to weave detailed narratives when presenting research findings. For data-driven sciences, this collaboration requires interrogating one's own research within social contexts and existing biases (44). For example, previous work investigating microbial mechanisms of health disparities has focused on how environmental, structural, and racial politico-economic discrimination and other inequities influence microbiomes, instead of falsely assuming inherent biological differences between people of different races (38). Interventions that ignore social interactions or neglect the social determinants of health may fail to meet their goals (44, 45).

Links between social equity and microbial communities cannot be studied solely within the confines of the laboratory; community engagement and clear communication about research impact improve inclusivity (47, 48). At its worst, barriers to inclusivity exclude populations from health care and research, treating them as study objects (49) or as sources of extractable resources (50, 51), rather than equal partners. The disregard of cultural and personal dignity, as well as "othered" forms of knowledge (52, 53), creates a lasting atmosphere of institutional betrayal (54) in health care and research. We embark on this work with acknowledgment of colonial histories from which our universities and disciplines emerged (52, 55–57).

Microbiome science must consider applications that will benefit study populations in the foreseeable future, since direct, immediate intervention is unlikely at this stage of our understanding. Thus, we support an "ethics of care" (58) that requires microbiome researchers not only to attend to current predicaments of research participants, to support meaningful infrastructural changes, and to remain alert to possible commercial exploitation (38, 59–61) but also to consider that a participant's health extends well beyond the boundaries of "skin and skull," and to consider the microbiome as integral to the individual's inherent functioning (38, 46, 59–61). Certainly, this complicates the ways in which we understand our own physiology (44) and calls into question our self-conception (62, 63), our individuality (64), and, thus, some of the most central categories that we integrate into our ethical and political reasonings. Accordingly, collaboration within the MSE Working Group necessitates an explicit feminist, antiracist, anti-imperial, and anticolonial framework for knowledge production. Our goals are aspirational, and as with all abolitionist future-making projects which seek liberation from oppressive systems and institutions, our imperfect endeavor necessitates revision and reflexivity over time (65, 66).

## FOSTERING THE NEXT GENERATION OF RESEARCHERS

**In many global contexts, there is an epistemological divide between social and "other" sciences. MSE has the potential to offer a diverse—yet unifying—ground for transdisciplinary efforts.**

—Francisco J. Parada, MSE Working Group writing session, 2021

A central challenge in accelerating scientific progress on MSE issues is the need to train a generation of interdisciplinary scientists, many from minoritized groups (67), who can deploy complex systems thinking (68) to understand and model large, diverse, microbe-human systems (69). The goal is a novel transdisciplinary research and application agenda which combines disciplinary perspectives to forge a new, synthetic field or framework. In addition to domain-specific and mathematical approaches that drive the development of conceptual and quantitative theories, parallel training in "big data" analysis will be fundamental (70, 71). Lessons from other research programs indicate that future curricula will benefit from emphasizing both inductive and deductive scientific methods and the strategic combination of theory and data (72).

Further, integration between disciplines necessitates an epistemic change in the understanding of both the object of study and the observer (73). The success of transdisciplinary efforts requires novel funding and training opportunities as well as new epistemic frameworks and methods for integrating social, ethical, and justice issues into technoscientific practice and the design of technologies (74, 91, 156). Research initiatives, such as One Health (75, 76), which simultaneously considers human, social, and environmental health, or academic microbiome programs, such as the Oxford Interdisciplinary Microbiome Project (University of Oxford) and the Microbiome Initiative (University of California Riverside), foster interdisciplinary education and research to meld social and natural sciences. Similarly, “citizen science” initiatives engage both researchers and the general public. However, maintaining an interdisciplinary career or creating a transdisciplinary one requires governmental funding agencies and academic institutions to adopt creative or field-inclusive funding strategies (e.g., National Science Foundation program nsf19550) in order to promote a multifaceted scientific future (77–79).

**A Call to Integrated Curricula.** While grade school to graduate-level training requires an educational balance of biological science, social sciences, and humanities coursework, these disciplines are treated as epistemologically incompatible. Courses that meld these curricula (80; S. L. Ishaq’s “Microbes and Social Equity” course materials) attract students from multiple disciplines and promote their agency in tackling seemingly intractable social problems through collaborative problem-solving assignments (1). Further, decades of attempts to diversify the science, technology, engineering, and mathematics (STEM) workforce have resulted in only modest increases (67). This necessitates a paradigm shift that centers and values marginalized voices in science curriculum development. Marginalized minorities (e.g., Indigenous peoples and nonwhite, sexual, and gender minorities) are usually left out of the system due to logistical (e.g., lack of infrastructure), technical (e.g., lack of formal education), and/or structural (e.g., lack of resources, institutional racism) circumstances. Centering intersections between microbiomes, human health, planetary health, social justice, and environmental justice signals to students the importance of an integrated worldview and is a means of promoting congruent scientific and cultural identities for those from marginalized groups (81, 82). Trainees have expressed a desire for integrated educational approaches (83) which ultimately promote the success of a diverse student population in the sciences (82, 84, 85).

Universities can actively support these efforts by (i) promoting and funding socially integrated science courses and programs; (ii) including and funding out-of-discipline students, educators, and researchers (86); (iii) collaborating with other institutions to implement multisite global classrooms; and (iv) changing the underlying model of education and research, which establishes a clear divide between basic and applied science (or as D. E. Stokes put it, rigor versus relevance [87]). Further, this assumes that the social benefits of research and education will eventually be derived, but this relationship is not linear. It is circular and complex; research and education embedded in people’s social, cultural, and political realities mean inherently applying and creating knowledge. The modern conception of the educational system as a supermarket of knowledge deters itself from seamlessly applying that very same knowledge into broad understandings and meaningful interventions, programs, products, and devices. This is relevant because scientists are expert dichotomy creators; the paradigmatic example is the ages-long nature-versus-nurture debate, whose solution is almost never nature or nurture but both. Future scientific efforts—as an embedded dialogue between the world and the laboratory—should deal with the diverse realities afforded by rethinking the basic/applied dichotomy. Likewise, microbiology, a discipline that emerged from the study of microorganisms in contexts of hosts or ecosystems, has long spanned this divide given that Pasteur’s seminal work makes both basic and applied contributions to science and society (87). The MSE Working Group naturally affords a setting for the simultaneous pursuit of both research and educational

programs with direct impacts on developing and testing novel hypotheses, as well as promoting and creating more effective practices.

## IDENTIFYING FUTURE RESEARCH

Identifying the most pressing research needs (37, 88, 89) in the emerging field of MSE is one of our fundamental aims. In late 2020, we invited researchers and practitioners from 18 institutions across the world to identify 20 important MSE-related research questions. To maximize rigor and diversity, the project involved a systematic approach adapted from previous methodology to identify research needs (89), and diverse backgrounds provided lateral thinking, fostered critical thinking (90), and enabled researchers to identify and refine novel and impactful agendas. In summary, individuals in research, education, clinical care, and policy are considering how microbiomes are a record of the material conditions and of the social relations to which a host has been exposed and how they impact human physical and mental health outcomes, food security and planning, or the environment writ large. The MSE Working Group expands our perception of microorganisms from solely biological entities to biopolitical resources and, consequently, serves as a target for intervention across social and ecological dimensions (157–161).

Inhabitants of prisons and homeless shelters and those who reside in neighborhoods zoned for industrial use can experience higher rates of exposure to pathogenic microorganisms (6, 92–94), strains of antibiotic-resistant bacteria (95), and industrial chemicals (26, 96, 97). These exposures can severely impact human health by altering the microbiome, causing illness and disease, or resulting in epigenetic changes (98, 99). The situated nature of microbial community dynamics, known as the exposome (100, 101), unveils complexities between environmental chemical and biological exposures with internal health consequences. With regard to their exposomes, some populations are disproportionately vulnerable. Novel hypotheses will use recent theoretical (102–104) and technological (105, 106) advancements to quantify the extent to which lifetime interconnections impact physiological and neurobehavioral dynamics and consequences for health, i.e., ontogeny. The challenge is manifold, as exposomics encounters (i) a scarcity of systematic multilevel data, (ii) an underdeveloped analytical framework to deal with those data, and (iii) the lack of an appropriate epistemological framework that would do justice (107) to the complexity of the phenomenon.

**A Call to Creative Design.** There are major logistical challenges to effectively recruiting and engaging diverse human study participants in microbiome projects (48, 108–110). Even when participants are compensated, there is a cost to participating in a research study that precludes true representation because it not only skews our understanding of microbiomes but also deepens the divide of research exclusionism. These costs include personal time (precluding those with multiple jobs, shift-based employment, or family care responsibilities), transportation to research facilities, and the time and mental energy needed to fit research activities into daily life (48, 111–113).

To overcome logistical challenges, creative techniques based on empathy and anthropological understanding are required to reduce these impacts (48, 110, 114, 115). These can include sample collection training (116); accounting for local resources, such as providing freezers or using alternate sample preservation methods, ensuring reliable power for laboratory equipment, and providing for transportation of samples from field sites; and/or using biological or environmental samples previously collected for another purpose (117). Establishing sustained and equitable partnerships with communities also requires an awareness of the barriers posed by the use of English as the primary language of science. While an expansion of scientific literacy will be critical to forming connections with many underserved communities, the process of literature review and knowledge generation would also benefit from expanding linguistic boundaries (118).

### A Call to Action.

**To name a thing is to call it into existence, to give it agency. Today, we are named. Today, we become agents of change.**

—Suzanne L. Ishaq, MSE Working Group writing session, 2021

Even without an understanding of the effect of microorganisms on our lives, most

people recognize that individual health and well-being are common global goods (119). The benefits of considering social inequities in microbial ecology are both qualitative and quantitative, but for some audiences, “money talks.” Fortunately, the benefits of social policies that promote equitable access to resources are strongly supported by demonstrable, repeatable returns on investment (120–127). Future research must examine the effects of neoliberal racial capitalism and its corollaries that promote market-based solutions, such as mass-produced commodities or lifestyles. For instance, what are the effects of industrial diets on human microbiomes or the impacts of political, economic, and social variables in shaping microbial communities (128, 129)?

We need comparative research that examines the structural constraints faced by people with microbe-associated disease (1), while staying vigilant about “magic bullet” biotechnological solutions that, while often endorsed by policymakers, rarely address the sociocultural, political, or economic factors that engender and reproduce health inequities on a global scale. Singling out nutritional deficiencies (e.g., golden rice to resolve vitamin A deficiency) without considering broader dietary contexts of food insecurity or placing an isolated focus on particular public health concerns (e.g., obesity interventions instead of food quality and access interventions) may lead to lopsided social outcomes which resolve health issues in those populations which had available resources for short-term treatment but do not supply sustainable, prevention-based solutions to underresourced populations (130, 131). Moreover, the neocolonial attitude of international aid and global/public health programs frequently equates “development” with Western hygiene and behaviors, with little regard for microbial community dynamics *in situ*. While microbiome sciences continue to identify certain biological patterns that are more reliably correlated with health and disease, it is still worth mentioning that “healthy microbiomes” are broadly situational and continue to defy standard definitions. We reiterate that “one microbiome does not fit all.”

For a greater impact on public health and to achieve equitable health outcomes, policy efforts can focus on improving the local nutrition environment. While programs like the Supplemental Nutrition Assistance Program (SNAP) in the United States increase the food-purchasing power of lower-income households, increased food security may not translate into improved food quality (132), as neighborhoods of lower socioeconomic status have fewer supermarkets and more convenience, liquor, and fast-food outlets (133–135). Predatory marketing practices in these neighborhoods create higher proportions of advertisements promoting unhealthy foods (136, 137). It is crucial that policy efforts not only focus on providing enough calories but also use a combination of incentive (138, 139, 152) and disincentive (140, 141) programs to improve the affordability, availability, and accessibility of healthy options. Further, much remains unknown about the impact of food processing and food additives on microbial ecology, and we need microbiome research in partnership with the food industry and policy makers to mitigate potential harmful effects.

Healthy soils are intimately linked to human health through ecosystem processes like global nutrient cycling and food production, and more research should focus on how human-mediated land use change (i.e., deforestation, intensive agriculture, urbanization) impacts patterns of soil biodiversity (32, 142). For example, plant biodiversity, a primary driver of soil microbiome diversity and community structure, is lower in communities disenfranchised through “redlining” (inequitable development districting), demonstrating how systemic racism affects ecosystem biodiversity (143). Soil microbiomes offer promising metrics for assessing soil health across environmental change and through time (144). It is critical to understand how anthropogenic climate change impacts environmental microbes, as well as how microbes drive global change processes (8), and to consider this during environmental impact studies for infrastructure development or industry permitting to avoid ecosystem disruption.

By placing social justice as the central articulator between health and disease over a lifetime, the MSE Working Group provides a multidimensional perspective on social justice, situating the health consequences of exposure to depauperate or pathogenic

microbial communities among systemic issues, like disempowerment, threats of violence, abiotic environmental hazards, and others. Likewise, the MSE Working Group has a core focus on the effective translation of its principles into successful research outcomes and impactful public policy. Thus, the vision of the MSE Working Group necessitates engaging with public policy and pushing back on private interests that are both responsible for and seek to profit from microbial (and human) inequities. Finally, the MSE Working Group is poised to advance the concept of “microbial stewardship” (119) in fostering the resilience and sustainability of environmental microbial communities and promoting equity in the ways in which people are exposed to and interact with these communities. However, this cannot be accomplished through research alone. If we recognize microbiomes as a common good, then it requires all of us to progress our knowledge to action and advocate to protect that good.

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## REFERENCES

- Ishaq SL, Rapp M, Byerly R, McClellan LS, O’Boyle MR, Nykanen A, Fuller PJ, Aas C, Stone JM, Killpatrick S, Uptegrove MM, Vischer A, Wolf H, Smallman F, Eymann H, Narode S, Stapleton E, Cioffi CC, Tavalire HF. 2019. Framing the discussion of microorganisms as a facet of social equity in human health. *PLoS Biol* 17:e3000536. <https://doi.org/10.1371/journal.pbio.3000536>.
- Prescott SL, Wegienka G, Logan AC, Katz DL. 2018. Dysbiotic drift and biopsychosocial medicine: how the microbiome links personal, public



- and planetary health. *Biopsychosoc Med* 12:7. <https://doi.org/10.1186/s13030-018-0126-z>.
3. Rook G, Martinelli R, Brunet L. 2005. The "Old Friends" hypothesis; how early contact with certain microorganisms may influence immunoregulatory circuits, p 183–194. *In* Perinatal programming. ResearchGate [https://www.researchgate.net/publication/299845129\\_The\\_'Old\\_Friends'\\_hypothesis\\_how\\_early\\_contact\\_with\\_certain\\_microorganisms\\_may\\_influence\\_immunoregulatory\\_circuits](https://www.researchgate.net/publication/299845129_The_'Old_Friends'_hypothesis_how_early_contact_with_certain_microorganisms_may_influence_immunoregulatory_circuits).
  4. Code of Federal Regulations. 2014. Executive Order 13676 of September 18, 2014. Combating antibiotic-resistant bacteria. CFR 3, presidential documents. <https://www.govinfo.gov/app/details/CFR-2015-title3-vol1/CFR-2015-title3-vol1-eo13676/summary>.
  5. Cauchemez S, Bhattarai A, Marchbanks TL, Fagan RP, Ostroff S, Ferguson NM, Swerdlow D, Pennsylvania H1N1 Working Group. 2011. Role of social networks in shaping disease transmission during a community outbreak of 2009 H1N1 pandemic influenza. *Proc Natl Acad Sci U S A* 108:2825–2830. <https://doi.org/10.1073/pnas.1008895108>.
  6. Montoya-Barthelemy AG, Lee CD, Cundiff DR, Smith EB. 2020. COVID-19 and the correctional environment: the American prison as a focal point for public health. *Am J Prev Med* 58:888–891. <https://doi.org/10.1016/j.amepre.2020.04.001>.
  7. Gilbert JA, Neufeld JD. 2014. Life in a world without microbes. *PLoS Biol* 12:e1002020. <https://doi.org/10.1371/journal.pbio.1002020>.
  8. Cavicchioli R, Ripple WJ, Timmis KN, Azam F, Bakken LR, Baylis M, Behrenfeld MJ, Boetius A, Boyd PW, Classen AT, Crowther TW, Danovaro R, Foreman CM, Huisman J, Hutchins DA, Jansson JK, Karl DM, Koskella B, Mark Welch DB, Martiny JBH, Moran MA, Orphan VJ, Reay DS, Remais JV, Rich VI, Singh BK, Stein LY, Stewart FJ, Sullivan MB, van Oppen MJH, Weaver SC, Webb EA, Webster NS. 2019. Scientists' warning to humanity: microorganisms and climate change. *Nat Rev Microbiol* 17:569–586. <https://doi.org/10.1038/s41579-019-0222-5>.
  9. Lowry CA, Smith DG, Siebler PH, Schmidt D, Stamper CE, Hassell JE, Jr, Yamashita PS, Fox JH, Reber SO, Brenner LA, Hoisington AJ, Postolache TT, Kinney KA, Marciari D, Hernandez M, Hemmings SMJ, Malan-Muller S, Wright KP, Knight R, Raison CL, Rook GAW. 2016. The microbiota, immunoregulation, and mental health: implications for public health. *Curr Environ Health Rep* 3:270–286. <https://doi.org/10.1007/s40572-016-0100-5>.
  10. Rook GAW, Raison CL, Lowry CA. 2014. Microbial 'old friends', immunoregulation and socioeconomic status. *Clin Exp Immunol* 177:1–12. <https://doi.org/10.1111/cei.12269>.
  11. Zhu X, Han Y, Du J, Liu R, Jin K, Yi W. 2017. Microbiota-gut-brain axis and the central nervous system. *Oncotarget* 8:53829–53838. <https://doi.org/10.18632/oncotarget.17754>.
  12. Cantor J, Beckman R, Collins RL, Dastidar MG, Richardson AS, Dubowitz T. 2020. SNAP participants improved food security and diet after a full-service supermarket opened in an urban food desert. *Health Aff (Millwood)* 39:1386–1394. <https://doi.org/10.1377/hlthaff.2019.01309>.
  13. De Choudhury M, Sharma S, Kiciman E. 2016. Characterizing dietary choices, nutrition, and language in food deserts via social media, p 1157–1170. *In* Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing. Association for Computing Machinery, New York, NY. <https://doi.org/10.1145/2818048.2819956>.
  14. Allcott H, Diamond R, Dubé J-P. 2018. The geography of poverty and nutrition: food deserts and food choices across the United States. National Bureau of Economic Research, Cambridge, MA.
  15. Fink G, D'Acromont V, Leslie HH, Cohen J. 2020. Antibiotic exposure among children younger than 5 years in low-income and middle-income countries: a cross-sectional study of nationally representative facility-based and household-based surveys. *Lancet Infect Dis* 20:179–187. [https://doi.org/10.1016/S1473-3099\(19\)30572-9](https://doi.org/10.1016/S1473-3099(19)30572-9).
  16. Friedman M. 2018. Metabolic rift and the human microbiome. *Monthly Rev* 70. <https://monthlyreview.org/2018/07/01/metabolic-rift-and-the-human-microbiome/>.
  17. Blaser MJ. 2016. Antibiotic use and its consequences for the normal microbiome. *Science* 352:544–545. <https://doi.org/10.1126/science.aad9358>.
  18. Wypych TP, Marsland BJ. 2018. Antibiotics as instigators of microbial dysbiosis: implications for asthma and allergy. *Trends Immunol* 39:697–711. <https://doi.org/10.1016/j.it.2018.02.008>.
  19. Schwartz DJ, Langdon AE, Dantas G. 2020. Understanding the impact of antibiotic perturbation on the human microbiome. *Genome Med* 12:82. <https://doi.org/10.1186/s13073-020-00782-x>.
  20. Le Bastard Q, Al-Ghalith GA, Grégoire M, Chapelet G, Javaudin F, Dailly E, Batard E, Knights D, Montassier E. 2018. Systematic review: human gut dysbiosis induced by non-antibiotic prescription medications. *Aliment Pharmacol Ther* 47:332–345. <https://doi.org/10.1111/apt.14451>.
  21. Selway CA, Mills JG, Weinstein P, Skelly C, Yadav S, Lowe A, Breed MF, Weyrich LS. 2020. Transfer of environmental microbes to the skin and respiratory tract of humans after urban green space exposure. *Environ Int* 145:106084. <https://doi.org/10.1016/j.envint.2020.106084>.
  22. Mills JG, Weinstein P, Gellie NJC, Weyrich LS, Lowe AJ, Breed MF. 2017. Urban habitat restoration provides a human health benefit through microbiome rewilding: the microbiome rewilding hypothesis. *Restor Ecol* 25:866–872. <https://doi.org/10.1111/rec.12610>.
  23. Raison CL, Lowry CA, Rook GAW. 2010. Inflammation, sanitation, and consternation: loss of contact with coevolved, tolerogenic microorganisms and the pathophysiology and treatment of major depression. *Arch Gen Psychiatry* 67:1211–1224. <https://doi.org/10.1001/archgenpsychiatry.2010.161>.
  24. Vandegriff R, Fahimipour AK, Muscarella M, Bateman Ac Van Den Wymelenberg K, Bohannon BJM. 2019. Moving microbes: the dynamics of transient microbial residence on human skin. *BioArchiv* <https://www.biorxiv.org/content/10.1101/586008v1>.
  25. Hoisington AJ, Brenner LA, Kinney KA, Postolache TT, Lowry CA, Tompkins TA. 2015. The microbiome of the built environment and mental health. *Microbiome* 3:60. <https://doi.org/10.1186/s40168-015-0127-0>.
  26. Pulido L. 2000. Rethinking environmental racism: white privilege and urban development in southern California. *Ann Assoc Am Geogr* 90:12–40. <https://doi.org/10.1111/0004-5608.00182>.
  27. Singh BK, Trivedi P, Egidi E, Macdonald CA, Delgado-Baquerizo M. 2020. Crop microbiome and sustainable agriculture. *Nat Rev Microbiol* 18:601–602. <https://doi.org/10.1038/s41579-020-00446-y>.
  28. Busby PE, Soman C, Wagner MR, Friesen ML, Kremer J, Bennett A, Morsy M, Eisen JA, Leach JE, Dangl JL. 2017. Research priorities for harnessing plant microbiomes in sustainable agriculture. *PLoS Biol* 15:e2001793. <https://doi.org/10.1371/journal.pbio.2001793>.
  29. Jansson JK, Hofmockel KS. 2020. Soil microbiomes and climate change. *Nat Rev Microbiol* 18:35–46. <https://doi.org/10.1038/s41579-019-0265-7>.
  30. Lane SN, Bakker M, Costa A, Girardclos S, Loizeau J-L, Molnar P, Silva T, Stutenbecker L, Schlunegger F. 2019. Making stratigraphy in the Anthropocene: climate change impacts and economic conditions controlling the supply of sediment to Lake Geneva. *Sci Rep* 9:8904. <https://doi.org/10.1038/s41598-019-44914-9>.
  31. US Global Change Research Program. 2018. Impacts, risks, and adaptation in the United States: fourth national climate assessment, vol II. US Global Change Research Program, Washington, DC.
  32. Bach EM, Ramirez KS, Fraser TD, Wall DH. 2020. Soil biodiversity integrates solutions for a sustainable future. *Sustain Sci Pract Policy* 12:2662. <https://doi.org/10.3390/su12072662>.
  33. United Nations. 2010. General Assembly resolution 64/292. The human right to water and sanitation. A/RES/64/292. United Nations, New York, NY.
  34. Human Rights Council. 2019. Issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment. A/HRC/40/55. United Nations, General Assembly, New York, NY.
  35. United Nations. 1948. Universal Declaration of Human Rights. General Assembly Resolution 217 A (III). United Nations, New York, NY.
  36. Amato KR, Maurice CF, Guillemin K, Giles-Vernick T. 2019. Multidisciplinary in microbiome research: a challenge and opportunity to rethink causation, variability, and scale. *Bioessays* 41:e1900007. <https://doi.org/10.1002/bies.201900007>.
  37. Greenhough B, Read CJ, Lorimer J, Lezaun J, McLeod C, Benezra A, Bloomfield S, Brown T, Clinch M, D'Acquisto F, Dumitriu A, Evans J, Fawcett N, Fortané N, Hall LJ, Giraldo Herrera CE, Hodgetts T, Johnson KV-A, Kirchhelle C, Krzywoszynska A, Lambert H, Monaghan T, Nading A, Nerlich B, Singer AC, Szymanski E, Wills J. 2020. Setting the agenda for social science research on the human microbiome. *Palgrave Commun* 6:18. <https://doi.org/10.1057/s41599-020-0388-5>.
  38. Benezra A. 2020. Race in the microbiome. *Sci Technol Human Values* 45:877–902. <https://doi.org/10.1177/0162243920911998>.
  39. Benezra A, DeStefano J, Gordon JI. 2012. Anthropology of microbes. *Proc Natl Acad Sci U S A* 109:6378–6381. <https://doi.org/10.1073/pnas.1200515109>.
  40. Brown H, Nading AM. 2019. Introduction: human animal health in medical anthropology. *Med Anthropol Q* 33:5–23. <https://doi.org/10.1111/maq.12488>.
  41. Findley K, Williams DR, Grice EA, Bonham VL. 2016. Health disparities and the microbiome. *Trends Microbiol* 24:847–850. <https://doi.org/10.1016/j.tim.2016.08.001>.

42. O'Doherty KC, Virani A, Wilcox ES. 2016. The human microbiome and public health: social and ethical considerations. *Am J Public Health* 106:414–420. <https://doi.org/10.2105/AJPH.2015.302989>.
43. Carney MA. 2020. Critical perspectives on the microbiome. *Am Anthropol* 122:643–644. <https://doi.org/10.1111/aman.13439>.
44. Taylor K. 2020. mSphere of Influence: That's racist—COVID-19, biological determinism, and the limits of hypotheses. *mSphere* 5:e00945-20. <https://doi.org/10.1128/mSphere.00945-20>.
45. Morar N, Skorburg JA. 2020. Why we never eat alone: the overlooked role of microbes and partners in obesity debates in bioethics. *J Bioeth Inq* 17:435–448. <https://doi.org/10.1007/s11673-020-10047-2>.
46. Morar N, Skorburg JA. 2018. Bioethics and the hypothesis of extended health. *Kennedy Inst Ethics J* 28:341–376. <https://doi.org/10.1353/ken.2018.0020>.
47. Benjamin R. 2016. Informed refusal: toward a justice-based bioethics. *Sci Technol Human Values* 41:967–990. <https://doi.org/10.1177/0162243916656059>.
48. Lemas D, Wright L, Francois M, Chen L, Hentschel A, Schleffer A, Chen H, Flood-Grady E, Neu J, Shenkman E, Krieger J. 2019. Recruitment and retention of pregnant and breastfeeding mothers for longitudinal clinical microbiome studies (OR30-08-19). *Curr Dev Nutr* 3(Suppl 1):nzz048. OR30-08-19. <https://doi.org/10.1093/cdn/nzz048.OR30-08-19>.
49. Alsan M, Wanamaker M, Hardeman RR. 2020. The Tuskegee Study of Untreated Syphilis: a case study in peripheral trauma with implications for health professionals. *J Gen Intern Med* 35:322–325. <https://doi.org/10.1007/s11606-019-05309-8>.
50. Garrison NA. 2013. Genomic justice for native Americans: impact of the Havasupai case on genetic research. *Sci Technol Human Values* 38:201–223. <https://doi.org/10.1177/0162243912470009>.
51. Lewis CM, Spicer P. 2012. Human microbiome research and Indigenous communities, project, p 1–3. *In* Nelson KE (ed), *Encyclopedia of metagenomics*. Springer, New York City, NY.
52. Tuhiwai Smith L. 2012. *Decolonizing methodologies: research and Indigenous peoples*, 2nd ed. ZED Scholar, London, England.
53. Redvers N. 2019. *The science of the sacred: bridging global Indigenous medicine systems and modern scientific principles*. North Atlantic Books, Berkeley, CA.
54. Smith CP, Freyd JJ. 2017. Insult, then injury: interpersonal and institutional betrayal linked to health and dissociation. *J Aggress Maltreat Trauma* 26:1117–1131. <https://doi.org/10.1080/10926771.2017.1322654>.
55. Mohanty CT. 2003. *Feminism without borders*. Duke University Press, Durham, NC.
56. Lyons KM. 2020. *Vital decomposition: soil practitioners and life politics*. Duke University Press, Durham, NC.
57. Boggs A, Mitchell N. 2018. Critical university studies and the crisis consensus. *Feminist Stud* 44:432–463. <https://doi.org/10.15767/feministstudies.44.2.0432>.
58. de la Bellacasa MP. 2011. Matters of care in technoscience: assembling neglected things. *Soc Stud Sci* 41:85–106. <https://doi.org/10.1177/0306312710380301>.
59. Sankaranarayanan K, Ozga AT, Warinner C, Tito RY, Obregon-Tito AJ, Xu J, Gaffney PM, Jervis LL, Cox D, Stephens L, Foster M, Tallbull G, Spicer P, Lewis CM. 2015. Gut microbiome diversity among Cheyenne and Arapaho individuals from western Oklahoma. *Curr Biol* 25:3161–3169. <https://doi.org/10.1016/j.cub.2015.10.060>.
60. Hawkins AK, O'Doherty KC. 2011. Who owns your poop?: insights regarding the intersection of human microbiome research and the ELSI aspects of biobanking and related studies. *BMC Med Genomics* 4:72. <https://doi.org/10.1186/1755-8794-4-72>.
61. Chuong KH, Hwang DM, Tullis DE, Waters VJ, Yau YCW, Guttman DS, O'Doherty KC. 2017. Navigating social and ethical challenges of biobanking for human microbiome research. *BMC Med Ethics* 18:1. <https://doi.org/10.1186/s12910-016-0160-y>.
62. Rees T, Bosch T, Douglas AE. 2018. How the microbiome challenges our concept of self. *PLoS Biol* 16:e2005358. <https://doi.org/10.1371/journal.pbio.2005358>.
63. Morar N, Bohannon BJM. 2019. The conceptual ecology of the human microbiome. *Q Rev Biol* 94:149–175. <https://doi.org/10.1086/703582>.
64. Gilbert SF, Sapp J, Tauber AI. 2012. A symbiotic view of life: we have never been individuals. *Q Rev Biol* 87:325–341. <https://doi.org/10.1086/668166>.
65. Gilmore RW. 2021. *Change everything: racial capitalism and the case for abolition*. Haymarket Books, Chicago, IL.
66. Benjamin R. 2016. Interrogating equity: a disability justice approach to genetic engineering. *Issues Sci Technol* 32. <https://issues.org/interrogating-equity-a-disability-justice-approach-to-genetic-engineering/>.
67. National Center for Science and Engineering Statistics. 2019. *Women, minorities, and persons with disabilities in science and engineering: 2019*. NSF 19-302. National Science Foundation, Alexandria, VA.
68. Mitchell M. 2011. *Complexity: a guided tour*, 1st ed. Oxford University Press, New York, NY.
69. Gibbons SM. 2019. Defining microbiome health through a host lens. *mSystems* 4:e00155-19. <https://doi.org/10.1128/mSystems.00155-19>.
70. Bollier D. 2010. *The promise and peril of big data*. The Aspen Institute Communications and Society Program, Aspen, CO.
71. Anderson C. 23 June 2008. The end of theory: the data deluge makes the scientific method obsolete. *Wired* <https://www.wired.com/2008/06/pb-theory/>.
72. Marquet PA, Allen AP, Brown JH, Dunne JA, Enquist BJ, Gillooly JF, Gowaty PA, Green JL, Harte J, Hubbell SP, O'Dwyer J, Okie JG, Ostling A, Ritchie M, Storch D, West GB. 2014. On theory in ecology. *Bioscience* 64:701–710. <https://doi.org/10.1093/biosci/biu098>.
73. Haraway DJ. 2007. *When species meet*. University of Minnesota Press, Minneapolis, MN.
74. Darling KW, Boyce AM, Cho MK, Sankar PL. 2015. What is the FDA going to think? Negotiating values through reflective and strategic category work in microbiome science. *Sci Technol Human Values* 40:71–95. <https://doi.org/10.1177/0162243914545405>.
75. CDC. 2021. *One health*. Centers for Disease Control and Prevention, Atlanta, GA.
76. Mackenzie JS, Jeggo M. 2019. The one health approach—why is it so important? *Trop Med Infect Dis* 4:88. <https://doi.org/10.3390/tropicalmed4020088>.
77. Bol T, de Vaan M, van de Rijt A. 2018. The Matthew effect in science funding. *Proc Natl Acad Sci U S A* 115:4887–4890. <https://doi.org/10.1073/pnas.1719557115>.
78. Shen H. 2013. Inequality quantified: mind the gender gap. *Nature* 495:22–24. <https://doi.org/10.1038/495022a>.
79. Pritlove C, Juando-Prats C, Ala-Leppilampi K, Parsons JA. 2019. The good, the bad, and the ugly of implicit bias. *Lancet* 393:502–504. [https://doi.org/10.1016/S0140-6736\(18\)32267-0](https://doi.org/10.1016/S0140-6736(18)32267-0).
80. DeAngelis K, Horta LD. 2020. Integrative experience: soil microbes and the sustainability of organic agriculture. University of Massachusetts Amherst, Amherst, MA. [https://works.bepress.com/kristen\\_deangelis/27/](https://works.bepress.com/kristen_deangelis/27/).
81. Jackson MC, Galvez G, Landa I, Buonora P, Thoman DB. 2016. Science that matters: the importance of a cultural connection in underrepresented students' science pursuit. *CBE Life Sci Educ* 15:ar42. <https://doi.org/10.1187/cbe.16-01-0067>.
82. Montgomery BL. 2020. Lessons from microbes: what can we learn about equity from unculturable bacteria? *mSphere* 5:e01046-20. <https://doi.org/10.1128/mSphere.01046-20>.
83. Campbell AG, Skvirsky R, Wortis H, Thomas S, Kawachi I, Hohmann C. 2014. NEST 2014: views from the trainees—talking about what matters in efforts to diversify the STEM workforce. *CBE Life Sci Educ* 13:587–592. <https://doi.org/10.1187/cbe.14-04-0068>.
84. Thoman DB, Brown ER, Mason AZ, Harmsen AG, Smith JL. 2015. The role of altruistic values in motivating underrepresented minority students for bio-medicine. *Bioscience* 65:183–188. <https://doi.org/10.1093/biosci/biu199>.
85. Chamany K, Allen D, Tanner K. 2008. Making biology learning relevant to students: integrating people, history, and context into college biology teaching. *CBE Life Sci Educ* 7:267–278. <https://doi.org/10.1187/cbe.08-06-0029>.
86. Gevin V, Wright V, Richards M, Taylor K, Pittman N, Henderson H, Abdi A. 2020. *Fighting racism demands more than just words*. Nature Publishing Group, London, England.
87. Stokes DE. 2011. *Pasteur's quadrant: basic science and technological innovation*. Brookings Institution Press, Washington, DC.
88. Wilkinson JE, Franzosa EA, Everett C, Li C, HCMPH researchers and trainees, HCMPH investigators, Hu FB, Wirth DF, Song M, Chan AT, Rimm E, Garrett WS, Huttenhower C. 2021. A framework for microbiome science in public health. *Nat Med* 27:766–774. <https://doi.org/10.1038/s41591-021-01258-0>.
89. Antwis RE, Griffiths SM, Harrison XA, Aranega-Bou P, Arce A, Bettridge AS, Brailsford FL, de Menezes A, Devaynes A, Forbes KM, Fry EL, Goodhead I, Haskell E, Heys C, James C, Johnston SR, Lewis GR, Lewis Z, Macey MC, McCarthy A, McDonald JE, Mejia-Florez NL, O'Brien D, Orland C, Pautasso M, Reid WDK, Robinson HA, Wilson K, Sutherland WJ. 2017.

- Fifty important research questions in microbial ecology. *FEMS Microbiol Ecol* 93:fx044. <https://doi.org/10.1093/femsec/fix044>.
90. Dekker TJ. 2020. Teaching critical thinking through engagement with multiplicity. *Think Skills Creat* 37:100701. <https://doi.org/10.1016/j.tsc.2020.100701>.
  91. Obasogie OK, Darnovsky M, Duster T, Williams PJ. 2018. Beyond bioethics: toward a new biopolitics. University of California Press, Berkeley, CA.
  92. Levy MH, Mogg D. 2009. Infection control standards for Australian prisons: forgotten, but not forgiving. *Healthc Infect* 14:13–19. <https://doi.org/10.1071/HI09004>.
  93. O'Grady J, Maeurer M, Atun R, Abubakar I, Mwaba P, Bates M, Kapata N, Ferrara G, Hoelscher M, Zumla A. 2011. Tuberculosis in prisons: anatomy of global neglect. *Eur Respir J* 38:752–754. <https://doi.org/10.1183/09031936.00041211>.
  94. de Deus Quirino J, Jr, Leite Rolim Neto M, Barbosa do Nascimento V. 2020. Incarcerated people in prisons: a public health priority in resource-poor settings. *Forensic Sci Int* 1:100007. <https://doi.org/10.1016/j.fsiml.2019.100007>.
  95. Jaradat ZW, Ababneh QO, Sha'aban ST, Alkofahi AA, Assaleh D, Al Shara A. 2020. Methicillin resistant *Staphylococcus aureus* and public fomites: a review. *Pathog Glob Health* 114:426–450. <https://doi.org/10.1080/20477724.2020.1824112>.
  96. Johnston J, Cushing L. 2020. Chemical exposures, health, and environmental justice in communities living on the fenceline of industry. *Curr Environ Health Rep* 7:48–57. <https://doi.org/10.1007/s40572-020-00263-8>.
  97. Fairburn J, Schüle SA, Dreger S, Karla Hilz L, Bolte G. 2019. Social inequalities in exposure to ambient air pollution: a systematic review in the WHO European Region. *Int J Environ Res Public Health* 16:3127. <https://doi.org/10.3390/ijerph16173127>.
  98. Fouladi F, Bailey MJ, Patterson WB, Sioda M, Blakley IC, Fodor AA, Jones RB, Chen Z, Kim JS, Lurmann F, Martino C, Knight R, Gilliland FD, Alderete TL. 2020. Air pollution exposure is associated with the gut microbiome as revealed by shotgun metagenomic sequencing. *Environ Int* 138:105604. <https://doi.org/10.1016/j.envint.2020.105604>.
  99. Sánchez OF, Lin L, Bryan CJ, Xie J, Freeman JL, Yuan C. 2020. Profiling epigenetic changes in human cell line induced by atrazine exposure. *Environ Pollut* 258:113712. <https://doi.org/10.1016/j.envpol.2019.113712>.
  100. Wild CP. 2005. Complementing the genome with an “exposome”: the outstanding challenge of environmental exposure measurement in molecular epidemiology. *Cancer Epidemiol Biomarkers Prev* 14:1847–1850. <https://doi.org/10.1158/1055-9965.EPI-05-0456>.
  101. Rappaport SM, Smith MT. 2010. Epidemiology. Environment and disease risks. *Science* 330:460–461. <https://doi.org/10.1126/science.1192603>.
  102. Parada FJ, Rossi A. 18 May 2020. Perfect timing: mobile brain/body imaging scaffolds the 4E-cognition research program. *Eur J Neurosci* <https://doi.org/10.1111/ejn.14783>.
  103. Palacios-García I, Parada FJ. 2019. Measuring the brain-gut axis in psychological sciences: a necessary challenge. *Front Integr Neurosci* 13:73. <https://doi.org/10.3389/fnint.2019.00073>.
  104. Christensen K, di Collobiano SA, Hall M, Jensen HJ. 2002. Tangled nature: a model of evolutionary ecology. *J Theor Biol* 216:73–84. <https://doi.org/10.1006/jtbi.2002.2530>.
  105. Vujic A, Tong S, Picard R, Maes P. 2020. Going with our guts: potentials of wearable electrogastronomy (EGG) for affect detection, p 260–268. *In Proceedings of the 2020 International Conference on Multimodal Interaction*. Association for Computing Machinery, New York, NY.
  106. Hölle D, Meekes J, Bleichner MG. 15 March 2021. Mobile ear-EEG to study auditory attention in everyday life. *Behav Res Methods* <https://doi.org/10.3758/s13428-021-01538-0>.
  107. Teo T. 2021. “Doing justice” in psychological methodology: from science and experiments to anecdotes. *New Ideas Psychol* 61:100854. <https://doi.org/10.1016/j.newideapsych.2021.100854>.
  108. Ross-Hellauer T, Fessl A, Klebel T. 2020. Open science—who is left behind? The London School of Economics and Political Science, London, United Kingdom.
  109. Byrd DA, Carson TL, Williams F, Vogtmann E. 2020. Elucidating the role of the gastrointestinal microbiota in racial and ethnic health disparities. *Genome Biol* 21:192. <https://doi.org/10.1186/s13059-020-02117-w>.
  110. Debelius JW, Vázquez-Baeza Y, McDonald D, Xu Z, Wolfe E, Knight R. 2016. Turning participatory microbiome research into usable data: lessons from the American Gut Project. *J Microbiol Biol Educ* 17:46–50. <https://doi.org/10.1128/jmbe.v17i1.1034>.
  111. Spade D. 2020. Mutual aid: building solidarity during this crisis (and the next). Verso Books, Brooklyn, NY.
  112. Morgan LL, Fahs PS, Klesh J. 2005. Barriers to research participation identified by rural people. *J Agric Saf Health* 11:407–414. <https://doi.org/10.13031/2013.19719>.
  113. George S, Duran N, Norris K. 2014. A systematic review of barriers and facilitators to minority research participation among African Americans, Latinos, Asian Americans, and Pacific Islanders. *Am J Public Health* 104:e16–31. <https://doi.org/10.2105/AJPH.2013.301706>.
  114. Johnson AJ, Zheng JJ, Kang JW, Saboe A, Knights D, Zivkovic AM. 2020. A guide to diet-microbiome study design. *Front Nutr* 7:79. <https://doi.org/10.3389/fnut.2020.00079>.
  115. McGuire AL, Achenbaum LS, Whitney SN, Slashinski MJ, Versalovic J, Keitel WA, McCurdy SA. 2012. Perspectives on human microbiome research ethics. *J Empir Res Hum Res Ethics* 7:1–14. <https://doi.org/10.1525/jer.2012.7.3.1>.
  116. Chen CX, Carpenter JS, Murphy T, Brooks P, Fortenberry JD. 2020. Engaging adolescent and young adults in microbiome sample self-collection: strategies for success. *Biol Res Nurs* 23:402–407. <https://doi.org/10.1177/1099800420979606>.
  117. Byrd DA, Sinha R, Hoffman KL, Chen J, Hua X, Shi J, Chia N, Petrosino J, Vogtmann E. 2020. Comparison of methods to collect fecal samples for microbiome studies using whole-genome shotgun metagenomic sequencing. *mSphere* 5:e00827-19. <https://doi.org/10.1128/mSphere.00827-19>.
  118. Amano T, González-Varo JP, Sutherland WJ. 2016. Languages are still a major barrier to global science. *PLoS Biol* 14:e2000933. <https://doi.org/10.1371/journal.pbio.2000933>.
  119. O'Doherty KC, Neufeld JD, Brinkman FSL, Gardner H, Guttman DS, Beiko RG. 2014. Opinion: conservation and stewardship of the human microbiome. *Proc Natl Acad Sci U S A* 111:14312–14313. <https://doi.org/10.1073/pnas.1413200111>.
  120. Henderson JW. 1994. The cost effectiveness of prenatal care. *Health Care Financ Rev* 15:21–32.
  121. Canning D, Bennathan E (ed). 2000. The social rate of return on infrastructure investments. The World Bank Group, Washington, DC.
  122. Avruch S, Cackley AP. 1995. Savings achieved by giving WIC benefits to women prenatally. *Public Health Rep* 110:27–34.
  123. Masters R, Anwar E, Collins B, Cookson R, Capewell S. 2017. Return on investment of public health interventions: a systematic review. *J Epidemiol Community Health* 71:827–834. <https://doi.org/10.1136/jech-2016-208141>.
  124. Misch F, Wolff P. 2008. The returns on public investment. Concepts, evidence, and policy challenges. Deutsches Institut für Entwicklungspolitik, Bonn, Germany.
  125. Watson KJ, Whitley T. 2017. Applying social return on investment (SROI) to the built environment. *Build Res Inf* 45:875–891. <https://doi.org/10.1080/09613218.2016.1223486>.
  126. Walker C. 2004. The public value of urban parks. The Urban Institute, Washington, DC.
  127. Cecchini M, Sassi F, Lauer JA, Lee YY, Guajardo-Barron V, Chisholm D. 2010. Tackling of unhealthy diets, physical inactivity, and obesity: health effects and cost-effectiveness. *Lancet* 376:1775–1784. [https://doi.org/10.1016/S0140-6736\(10\)61514-0](https://doi.org/10.1016/S0140-6736(10)61514-0).
  128. Hite A. 2020. A critical perspective on “diet-related” diseases. *Am Anthropol* 122:657–658. <https://doi.org/10.1111/aman.13446>.
  129. Gálvez A, Carney M, Yates-Doerr E. 2020. Vital topics forum chronic disaster: reimaging noncommunicable chronic disease. *Am Anthropol* 122:639–665. <https://doi.org/10.1111/aman.13437>.
  130. Guthman J. 2011. Weighing in: obesity, food justice, and the limits of capitalism. University of California Press, Oakland, CA.
  131. Garth H. 2020. The violence of racial capitalism and south Los Angeles's obesity “epidemic.” *Am Anthropol* 122:653–654. <https://doi.org/10.1111/aman.13444>.
  132. Singleton CR, Young SK, Kesse N, Springfield SE, Sen BP. 2020. Examining disparities in diet quality between SNAP participants and non-participants using Oaxaca-Blinder decomposition analysis. *Prev Med Rep* 19:101134. <https://doi.org/10.1016/j.pmedr.2020.101134>.
  133. Crowe J, Lacy C, Columbus Y. 2018. Barriers to food security and community stress in an urban food desert. *Urban Sci* 2:46. <https://doi.org/10.3390/urbansci2020046>.
  134. Zenk SN, Schulz AJ, Israel BA, James SA, Bao S, Wilson ML. 2005. Neighborhood racial composition, neighborhood poverty, and the spatial accessibility of supermarkets in metropolitan Detroit. *Am J Public Health* 95:660–667. <https://doi.org/10.2105/AJPH.2004.042150>.

135. Baker EA, Schootman M, Barnidge E, Kelly C. 2006. The role of race and poverty in access to foods that enable individuals to adhere to dietary guidelines. *Prev Chronic Dis* 3:A76.
136. Hilmers A, Hilmers DC, Dave J. 2012. Neighborhood disparities in access to healthy foods and their effects on environmental justice. *Am J Public Health* 102:1644–1654. <https://doi.org/10.2105/AJPH.2012.300865>.
137. Cassidy DL, Liaw K, Miller LMS. 2015. Disparities in obesity-related outdoor advertising by neighborhood income and race. *J Urban Health* 92:835–842. <https://doi.org/10.1007/s11524-015-9980-1>.
138. Eom H, Wilde P, Cudhea F, Du M, Michaud D, Wong J, Mozaffarian D, Zhang FF. 2019. Reducing US cancer burden and disparities through national and targeted food price policies (P04-101-19). *Curr Dev Nutr* 3(Suppl 1):nzz051.P04-101-19. <https://doi.org/10.1093/cdn/nzz051.P04-101-19>.
139. Vijayan K. 14 February 2018. HFFI bill would expand healthy food access, revitalize communities. PolicyLink <https://www.policylink.org/equity-in-action/support-hffi-reauthorization>.
140. Hagenaaers LL, Jevdjevic M, Jeurissen PPT, Klazinga NS. 2020. Six lessons from introducing sweetened beverage taxes in Berkeley, Cook County, and Philadelphia: a case study comparison in agenda setting and decision making. *Health Policy* 124:932–942. <https://doi.org/10.1016/j.healthpol.2020.06.002>.
141. Parlow MJ. 2017. Healthy zoning. *Fordham Urban Law J* 44:33. <https://ir.lawnet.fordham.edu/ulj/vol44/iss1/2>.
142. Wall DH, Nielsen UN, Six J. 2015. Soil biodiversity and human health. *Nature* 528:69–76. <https://doi.org/10.1038/nature15744>.
143. Schell CJ, Dyson K, Fuentes TL, Des Roches S, Harris NC, Miller DS, Woelfle-Erskine CA, Lambert MR. 2020. The ecological and evolutionary consequences of systemic racism in urban environments. *Science* 369:eaay4497. <https://doi.org/10.1126/science.aay4497>.
144. Fierer N, Wood SA, Bueno de Mesquita CP. 2021. How microbes can, and cannot, be used to assess soil health. *Soil Biol Biochem* 153:108111. <https://doi.org/10.1016/j.soilbio.2020.108111>.
145. Schlosberg D. 2009. *Defining environmental justice: theories, movements, and nature*. Oxford University Press, Oxford, England. <https://doi.org/10.1093/acprof:oso/9780199286294.001.0001>.
146. Reference deleted.
147. Berg G, Rybakova D, Fischer D, Cernava T, Vergès M-CC, Charles T, Chen X, Cocolin L, Eversole K, Corral GH, Kazou M, Kinkel L, Lange L, Lima N, Loy A, Macklin JA, Maguin E, Mauchline T, McClure R, Mitter B, Ryan M, Sarand I, Smidt H, Schelkle B, Roume H, Seghal Kiran G, Selvin J, de Souza RSC, van Overbeek L, Singh BK, Wagner M, Walsh A, Sessitsch A, Schlöter M. 2020. Microbiome definition re-visited: old concepts and new challenges. *Microbiome* 8:103. <https://doi.org/10.1186/s40168-020-00905-x>.
148. Harvey D. 2007. *A brief history of neoliberalism*. Oxford University Press, New York, NY.
149. Johansen M. 2019. Toward a more global conceptualization of social equity. *In* *Social equity in the Asia-Pacific region*. Palgrave Macmillan, Cham, Switzerland.
150. Commission on Social Determinants of Health. 2008. *Closing the gap in a generation: health equity through action on the social determinants of health*. WHO/IER/CSDH/08.1. World Health Organization, Geneva, Switzerland.
151. Soja EW. 2013. *Seeking spatial justice*. University of Minnesota Press, Minneapolis, MN.
152. U.S. Department of Health & Human Services, Office of Community Service. 2016. CED Healthy Food Financing Initiative FY 2016. Accessed 13 April 2021. Updated 20 June 2019. <https://www.acf.hhs.gov/archive/ocs/programs/community-economic-development/healthy-food-financing>.
153. Haraway DJ. 1988. Situated knowledges: the science question in feminism and the privilege of partial perspective. *Feminist Studies* 14:575–599. <https://doi.org/10.2307/3178066>.
154. Cho S, Crenshaw K, McCall L. 2013. Toward a field of intersectionality studies: theory, applications, and praxis. *Signs* 38:785–810. <https://doi.org/10.1086/669608>.
155. Hill Collins P, Bilge S. 2016. *Intersectionality*. Polity Press, New York, NY.
156. Science & Justice Research Center (Collaborations Group). 2013. Experiments in collaboration: interdisciplinary graduate education in science and justice. *PLoS Biol* 11:e1001619. <https://doi.org/10.1371/journal.pbio.1001619>.
157. Paxson H, Helmreich S. 2014. The perils and promises of microbial abundance: novel natures and model ecosystems, from artisanal cheese to alien seas. *Social Studies Science* 44:165–193. Retrieved 23 June 2021. <http://www.jstor.org/stable/43284227>.
158. Hannah L. 2016. Antibiotic resistance and the biology of history. *Body Society* 22:19–52. <https://doi.org/10.1177/1357034X14561341>.
159. Benezra A. 2018. Making microbiomes, p 283–290. *In* Gibbon S, Prainsack B, Hilgartner S, Lamoreaux J (ed), *Handbook of genomics, health and society*. Routledge.
160. Wolf-Meyer MJ. 2017. Normal, regular, and standard: scaling the body through fecal microbial transplants. *Med Anthropol Quarterly* 31:297–314. <https://doi.org/10.1111/maq.12328>.
161. Pentecost M, Cousins T. 2017. Strata of the political: epigenetic and microbial imaginaries in post-apartheid Cape Town. *Antipode* 49:1368–1384. <https://doi.org/10.1111/anti.12315>.
162. Collins PH. 2015. Intersectionality's definitional dilemmas. *Annu Rev Sociol* 41:1–20. <https://doi.org/10.1146/annurev-soc-073014-112142>.