SARAH WEISBERG*

Pipeline, Pathway, Burrow: Reworking Science's Metaphorical Terrain

What happens to a science laboratory when you put it on a bus?

Let's start with the obvious: mobility changes *who* has access to research experiences. Science on a bus is a public enterprise, subject to parking tickets and the interested eyes of passers-by. As the doors open and shut, as the windows pop open on a hot spring day, or if you break down on a busy bridge during rush hour, there's no keycard-enabled door to lock, no turnstile to hide behind. Science on wheels is science in the streets.

Creating novel pathways into science, or plugging so-called leaky pipelines into our fields, is the most common rationale for mobilizing the laboratory. We know that hands-on, inquiry-driven research opportunities increase young people's interest (and perception of belonging) in science.[1] Bringing the biology lab to the block party, therefore, can change who is inspired to pursue a STEM career.

But, having spent nearly a decade doing science on a bus, I want to focus on what happens to scientists, and science itself, when we do it in new ways. It is time to move beyond the external-facing ideas of pathways and pipelines, which assume that science itself is fine as-is—that centuries of exclusion and underrepresentation are functions of access and not of the internal culture and value system of the scientific community. In other words, we need new

*School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, NY 11794–5000, USA; BioBus, Inc., 1361 Amsterdam Avenue, Suite 340, New York, NY 10027 sarah.j.weisberg@stonybrook.edu

1. See, for example, Dina G. Markowitz, "Evaluation of the Long-Term Impact of a University High School Summer Science Program on Students' Interest and Perceived Abilities in Science," *Journal of Science Education and Technology* 13, no. 3 (2004): 395–407.

Historical Studies in the Natural Sciences, Vol. 52, Number 5, pps. 629–639. ISSN 1939-1811, electronic ISSN 1939-182X. DOI: https://doi.org/10.1525/hsns.2022.52.5.629.

metaphors, reflecting new conceptual frameworks, if we want to make science more equitable and inclusive.

Let us think of scientific practice as an ecosystem, with myriad interactions (some competitive, others symbiotic) and a diversity of functional roles. One such role is the "ecosystem engineer," an organism whose behavior alters, creates, or maintains the environment itself, and makes it habitable for others.[2] One of my favorite forms of ecosystem engineering is "bioturbation," the act of reworking soils or sediments. Think of an earthworm creating a burrow. While this is a local (and, from the perspective of the worm, perhaps selfish) act, when multiplied it increases nutrient availability, oxygenation, irrigation, and drainage such that other organisms are able to survive where they otherwise could not. At scale, bioturbation can reshape a landscape: the burrowing behaviors of a whole population add up to change over time.

What follows is an account of what happens to biology when it leaves the building and boards the bus. It is also the story of how I came to see bioturbation—burrowing into science to help make it more hospitable to those from historically excluded backgrounds—as my most important role within the STEM ecosystem. I believe others can and must consider creating their own buses *and* burrows if we truly want equity within science. Welcome aboard!

THE BIOBUS EXPERIENCE

Imagine you're in ninth grade. It is 7:20 a.m. on a Tuesday, and you're arriving just in time for your first-period science class. You don't particularly care for the class, and not just because it's so early. A lot of the class is memorization—"the mitochondria is the powerhouse of the cell"—and you've never even seen a mitochondrion (or a "powerhouse," for that matter). It all feels abstract and irrelevant.

On your way toward the entrance, with its metal detector and temperature check, you notice something weird. There's a big shiny, silver, oblong vehicle, kind of like a spaceship, parked out front. You rush by, but as soon as you get to class your teacher takes you right back out to the spaceship. The doors open, and two people pop out who introduce themselves as scientists. They tell you that you're about to see how science really works and invite you to climb aboard.

2. Clive G. Jones, John H. Lawton, and Moshe Shachak, "Organisms as Ecosystem Engineers," *Oikos* 69, no. 3 (1994): 373–86.

What happens next? It depends. You might see a squiggling creature on a TV and find out it's actually right there, almost invisible, underneath a microscope. Even better: you get to use the microscope yourself, zooming in and out on a living, beating heart. Or maybe you pull off one of your own skin cells and look at that. No matter what, it's *you* doing the looking, seeing science for the first time as something active—and yourself as a scientist.

A few days later, your teacher announces that the scientists from the spaceship are starting an afterschool club. If you liked your day on the mobile lab, the teacher says, you should sign up. You and a couple friends give it a try, and—a few months later, after sessions on topics from urban ecology to neuroscience—the scientists invite you to apply for a paid internship program, working on your own research project and mentoring even younger kids. By the time you apply for college, you not only have this new kind of experience but—maybe more importantly—you think about science itself as something you like, and are *really good* at doing.

The spaceship described above is BioBus, and our imagined ninth-grader is a composite of the over 300,000 students across New York City who have boarded a BioBus mobile lab since 2008. As a co-founder of BioBus, I've been with the organization since we were two scientists and a retired 1974 transit bus (purchased on Craigslist), which tended to break down on either busy bridges or remote highways. In 2010, I had just completed my master's in cell biology and was en route to a PhD at the University of California-San Francisco. A fortuitous Google search during my summer downtime led to volunteering at a few BioBus school visits. Once I saw students' responses to boarding the bus ("I never liked science, but I love this!," "I didn't think scientists looked like you!," "This is the best day of my life!"), I postponed, and then canceled, my trip out west.

Now, we have a staff of twenty-five, a $3 million annual budget, custom-built Airstream trailers, and lines in the New York City and State budgets. Like me, most BioBus team members are trained as academic scientists; many have PhDs, and some have postdoctoral research experience. We come from a range of disciplinary backgrounds but share a frustration with the persistent inequities we've witnessed and experienced in our fields. We desperately want to shift the racial and economic makeup of science, and we have all found our way to mobile labs—and BioBus, in particular—as a way to do that.

Here, I want to provide an overview of the mobile lab movement in general, reflect on some of my experiences with BioBus, and suggest a few things that the movement might do for science education and, more importantly, scientific practice. I am now back in academia, pursuing a PhD in marine science at Stony Brook University; I've carried the lessons of BioBus with me into my research and career plans. While I do not expect all scientists to become commercial drivers and spend years on buses, these lessons can and should be institutionalized more broadly.

THE MOBILE LAB MOVEMENT

A mobile lab is exactly what it sounds like: a vehicle outfitted with top-tier tools for science engagement, capable of reaching communities lacking access to such tools. BioBus primarily serves New York City, but mobile labs promote engagement anywhere the issue of access hampers engagement with science and its practices—urban, rural, or otherwise.[3]

BioBus is part of a larger movement in science education that is represented by the Mobile Laboratory Coalition (MLC), an international organization with participating programs that include a paleontology exhibit built in a Winnebago that travels around remote regions of Mongolia, a Colorado-based van that unfolds into a telescope, and a trailer that transforms into 1,000 square feet of biotech lab space and serves students across Maryland.

In the last decade, I have seen the mobile lab movement grow from a few scientists with idiosyncratic visions to a coherent organization capable of supporting new and existing ventures and lobbying for changes in science education and science funding at the municipal, state, and even national levels. When MLC members were surveyed in 2016, member programs had collectively reached 1.2 million students.[4] Given that not all mobile labs are MLC members, and that the survey is over six years old, the real mobile lab reach is likely more than 2 million. The majority of those participants would never otherwise experience a research-grade science lab.

Most MLC member programs, including BioBus, are connected to the nonprofit sector. They are either independent organizations with nonprofit

3. Consider this a practical complement to work in science studies on the boundaries of lab and field. The work of Robert Kohler remains canonical. See, for example, Robert Kohler, "Place and Practice in Field Biology," *History of Science* 40, no. 2 (2002): 189–210. More recently, see the recent Focus Section on "Fields" edited by Cameron Brinitzer and Etienne Benson in *Isis* 13, no. 1 (2022): 108–156.

4. Amanda L. Jones and Mary K. Stapleton, "1.2 Million Kids and Counting—Mobile Science Laboratories Drive Student Interest in STEM," *PLOS Biology* 15, no. 5 (2017): e2001692.

status or outreach programs connected to a larger nonprofit like a university or a museum. As nonprofits, we regularly present our work to funders, both public and private, for whom stories and testimonies from students can and often do speak for themselves. It's my sense that presenting BioBus as a semi-public good taps into the memories many of us have of our own "A-ha moments," inside and outside the classroom.

FROM PIPELINE TO PATHWAY

Mobile labs are often pitched as "solutions" to known, quantifiable problems. And for good reason: it is well documented that residents of the United States, both younger and older, score poorly on measures of science literacy; that American students routinely fail science and math standardized tests, especially in communities of color; that we do not currently have enough trained STEM professionals to fill available positions; that our existing (if insufficient) STEM pipeline is "leaky" and loses women and people of color at disproportionate rates; that STEM is broadly plagued by persistent lack of diversity and equitable representation; and that many of these issues are connected to the ongoing scourge of science denial and misinformation that has played a role in our less-than-stellar response to crises like climate change and the COVID-19 pandemic.

The "pipeline" is perhaps the biggest problem to which mobile labs like BioBus are pitched as solutions. Typically, pipeline solutions focus on populations historically excluded from science due to factors including race, gender, economic status, and disability—that is, those who "leak out" for various reasons.[5] The pipeline metaphor has a host of issues, some of which have been discussed at length elsewhere. Most of us do not follow a linear course from one year to the next. The pipeline model is even less fitting for low-income communities of color, where multiple stressors and disruptions make such assumed linearity unlikely, if not impossible.[6]

5. Sin-Ning C. Liu, Stephanie E.V. Brown, and Isaac E. Sabat, "Patching the 'Leaky Pipeline': Interventions for Women of Color Faculty in STEM Academia," *Archives of Scientific Psychology* 7, no. 1 (2019): 32–39.

6. For a recent critique, see Asmeret Asefaw Berhe, Rebecca T. Barnes, Meredith G. Hastings, et al., "Scientists from Historically Excluded Groups Face a Hostile Obstacle Course," *Nature Geoscience* 15, no. 1 (2022): 2–4. The classic study remains Matthew A. Cannady, Eric Greenwald, and Kimberly N. Harris, "Problematizing the STEM Pipeline Metaphor: Is the STEM Pipeline

I've often found myself frustrated when others view mobile labs as plugs to leaky STEM pipelines—or imagine that, by increasing the volume of youth of color at one end of the pipeline, we will see greater representation at the other end (despite leaks). The implication is that if a student chooses *not* to pursue a STEM career immediately after a BioBus program, that program was not valuable. What of the student who has to take time off school to care for a sick relative, or the one who can't afford an unpaid internship but is not accepted into the ultra-competitive paid research programs? If that student has formed a positive relationship with science in general, and with a specific scientist-mentor, is that not a desired outcome?

Progressive leaders advocate replacing the pipeline metaphor with the idea of a *pathway*, one that features myriad entry and exit points. The benefit of the pathway is that students need not participate continuously or linearly but can access STEM enrichment when and how it fits their broader needs. In a pathways context, youth have access to STEM mentors on their own terms, with programs designed to increase in both difficulty *and support* as students navigate them at their own pace and with their own interests and futures in mind.

Following the thoughtful work of Project Exploration in Chicago, BioBus embraced this pathway model several years ago.[7] Instead of one program type, we built a suite of complementary approaches that we call Discover, Explore, and Pursue. Discovery happens when we visit a new school, reaching a large audience and (we hope) sparking interest. Exploration follows, offering multi-session dives into particular topics via afterschool clubs or a week-long summer camp. Pursuit involves months- to years-long training for those who've come on board, including paid research internships and support in applying to college.

FROM PATHWAY TO BURROW

While the pathway metaphor has been a marked improvement over the pipeline, it falls short. How? The pathway approach no doubt captures something essential about youth STEM experiences, forcing educators to rethink the assumptions that go into how we teach science in schools and engage with

Metaphor Serving Our Students and the STEM Workforce?" *Science Education* 98, no. 3 (2014): 443–60.

7. Gabrielle H. Lyon, Jameela Jafri, and Kathleen St Louis. "STEM Pathways for Youth Development," *Afterschool Matters* 10 (2012): 49–57.

broader publics. But the pathway does *not* change how science itself is done. I think of it as a new, more humane arrangement of on-ramps to a highway that stays the same in terms of its structures, processes, and overall culture. The students I mentor who opt to pursue STEM after high school continue to face the same structural and cultural inequalities that have existed within scientific communities for centuries. They've gotten on the pathway, but for many it still feels—in college, or afterward—like it leads to the same problematic place.

Perhaps rather than focusing on how we move people through the scientific space—be it via a pipeline or a pathway—we need to reshape the space itself. Perhaps we need to focus on how programs like BioBus show *scientists* a new way to practice—a practice embedded in historically disenfranchised communities, one that uses insight from those communities as a guiding light and allows diverse voices to alter the trajectory of scientific inquiry. Rather than pipelines or pathways, we need a metaphor that can help us rework the terrain of science—to understand it as a dynamic whole, a system in which grade-school education is connected in complex ways to research at the highest levels. We need, in other words, something more like an *ecosystems* approach. Today's scientists must view themselves as ecosystem engineers, creating burrows hospitable to people from diverse backgrounds, moving resources around so that more individuals *and* communities can prosper: remaking the soils and sediments of science to become more inviting and inclusive.

BURROWING IN PRACTICE

A few years ago, I returned to academia to pursue a PhD in marine science. Broadly, my research seeks to understand how climate change in general, and ocean warming in particular, affects fish abundance and distribution, and how these shifts alter the structures and functions of marine ecosystems. In other words: my choice of the ecosystem metaphor is no accident—just not in the way you might expect. Rather than cherry-pick a metaphor for science education from my field of research, something more like the opposite occurred: I was drawn to the study of ecosystems in general (and fisheries science in particular) because of its connections with the wider world, the sort of connections that I spent a decade elucidating for students.

In my field, these connections are unavoidable. The data collected and models crafted by fisheries scientists directly inform decisions on matters like fishing quotas and restrictions on fishing timing, location, and gear use—with the ultimate goal of ensuring that wild-caught fish are a sustainable resource. In fisheries science, the need for stakeholder engagement is obvious; moreover, members of this community already accept models of "post-normal" science.[8] In such models, local knowledge is not only validated but also incorporated into the study of ecosystems and the decision making about how best to utilize and preserve them. In fisheries, this often means working with fishers—who are not trained as scientists but have deep, highly relevant knowledge. For example, many fisheries scientists are looking to include and amplify Native voices and the knowledge that comes from generations of subsistence fishing.

This is crucial work—but we can take it even further. What about the millions of people living in coastal cities, especially in the United States, who have been disenfranchised and distanced from the marine environment as a bountiful food source? How can we include their voices in fisheries, even when they do not have specific "knowledge" to bring to the table? How can we nurture new stakeholders in a manner that not only respects historic relationships between community and ocean but helps support the development of emerging relationships? My years at BioBus made these issues front and center as I began this new adventure in basic research.

Or, to put it differently: they have convinced me that the distinction between basic and applied research can and should be broken down much more often than it is. In my case, this has meant recognizing that research into—for example—thermal bottlenecks in the niche construction of specific fish species across the life course could be improved, *as research*, if we pursue it with the priorities of inclusivity and justice front and center. I could take the lessons I learned teaching on BioBus all those years and integrate them seamlessly into my research, thus both benefiting my own training and helping to train others in the process.

I have designed my research protocols so that the middle and high school students I've met through BioBus can have roles. Specifically, the students process previously collected samples, sorting through thousands of animals to isolate individual fish eggs and larvae. Such processing requires hands-on work and plenty of microscopy—both of which are exactly what drew students into the work of BioBus in the first place. Once processed, the fish samples are identified to the species level via DNA barcoding—another simple, broadly used technique, already introduced in community-based learning by Cold

8. See, for example, Silvio O. Funtowicz and Jerome R. Ravetz, "Science for the Post-Normal Age." *Futures* 25, no. 7 (1993): 739–55 and subsequent elaborations by both authors.

Spring Harbor DNA Learning Center, among others.[9] With barcoding data in hand, I can build models for the thermal niches of species across their life cycles, sharing almost every step of the process with students who are learning to see both the diversity of life on earth and the diversity of options before them.

BACK TO BUILDINGS

My ecosystem approach to science education and research is nested. At the center, members of the broader community (really anyone) learn to see the value of plankton to their local environments and food chains; surrounding these are participants (my middle or early high school students) sorting through samples, looking for fish; around them are slightly more skilled participants (later high school or college students) who isolate and amplify DNA, and then analyze sequences and generate species identifications; and in the final layer are those with training in data manipulation, statistical modeling, and fish biology.

In Spring 2021, as COVID-19 raged interminably, I was contacted by two high school students whom I've known for several years through their participation with BioBus. They were eager to return to hands-on science, and expressed a specific interest in marine biology. Did I have any opportunities to share? I described the plankton sorting role to them—though I also cautioned that this work would require over two hours of commuting, each way, between my lab in the suburbs and their homes in New York City. I fully expected the travel time to be a dealbreaker for these young New Yorkers looking ahead to summer. I was wrong.

These students, both from underrepresented groups not just in the sciences but in the American university system, have no history of scientific research in their immediate families—making it otherwise extremely unlikely that they pursue such work. But because BioBus altered their local scientific ecosystem, they found a more hospitable and healthy STEM context. They happily spend hours in the lab, entirely focused on meticulous measuring, labeling, sorting, isolating, and microscopy. My lab mates routinely remark on their extraordinary enthusiasm, determination, and focus. They are funny and kind;

9. Christine Marizzi, Antonia Florio, Melissa Lee, Mohammed Khalfan, Cornel Ghiban, et al., "DNA Barcoding Brooklyn (New York): A First Assessment of Biodiversity in Marine Park by Citizen Scientists," *PLOS ONE* 13, no. 7 (2018): e0199015.

they take pride in their work. In other words, they are ideal lab members themselves—ideal scientists.

When the summer ended, the students asked to continue the project; recognizing time constraints, they adapted our protocols so work could be done in their school building in parallel with the more limited on-campus meetings. They proposed ways to share their work with their classmates, fulfilling my vision of placing community members at the center of the project. Both by osmosis and through my deliberate actions, they have become increasingly interested in marine science—a field with some of the worst rates of underrepresentation in the sciences.[10] They are now, like me, actively reshaping an ecosystem that was otherwise inhospitable.

And yet. I cannot help but worry about what these students will experience as they move through this space, leaving the microenvironment of BioBus and entering the larger ecosystem. It is not lost on them that there are no other Black people—students, faculty, or staff—in my lab, and few in my department. These are students who have navigated STEM pathways for years, who are progressing through the proverbial pipeline, but the terrain still feels unwelcoming and foreboding. *That* is what needs to change. Thinking in terms of ecosystems may well be a start—but only a start.

Personally, I am plagued by a mixed sense of my value. On the one hand, I know that I was welcomed into my department, without prior training in marine science, precisely because my BioBus experience was identified as an emerging area of interest in the field. On the other hand, I am constantly, self-consciously aware that the inclusive project I described above does not fit the mold of "cutting-edge" research. It is simple by design—simplicity being the key to its inclusivity. It takes more time to get results, time spent on communication, listening, observing, training, and mentoring. Each of these tasks is undervalued relative to what is imagined to be the "pure" work of basic research—undervalued at every level of the scientific ecosystem. This is changing in science education (and especially in mobile labs), but it will take real work to make those shifts felt "back in the building," where my own research now takes place.

When I tell colleagues about my inclusive research, a common response is, "That's great! I wish I could host high school and undergraduate students in my lab, *but I just don't have any appropriate projects*." I want to tell them: that's

10. Rachel E. Bernard and Emily H. G. Cooperdock, "No Progress on Diversity in 40 Years," *Nature Geoscience* 11, no. 5 (2018): 292–95.

because you designed your projects with none of these issues in mind! Making science simple may be *harder* than making it complex.

So, what if: We could facilitate "a-ha moments" for scientists, as we did for our ninth-grader? Moments of insight into how to reframe their scientific enterprises so as to intentionally rework their local research environments to be more inclusive? In other words, examples and support with which to shift the way their questions are posed and explored, making those processes accessible and hospitable at a range of skill and training levels? And what if we gave them the resources to do so without losing prestige—instead even gaining some?

Such is my vision for bioturbation in the ecosystem of science. I know it is possible at the individual level; I know that, were such individuals to be supported across the scientific landscape, that landscape would meaningfully change. Questions would be asked and answered differently; future knowledge generation would be altered. Is this extreme? Not as extreme as the problem. Will it work? No guarantees, but it's the best metaphor I've come up with yet.