Preparing Dinosaurs

The Work behind the Scenes

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CONCLUSION

Every other Thursday morning during my five-week visit to the Northern Museum's fossil preparation lab, preparator Amanda would unearth a giant slow cooker from among the lab's tools, fossils, potted plants, and fish tank for Jack the guppy. She would add spices, chopped vegetables, and cans of beans and tomatoes to the vat, which would soon fill the lab with pungent smells. Word of mouth, a hallway chalkboard, and emails would circulate reminders for Chili Thursday around the department, as people popped into the lab all morning to confirm the event and taste-test the chili. By noon, at least thirty people would be jostling for a place in line, bowls in hand. The regular attendees of these much-anticipated meals included researchers, collection managers, preparators, conservators, and volunteers, all mingling freely over chili and preparator Carla's renowned cornbread. These diners all worked with fossils of vertebrates, invertebrates, or plants. They ranged from teenagers to retirees, and those with high school diplomas to doctorates. Twice a month they crowded into the lab to share museum gossip, catch up on the status of projects, and tell stories about fieldwork, travel, childhood, and—a major source of conversation that summer—an online livestream of a wild eagle's nest that everyone was watching in their offices. These representatives of several communities of practice were brought together not just by free lunch and deep interest in the natural world but also by shared reliance on the fossil preparators.

Like this scene, this book puts creative, nonstandard, nonscientist workers at the center of scientific communities and work. Unlike the dinosaur-focused displays we encountered at the start of this book, in this scene people are the foreground and specimens are the background. Collaborators chatting over lunch in a bustling backstage lab is a crucial part of maintaining social bonds and learning from each other. Thinking about science as knowledge preparation highlights the interlocking relationship between evidence, communities, technologies, and conceptions of science, and thereby encompasses the entire research community, the variety of work those people do, and the ongoing feedback between research work and knowledge. Regardless of workers' credentials, institutional status, or recognition in print or exhibits, everyone contributes to how this community makes sense of nature. Their work does not finish with a new publication or theory; rather, the process continues and adapts to new specimens, workers, technologies, and beliefs. The concept of knowledge preparation yields rich insights into the social structure of research communities, and reframes who can and should contribute to research.

Like they artfully mixed ingredients to prepare chili and cornbread, Amanda and Carla regularly combine skills, technologies, conceptions of science, and knowledge to prepare fossils. They craft messy, difficult-to-define, and fragile pieces of nature into physically delineated, somewhat less fragile specimens that are trusted to represent particular species and environments. This transformation is more than mere cleaning or routine processing; deciding what to "clean" off requires experience-based judgment, and has irrevocable implications for specimens' physical and epistemic form. Furthermore, deciding how to remove unwanted material—and preserve the treasured material beneath—relies on expert assessments of tools and techniques, innovative ways to adapt and design them, skillful applications of them, and ongoing evaluations of their effects with regard to the priorities of various fields. Piecing those prepared fragments together into an animal—or perhaps just a single bone—is also equally complicated, significant, and not obvious or predetermined. Fossil preparators do not sculpt fossils from matrix like artists sculpt statues from marble, nor do they collect them from the ground as pristine, stable, complete skeletons. Instead, preparators draw on creativity, sensory judgment, and notions of beauty to craft evidence from nature. Other members of their research community then interpret this evidence to craft knowledge about nature.

I derived these arguments from the particularities of fossil preparation, yet they ring familiar about many kinds of scientific research. In this conclusion, I draw on three ethnographic moments to crystallize the book's arguments about laboratory labor and scientific evidence, and propose how knowledge preparation defines important trajectories for studying scientific work and workers. I end with a reflection on the implications of knowledge preparation for the inclusivity of scientific communities. Specifically, this book shows the pivotal contributions of nonscientists to research as well as the many kinds of interesting work that research relies on. This approach has the potential to frame science as more relatable, comprehensible, and hopefully appealing to people who feel excluded by stereotypes about who can do research.

ETHNOGRAPHIC MOMENT #1: WHAT CHILI THURSDAY SHOWS US ABOUT SCIENCE

Labor as Relationships and Relationships as Labor

The Northern Museum preparators were committed to hosting Chili Thursday in part because these informal interactions were key to community building. Amanda and Carla dismissively labeled colleagues who didn't regularly attend as "antisocial," and described them only half jokingly as strangers, despite working with them for years. Attendance, then, was an important factor in earning the preparators' favor—a crucial commodity for anyone who needed prepared fossils, tools, or help repairing, identifying, or transporting fossils. Research workers nurture relationships with each other in order to facilitate mutually beneficial research work, such as specimens that suit each field's requirements (chapter 4). When I asked Amanda whether she worried about someone spilling chili on the fossils that occupied every surface in the lab, she shrugged: "They're rocks, right?" She said that the museum's safety officer opposed food in labs, but she and Carla valued the camaraderie of Chili Thursday—and their powerful role as hosts—enough to ignore the rules. As a result, they reigned over a regular meeting of (almost) everyone they worked with, thereby exchanging information as well as building loyalty and friendship in ways that effectively made the preparators the center of the department's work and social life.

The irony of the Northern Museum fossil research community being centered around its preparators is that those technicians are not recognized in any other setting besides the lab itself. They are not authors on scientific papers, principal investigators on grants, media personalities, or highly paid. Yet they are the crossroads of their department's diverse work, from collection management and conservation to research and display, and everyone they work with knows that. After all, preparators prepare the specimens that unite their coworkers' fields. Their lab is one space that everyone regularly visits, thus allowing preparators' news about projects, coworkers, and the eagle cam to spread quickly and comprehensively through their community. In some institutions, preparators even serve as the public face of paleontology by populating glass-walled display labs. These are significant domains of power for uncredentialed, unpublished, low-status "support staff."

Preparators' context-based autonomy illustrates that institutional hierarchy alone does not determine the social structure of research communities. Preparators claim these areas of autonomy and jurisdiction through the everyday interactions of defining boundaries and group identities, such as locking fossils into drawers to exclude a meddling researcher, telling jokes that only preparators understand, reprimanding volunteers if they attempt to choose their techniques instead of following directions, and nicknaming fossils to express affection and a kind of ownership (chapters 2 and 4). Preparators work closely with other fields, such as to negotiate preparation deadlines and priorities with scientists, discuss appropriate adhesives and specimen safety with conservators, coordinate fossils' organization and documentation with collection managers, dust mounted skeletons, and create labs that are simultaneously displays and workplaces with exhibit designers. This collaboration thrives on mutual trust and goodwill, with rare exceptions of top-down orders from scientist-bosses whom preparators resent as a result. Despite—or perhaps thanks to—this tandem work with several fields, preparators define themselves as distinct from impatient scientists, risk-averse conservators, paperwork-loving collection managers, and visitor-focused display designers. They first learn to enact this group identity while learning how to remove matrix, glue frags, open field jackets, microsort, and build storage cradles from more experienced preparators on the job (chapter 2). Selecting and teaching novices grants preparators enormous power over their field's skills, values, techniques, and shared sense of what it means to be a preparator.

The ongoing collaboration across fossil-focused fields means that everyone understands each other's motivations and priorities to some extent. Thanks to a shared conception of science—that is, a sense of what they're doing together—these fields are motivated to try to respect each other's needs and values, even when those priorities conflict. This respect inspires communication and compromise to prepare specimens such that they make each field's work possible. Preparators are the skillful, creative tinkerers who craft fossils into specimens that serve a variety of purposes for several fields. For example, scientists Grande and Hilton's desire to see the fossil sturgeon skull disassembled and entirely free of matrix challenged preparator Van Beek's desire to protect the skull from potential damage from both preparation and the long-term chemical degradation of adhesives (chapter 4). Of course, the scientists likewise didn't want to harm the specimen, and the preparator wanted to facilitate learning about the magnificently preserved fish too. By each taking responsibility for one of these perspectives, they managed to negotiate a middle ground approach in which Van Beek's expert matrix removal, adhesive selection, and storage box design achieved a specimen that enabled research access while preventing major damage and data loss. Yet the collaborators disagreed about who deserved credit for this success. The scientists claimed in their paper to have prepared the specimen, which so astonished Van Beek that she and a colleague published their own version of the event. Even when fields achieve a mutually satisfactory specimen, they can still disagree about how to recognize each other's contributions.

It is when we recognize science as the actions of distinct groups of actors, with varying values, goals, expertise, and forms of power, that we can fully understand knowledge as the hard-won outcome of compromise and cooperation. Because of the unequal institutional status of interdependent fields in vertebrate paleontology, one might assume that nonscientist research workers are oppressed by their omission in scientists' main form of recognition: publications. Some preparators do feel underappreciated, although being excluded from scientists' publications yields some benefits—principally preparators' control over their techniques and training. Sociologists Susan Leigh Star and Anselm Strauss (1999, 20–21) found that a lack of recognition can protect practitioners' autonomous decision making, while by contrast, imposing documentation of previously unwritten work can cause the insulting "eradication of discretion from skilled workers." So if scientists begin to coauthor with preparators or record preparators' methods in print, it's likely that the scientists would pay more attention to preparators' training and methodological decisions, and try to align them with scientists' own relatively standardized backgrounds and techniques. This would limit or even deny preparators' cherished creative problem solving and control over their practices. Thus "the phenomenon [of invisibility in print] is one of tradeoffs and balances" (Star and Strauss 1999, 24). Identifying those trade-offs and balances reveals the priorities of the groups involved, and sheds light on the mechanisms of power in a community, including who is allowed to decide how they are represented (Suchman 1995). After all, "the politics of crediting" in science encompasses all the complexities of social interactions, including biases, competition, and personal relationships (Timmermans 2003).

Fossil preparators witness the everyday realities of laboratory life that don't include scientists, and that scientists and STS scholars therefore tend to overlook. Because preparators reject standardization and automation, don't value credentials, and embrace volunteers, their perspectives can help us imagine how research work in general can be done differently and recognized more inclusively. Specifically, preparators alone choose and design techniques tailored for each specimen, and select and train future preparators (chapters 1–2). They even teach their skills to volunteers with no fear of replacement by this free workforce. Many research communities rely on students in similar ways as fossil research communities rely on volunteers. Like volunteers, graduate and undergraduate student research workers are unpaid or low paid, and require substantial training (often from technicians) to conduct useful work (Wylie 2018a; 2019c). Nonetheless, like technicians and volunteers, students can contribute influential ideas and methodologies as well as labor to research groups (Wylie 2021).

Technicians' experience of doing science is not universal, of course, but there are some common trends. Technicians share low institutional status. They perform manual and epistemic work to produce objects or data that achieve their and their bosses' goals thanks to their somewhat inexplicable ability to conduct techniques, adapt tools, and troubleshoot machines (e.g., Law 1994; Goodwin 1995; Sims 1999, 2005; Timmermans 2003; Doing 2004, 2009). These poorly understood, seemingly magical skills characterize many kinds of technicians (Barley, Bechky, and Nelsen 2016), including medical technicians (Joyce 2005; Alac 2008), repair technicians (Orr 1996; Henning 1998), field collectors (e.g., in natural history [Kohler 2006; Delbourgo 2017] and anthropology [Bangham 2014]), and even supposedly unskilled factory workers (Kusterer 1978). Scientists know that technicians' abilities are crucial for successful research, though they typically express this appreciation, if at all, outside publications. Paleontologists regularly told me how important preparation is for research, and occasionally I heard them say that to preparators. Similarly, engineering firms colocate research and design work because they want researchers' abstractions and designers' hands-on skills to inform each other (Carlson 2005; Carlson and Sammis 2009). Some scientists' job negotiations include demands for positions for their most valued technicians (e.g., Timmermans 2003, 204). Similarly, paleobotantist Hope Jahren's (2016) best-selling memoir *Lab Girl* can be read as a tribute to the wisdom, work ethic, expertise with instruments and samples, and loyalty of her longtime technician, Bill. How a research community works together is intricately linked to the relationships between workers.

Who Is Missing?

The metaphor of preparing knowledge embraces the plurality of research work and workers, regardless of their forms of recognition or power. It highlights that making sense of nature relies on skills, foibles, social conventions, and relationships just as all human endeavors do. It focuses on the various ongoing kinds of research work more than on the intended outcomes. It thereby encompasses a broad arc of scientific labor by situating theory formation alongside how those theories influence work, workers, and ways of knowing, and vice versa, in an iterative, adaptive, dynamic cycle. This labor is done by many people, not all of whom are scientists. Yet research communities fail to recognize people's contributions for a variety of reasons that deserve further study. The marginalization of some research workers can be explained by many possible factors beyond scientists' long-standing efforts to hide the messy, subjective work of research, such as discrimination based on education, gender, and race and ethnicity. Knowledge preparation demands that we pay attention to all workers and ask why some may seem difficult to find. Understanding their exclusion offers insights into widespread social values and biases, and can help us conceptualize what research communities ought to look like.

One reason for exclusion is a lack of scientific credentials. For example, doctors and clinical researchers have long considered patients to be passive recipients of health care and experiments because they lack medical training. As a result, they typically ignore patients' experience-based expertise about illness. Clinical researchers also strip patients of their identities and individualities to make unique patients comparable in order to support generalizable epistemic claims about health (Campbell and Stark 2015), in addition to more recent reasons of privacy and ethics. Incorporating patients' knowledge into medical knowledge, however, can improve patients' treatments and doctors' understanding of the experience of disease (Pols 2014). For example, people with HIV/AIDS in the 1980s believed that established ways of knowing in medicine exploited patients such as in clinical drug trials that used placebos (Epstein 1998). In response, they developed alternative ways of testing drugs that the medical establishment eventually adopted, such as before-and-after-treatment comparisons of patients' own health records instead of placebo groups. Thus including diverse forms of knowledge and knowers can yield more valuable research and more satisfied participants.

Gender discrimination can also impede the categorization of women as contributors to knowledge. Women scientists in the nineteenth and twentieth centuries experienced many kinds of institutionalized and casual discrimination (e.g., Rossiter 1982; Oreskes 1996). Women nonscientists have gone unacknowledged for their contributions to research too, such as the only recently told stories of nineteenth-century women data analysts in astronomy at Harvard University (Sobel 2016), women machine operators at Oak Ridge during the Manhattan Project (Kiernan 2013), women tech experts in mid-twentieth-century Britain (Hicks 2017), and African American women "computers" at NASA during the space race (Shetterly 2016). This discrimination continues today as both a cause and effect of women's underrepresentation in the science and engineering workforce.[1] Women are overrepresented in lower-status, lower-paid "pink-collar" jobs like teaching, nursing, cleaning, service, and low-level administration (Blum 1991). These care-centered jobs resemble evidence preparation in the sense that workers receive little recognition even though their work permits the achievement of crucial social functions, such as education, health care, and research.

Bias against certain racial and ethnic groups similarly results in the denial of their knowledge and research work. European explorers and colonists in the eighteenth and nineteenth centuries relied on Indigenous and enslaved people for their familiarity with local environments, as well as for their labor. Naturalists, such as Sir Hans Sloane and Charles Darwin (1913), used local people as guides and collectors of natural history specimens (and food), without recording their names or considering their interpretations of their environments to be legitimate knowledge (Delbourgo 2017). One example of more recent race-based marginalization is Vivien Thomas, an African American technician in the United States in the 1940s–1970s. He conducted decades of influential physiology experiments and designed a lifesaving surgical technique, yet received no mention in print from his scientist-boss (Timmermans 2003). This invisibility was a result of many factors, including Thomas's race, occupational status, and lack of formal education as well as his boss's fear that Thomas would gain acclaim and then take another job, stranding the scientist (Timmermans 2003). Racism thus benefits the powerful. Likewise, Indigenous knowledge continues to be ignored if it does not fit empowered groups' paradigms or goals, such as when Native American communities' notions of identity conflict with—and are overridden by—the US government's definitions of tribal membership (TallBear 2013). The striking underrepresentation of most racial and ethnic groups in science degrees and careers today suggests that our society has regularly denied these groups access to the education, identity, and employment opportunities that have long been required for successful participation in science (National Science Foundation 2019).[2] Thinking about science as knowledge preparation calls attention to all research workers and why they may have been marginalized, and raises the question of who may still be missing in today's research communities, as I will discuss at the end of this conclusion. As the next section argues, how we think about the work of preparing nature into evidence through constitutive cleaning is an important way to broaden conceptions of research work and workers.

ETHNOGRAPHIC MOMENT #2: PREPARING EVIDENCE AS CRAFTING DATA

Volunteer Keith peered into a basketball-size plaster jacket, carefully scraping away rock with a pin vise from the just-visible edge of a dinosaur vertebra. Muted sunlight filtered through the lab's dusty windows at the Northern Museum, falling on a row of workers hunched over assorted fossils and tools at long tables. With his eyes on the fossil, Keith asked staff preparator Amanda which species this bone came from. She replied, with her own eyes pressed firmly against a binocular microscope mounted over a fossil, that one researcher had said that the specimen belonged to *Eolambia*, a genus of herbivorous dinosaurs. "Supposedly," researcher Todd chimed in from across the room. Keith and Amanda both looked up, surprised by his skepticism. Todd then explained the dearth of diagnostic evidence for the specimen's classification. Keith joked, "Oooh, I'm in a controversy! One little slip [of my pin vise] and it won't be *Eolambia*." Todd quipped, "It'll be neolambia!" Everyone laughed.

Preparators' ability to decide a specimen's appearance and therefore influence how a researcher interprets it is a secret that all research workers know, even though they only address it in the private, ephemeral medium of lab jokes (chapter 4). The idea of a preparator making a mistake that creates a new species—like Keith's "one little slip," or preparators' joke about making foramina—is funny because it could happen. Even during error-free preparation, fossils' appearance and designation as specimens rely on preparators' skill and expert decision making (chapter 1). For example, Jay decided which tiny chunks of teeth to glue together to reconstruct the fossil mammal jaw and which chunks to discard as useless tooth dust. Likewise, he trusted his judgment (and wisely rejected mine) to decide whether and where to reattach broken pieces of the fossil horse skull, including a canine tooth that was missing in the skull's published description. Adding the tooth altered the definition of the species for which this particular fossil serves as the type specimen. Also, Jay's cast of the fossil squirrel skull could have shown an animal with unidentifiable teeth (because they were obscured by air bubbles in the casting material) and an enormous sagittal crest (created by the gap between the two halves of the mold). As a result, he threw away the bubbled-teeth cast and carved off the fake crest. Furthermore, whether preparators are innately patient and dexterous, as the prep test assesses (chapter 2), has physical and epistemic implications for specimens, as in the case of the unskilled volunteer who accidentally bored holes through a skull that became the type specimen of a new dinosaur species (chapter 4).

Fossils can look like an undefined, chaotic mess. While cleaning and sculpting them into specimens, preparators' decisions and actions physically shape those fossils and the evidence they can yield. This is the process of constitutive cleaning. Likewise, handwritten field observations; samples of blood, pollutants, and pollen; a machine's readout of experimental results; and any other kind of data can appear incomprehensible. These potential sources of evidence are useless until someone skillfully makes them visible and legible, such as by removing the surrounding distractions and thereby defining the object of interest. In addition, someone has to categorize, document, and store those data in ways that make them safe and findable. As Leonelli (2015) argues, data also become evidence only when someone uses them to support a knowledge claim. Before that, they are merely objects without meaning. All steps and supposed missteps are part of the work of preparing knowledge, in which the work itself has no end but rather creates an ongoing series of possible paths that branch off and loop back together. I do not suggest that science is self-correcting, nor that knowledge preparation aims to uncover universal truth. Instead, the work of making sense of nature is shaped by practitioners' dynamic decisions, as is the knowledge that such work produces. Following all the components of that work can lead us to encounter all the relevant people, and learn how their backgrounds and expertise shape scientific practice, community, and knowledge.

Preparators are responsible for choosing techniques and tools to achieve appropriate outcomes for each fossil. They consult with members of different fields and try to prepare a specimen that satisfies each field's needs. Preparators revel in the power and challenge of this creative problem solving, in which they anticipate how different technologies might affect a fossil in terms of speed of preparation, risk of damage, and which aspects will be made visible, and then select the best approach, adapt it accordingly, or occasionally invent a new one (chapters 1 and 3). When Carla struggled to keep a beautiful fish's scales in place while removing the thin layer of rock on top of them (chapter 1), she switched tools from pin vise to air abrader, and then carefully tuned the air abrader's settings several times based on how each setting changed the specimen's scales and matrix. Her decisions and actions responded to the moment-to-moment behavior of the fossil, rock, and tool as well as her own hand. If her problem-solving judgment and movements had failed, the fish would have lost its scales. By succeeding, Carla provided scientists with visible scales positioned where they had been fossilized as a wonderfully complete and in situ source of data about the fish's anatomy and taphonomy.

Preparators so value their autonomy to choose and alter techniques and tools that they argue ardently about these decisions, and have no standardized protocols or universal methods. For example, consensus continues to elude them about how to balance the short- and long-term purposes of specimens, such as with regard to using cyanoacrylate or reversible adhesives on fossils (chapter 1). Because preparators have invested in learning how to adapt technologies to each fossil's particular situation, they have used essentially the same technologies for over a century, such as an air scribe as merely a pneumatically powered version of the ancient hammer and chisel. Preparators' inability to tinker with CT scanners may be one reason why they—and the scientists who are accustomed to relying on preparators' expertise—are wary of them (chapter 3). Asserting their jurisdiction over preparation techniques and tools defines preparators' identity as well as prepared fossils' physical structure.

The social and epistemic issues involved in deciding the durability of fossils shed light on the fraught process of preserving other kinds of data while also making them flexible enough to address a variety of research questions.[3] The rise of public databases and the open science movement have made research data more accessible and alterable for people who did not collect them (e.g., Leonelli 2008, 2016; Levin and Leonelli 2017). Data sets can thus be reprepared to serve as evidence for research questions beyond the ones for which they were created. The crucial work of organizing, formatting, labeling, and analyzing data sets involves similar evidence-crafting expertise as preparing specimens and managing specimen collections. As this constitutive cleaning is increasingly distanced from data creation, the importance of data curators and their practices to scientific knowledge and communities will only grow. The "data journeys" that result from this transfer and repreparation influence how data are structured, analyzed, and interpreted (Leonelli and Tempini 2020). Sometimes preparing evidence and preparing knowledge happen in different times and places during this journey, such as when Jay reprepared the horse skull fifty years after its original preparation and published description (chapter 1). Nonetheless, these processes are inseparable and have important implications for the iterative, responsive, ongoing cycle of preparing knowledge as well as for the people who do that work.

ETHNOGRAPHIC MOMENT #3: PREPARING AS INCLUSIVE AND TRUSTWORTHY

How Research Workers See Their Publics

Collection manager Bob strolled into the glass-walled prep lab at the Southern Museum with a mischievous gleam in his eyes. He told two volunteers and me that he had just examined an object whose owner had asked the museum to identify it. The owner, who had found the specimen, suggested that it was a "fossil male organ," Bob quoted with delight. Encouraged by his audience's cringing giggles and eye rolls, he described the specimen's cylindrical shape in lascivious detail and noted, with a straight face, that "the color was right on." Bob's assessment was that the specimen was "quartzite"—rock, not fossil—and was therefore no one's organ. "She was so disappointed," Bob sighed in mock sympathy for the specimen's owner. Then he launched into an enthusiastic impromptu lecture about the function and phylogeny of the baculum, which is a bone inside the penis of many extinct and extant mammal species.

Research workers often tell each other stories about objects that they've been asked to identify as a courtesy to the public. Most of these narratives, like Bob's, feature themes of how ignorant people are about fossils and how disappointed specimen bringers are by identifications that make their finds less interesting than they had hoped. Research workers don't mind these reactions as they consider it their responsibility to address people's lack of knowledge about fossils, even if that means making a kid cry by telling him that his cherished dinosaur tooth is merely an ammonite (as happened to Carla at the Northern Museum). According to a few stories, this disappointment has led specimen bringers to reject the workers' identification and insist that the object is indeed a T. rex claw, dinosaur feather, fossilized amber entombing *Jurassic Park*–inspired mosquitoes, or whatever other desirable designation they have already given it. This reaction offends research workers because these specimen owners deny the workers' expertise, refuse to be open to learning, and occasionally argue aggressively with the workers.

These stories show how interactions between research workers and visitors can challenge both groups' assumptions about specimens, nature, scientific practice, and scientific knowledge. For example, at the start of Bob's story, the volunteers and I were laughing at the specimen finder for making silly assumptions about any torpedo-shaped rock. But at the end, Bob justified the specimen finder's seemingly ridiculous classification by explaining that a "male organ" can in fact have a bone that can fossilize. The volunteers and I dismissed Bob's explanation as a joke, so he indignantly marched us out of the lab and into the exhibit hall to point at a baculum mounted on a fossil seal skeleton on display. Duly chastened, we listened as Bob added that fossil bacula are prized specimens for museums because they are rarely preserved due to their small size and presence only in male individuals. The object he'd evaluated that day wasn't a baculum, but it was not crazy for its finder to wonder—and ask an expert—whether it might be. And if it had been a baculum, that expert probably would have tried to acquire it as a valuable research specimen for the museum's collection.

Despite commiserating over stories about people's dumb questions and insulting skepticism, research workers also readily say that they serve and learn from the public. Their thoughtful attention to how they portray themselves and their work on the stage of glass-walled labs reflects how important it is to them to make a good impression on museum visitors (chapter 5). How they agonize over exhibit designs, such as whether to display real fossil bones or casts, indicates how deeply they care about visitors' access to specimens and scientific knowledge (chapter 5). Research workers also recognize that people provide them with valuable information about their local environments. Bob explained to me, "Very often it's the amateurs I'll call up and say, 'Hey, what quarries are open right now? Have you got anyplace rich that's really working?' and very often they're the ones who help us decide where to go when we're [collecting fossils] in the field." Experience with local conditions is a priceless form of expertise for specimen collecting. Bob is grateful for these collectors' generosity with their information: "You owe them something in return, and of course diffusion is part of our goals as [the Southern Museum], so you're educating them" through the museum's exhibits as well as by offering educational resources and fossil identification at festivals and other public events ("It's like *Antiques Roadshow*!"). Bob continued, "There is that selfish aspect. We'd like them to give us some of their fossils too. . . . People's basements and living rooms are the best place to find fossils." He portrays the relationship between the museum's employees and hobbyists as mutually beneficial; people trade their fossils and local expertise for research workers' knowledge about species, environments, and ethical collection practices that protect specimens along with their contextual data. Thus building relationships with the fossil-interested public can reap valuable donations of specimens and collection information for research workers as well as grow an important audience that enables them to share their knowledge and justify their work.

Beyond Scientists

The key role of fossil preparators in paleontology is an example of how all workers influence research communities' social structure and epistemic work. Knowledge preparation forces us to recognize unsung research workers, many of whom perform a range of critical tasks for little pay or glory. Technicians and other overlooked workers can thereby inspire models of more inclusive participation so that nonscientists can more easily influence how research is done. This is more than a pleasant experience for participants of Bob's top-down knowledge diffusion; it is a way to incorporate more voices, skills, and kinds of wisdom into what we know and how we know it.

Working as technicians is one way in which people can contribute to research without being scientists. Crucially, technicians' jobs do not always include the formal barriers and strict gatekeeping of scientists' jobs, such as a PhD, publications, grants, and experience working with respected mentors in a specific field. Some technicians have these credentials, while preparators and others learn on the job with little formal science education. Preparing evidence can be a paid career, temporary or part-time gig, or unpaid volunteering. Workers' motivations for joining a research community differ accordingly, such as career aspirations, support for a worthy institution (e.g., a museum or university), or personal interest in the topic (chapter 2). They all influence the preparation of knowledge by their work and social interactions. Furthermore, presenting science as work done by skillful, creative workers with control over their techniques and community can appeal to the currently widespread interest in craft (e.g., as artisanal food and services [Paxson 2012; Ocejo 2017], and social activism via "craftivism" [Roosth 2013; Greer 2014]). The abilities required for craftwork are arguably "shared in common by the large majority of human beings and in roughly equal measure" (Sennett 2008, 277); by this logic, craft is an inherently inclusive activity. Thus advertising flexible requirements and interesting craft-based tasks without long-term investment in specific credentials could encourage more kinds of people to contribute to research. Rethinking science as work and craft can create a welcoming invitation to participation.

Like technicians, volunteers also contribute to research without traditional credentials. They include people Bob calls amateurs, who pursue natural history as a hobby and might share their knowledge and specimens with scientific institutions. Other volunteers are tied closely to institutions, such as the many kinds of museum volunteers who prepare evidence by constitutively cleaning, conserving, organizing, and documenting specimens. Another category is citizen scientists, who collect and/or analyze data for scientists or conduct their own research. Citizen science projects invite the public to observe local wildlife through backyard bird counts or to analyze data online, such as using the GalaxyZoo website to categorize scientific images and playing the online game FoldIt to test potential protein structures (Strasser and Hacklay 2018; Strasser et al. 2019). These kinds of programs attract lots of participants, thanks to public interest in science and the programs' nonexistent or minimal training and commitment requirements. Citizen science benefits researchers by providing free labor, and participants by offering opportunities for learning and personal enjoyment (Rotman et al. 2012). Nonscientists also lead citizen science projects, usually as a form of advocacy. For example, some communities monitor their local environments for industrial pollution or nuclear fallout in order to demand protective action from corporations or governments (Ottinger 2013; Jalbert and Kinchy 2016; Lindee 2016). Other groups conduct research in order to call for appropriate governance of biotechnology (Kinchy 2012; Benjamin 2013) or more ethical clinical trials (Epstein 1998).

There are of course potential limitations to these participatory forms of research, such as conflicts between scientists and nonscientists, difficulties in assessing the quality of nonscientists' work outside traditional research avenues like peer review, and misleading promises about participants' learning and empowerment (Riesch and Potter 2014; Strasser et al. 2019).

Nonetheless, inclusive research communities can harness more kinds of knowledge. Volunteers, for instance, can bring a valuable "wisdom of peripherality" (Wenger 1998, 216) to expert communities as well as the wisdom of their own perspectives and experiences (Wylie and Sismondo 2015). Likewise, undergraduate research assistants ask paradigm-challenging questions and propose ideas inspired by their broad education, thereby highlighting research communities' tacit assumptions and providing fresh perspectives (Wylie 2021). Students, volunteers, and citizen scientists are even sometimes recognized as authors on scientific publications. Hence, even with a variety of backgrounds and roles, these groups all shape the community they work with and, consequently, the knowledge they prepare together.

Institutions, however, currently dedicate relatively little funding for technicians, students, volunteers, and other nonscientist research workers, even though there is an enormous amount of work for them to do (e.g., building and maintaining databases, conserving natural history specimens, organizing collections and archives, maintaining research equipment, preparing samples, running experiments, and leading public outreach activities). Even so, volunteers tend to prove their value as "museum friends," donors, and eager learners as well as laborers. Creating more (and better-paid) salaried positions for technicians and more (and better-funded) volunteer programs would further support these important opportunities for inclusive participation in knowledge preparation.

This more accessible social structure for research matches recent calls for science to be more open, such as through open-access publications, publicly available data and methods, and more inclusive research communities (e.g., National Academies of Sciences, Engineering, and Medicine 2018; Mendez et al. 2020). Building glass-walled research workplaces is one powerful way of making scientific work (more) transparent and its workers more familiar, relatable, and perhaps welcoming to museum visitors (chapter 5). Instead of the strictly divided scientific disciplines and professions formed in the nineteenth century (Bowler and Morus 2005, chap. 14), and the rise of the specialization and division of scientific labor in the twentieth century (Bowler and Morus 2005, chap. 11), today's science can—and should—be more integrated into mainstream society, such as by making its evidence and practices more open, research questions more socially beneficial, community more participatory, and knowledge more accessible and comprehensible.

The model of preparing knowledge thus proposes a public conception of science that is more relevant, inclusive, and hopefully appealing to more kinds of people. Welcoming nonscientists into research communities also welcomes new ideas, skills, and values to permeate the boundaries that have long demarcated science. Research workplaces can therefore function as a liminal space connecting scientists and nonscientists. In these communities, nonscientists can learn how science is done and potentially shape new ways to investigate based on their diverse skills and experiences, while scientists can learn what nonscientists want to know and can cultivate these collaborators as powerful supporters of scientific work, institutions, and knowledge. Inviting the public to view science as important and interesting work that they can contribute to would be a powerful way to address two critical problems: the underrepresentation in science of people with diverse identities and backgrounds, and growing public skepticism and outright denial of scientific knowledge.

What We Owe Technicians: Preparing Trust

To finish, let's return to these three ethnographic moments: the cheerful bustle of Chili Thursday, the joke about inventing neolambia, and the disappointed owner of a phallus-shaped rock. In each of these interactions, research workers nurtured trust. They invest time and effort (sometimes over lunch) to earn each other's trust, which serves as a foundation for all of their work. Trust underlies their collaborative compromises across fields, even during controversies. It gives credence to preparators' skillfully crafted specimens and creatively designed technologies. It leads museum visitors to respect and admire displays of scientific knowledge, specimens, and sometimes workers. It encourages amateur fossilists to swap expertise with research workers. Crucially, trust allows us all to see a rock not as a rock but instead as a fossilized relic of an unfamiliar animal in an alien environment, and therefore as one fragment of a grand narrative about life on Earth.

This book has shown the foundational contributions of nonscientists to the practices and people of research communities, conceptions of what science is, and the preparation of current and future scientific knowledge. These processes are best understood by following them in action within communities where a variety of workers transform unique pieces of nature into evidence for global knowledge claims. This approach yields insights into how science works as a critical starting point for evaluating how we want it to work in the future. Reframing research as an ongoing, iterative process of preparation enriches our understanding of how the everyday labor of familiarly multifaceted humans allows us to learn about nature. This framework offers a way to welcome more kinds of people to contribute to research. Broadening participation and improving inclusion can help achieve accessible, respected, socially significant science.

In our era of alternative facts and selective truths, more people are questioning whether science is a reliable way to understand the world. Making research work more transparent and inviting, and recognizing more kinds of people as contributors to knowledge, can inspire widespread trust in science. Throwing open the doors of the laboratory for public participation—and scrutiny—can help disprove denialism, and reassert that science is a credible and socially beneficial activity. It's possible this strategy could backfire if nonscientists are shocked by the "warts-and-all" view of science as human work (Shapin 1992, 28). But I think this fear discredits people's genuine curiosity to look behind the scenes of science as a seemingly secret society. Critique of science is bound to follow, but hopefully the resulting debates at least would be more informed and at best would offer insightful, actionable feedback for improving the process of preparing knowledge.