This PDF includes a chapter from the following book:

Preparing Dinosaurs

The Work behind the Scenes

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INTRODUCTION

Mounted dinosaur skeletons tower over museum visitors, broadcasting a sense of solidity and grace. They gaze eyeless into the distance, bathed in the dim light that protects the photosensitive glue supporting their bones. They seem to have stomped out of the distant past and paused on the exhibit's reinforced floor. Humans stream around them, incongruously active compared to the stiff dinosaurs. Children flit from specimen to specimen, crying out their excitement and (mostly) pretend fear. Adults look upward, pointing out teeth and claws and text panels to each other.

Fossils inspire curiosity and awe in part because they are natural. Visitors flock to see these skeletons not because they are science fiction but instead because they represent real (and bizarre) animals. Museums emphasize specimens' naturalness, such as in exhibit text panels that list facts about dinosaurs as once-living animals but not as fossilized bones that people have painstakingly collected, prepared, studied, and mounted. Paleontologists too focus on the animals by publishing proposed facts without describing how the specimens that inspired those facts were processed into scientific evidence. This book asks how these bones become specimens and, crucially, who does this expert work.

If visitors think about it, they would acknowledge that these magnificent skeletons did not stroll in from the Mesozoic era and stand obligingly in place in the museum. But they might not know that these skeletons were once fragmentary, distorted chunks of rock, embedded in the geologic strata formed from their prehistoric habitats and virtually unrecognizable

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to the untrained eye. After all, now those fossilized bones are clean and uncrushed. They have been assembled into skeletons with no missing parts, ringed by panels spelling out confident-sounding facts about the animals' lifestyles and environments. How does this transformation happen? Naive visitors might think that scientists pick up fossils from the ground, blow the dust off them, and declare them a new species. More savvy visitors might know that vertebrate fossils are usually rare, fragile, and encased in rock, but they might assume that removing that rock and keeping the fossils from disintegrating is relatively routine, easy work that doesn't affect the fossils' appearance or value as evidence. The people who do this work have a different view: the seemingly mundane processes of preparing specimens are skillful, creative, and a fundamental part of learning about past life. This book investigates the people who prepare fossil specimens for research and display, and, accordingly, how their work defines prehistoric animals, museum displays, and science itself.

Some exhibits hint at the people and work behind the specimens. Among the extinct animals standing upright (thanks to vertebra-cradling steel) or lying half buried in slabs of rock (perhaps still curled in their death pose), there might be information about how scientists, technicians, students, volunteers, and amateurs find fossils in the field, along with a shovel or geologic map.[1] Often this is the only public mention of the many kinds of work that make possible the intricate structures of petrified bone that we call dinosaurs, mammoths, and saber-toothed cats.

As a wonderful exception, a few exhibits house a small, brightly lit room enclosed by windows, in sharp contrast to the large twilight exhibit hall. This room looks like a display case—a giant version of the specimen-containing vitrines placed throughout the museum. But behind this glass are people (figure 0.1). Clad in dusty T-shirts, they bend over fossils, peering closely to look for the subtle interface between fossil bone and its surrounding rock, which they call matrix. Then they scratch away matrix—and not fossil, they fervently hope—with tools that resemble a dentist's. These workers are surrounded by tubs of plaster, bottles of glue, buckets of discarded matrix, microscopes, noisy fans sucking rock dust out of the air, and tables laden with specimens as well as coffee cups,

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Figure 0.1

Photographed from museum visitors' perspective outside a glass-walled laboratory, a volunteer preparator works on a fossil with video cameras capturing his hand (left screen) and his view down the microscope (right screen) for visitors to watch.

houseplants, and toy dinosaurs. Visitors typically assume that the people on display are scientists—a misconception that some museums' text panels perpetuate. These workers, however, claim a different identity from "scientist"; they are fossil preparators. Fossil preparators describe their work of removing matrix and gluing fragmented bones as preparing fossils. Another logical though incorrect interpretation of watching them work would be, as I heard one impressed visitor exclaim to a child, "Look! People making fossils!"

Preparators do not "make" fossils from scratch; rather, they make fossils into specimens. Selecting natural objects to study and then turning them into specimens that can be studied is one of the central tasks of science. After all, specimens are the foundation of knowledge about life and environments, and how they change. Some specimens are alive, such as the

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creatures nurtured by workers in zoos, aquariums, and botanical gardens. Others are preserved in forms such as pickled or dried animals, pressed plants, sliced rocks, polished minerals, insects pinned in boxes, and pollen grains captured on glass microscope slides. As objects carefully labeled and stored in perpetuity in museum and university collections, specimens offer trustworthy physical evidence for scientists' knowledge claims.

We might assume, as museums and scientists imply, that these objects move directly from their habitats into scientific papers and exhibits. Along the way, though, people process them physically and epistemically, so that they become researchable and displayable. For vertebrate fossils as well as other objects, this work involves separating useless background (such as matrix) from informative specimen (such as fossilized bone), often based only on subtle differences in appearance and material composition. Preparing nature for study and display requires decisions about what an object should look like, and what it should be capable of. For example, should a preparator remove all the matrix around a fossil or leave it partly embedded? Should a preparator make a fossil solid enough to be handled by applying glue that degrades over time, or omit the unstable chemical additives and allow the fossil to remain physically fragile? Should a preparator fill in the inevitable missing bones by imagining and sculpting replacement parts? Many questions like these shape how research workers, including scientists, preparators, conservators, collection managers, and volunteers, decide how to convert nature into specimens and knowledge. This book complements previous rich analyses of scientists' interpretations of specimens by investigating the people and practices involved in making these long-lasting, trusted, yet changeable objects.[2]

How workers prepare fossils illustrates how research communities produce the evidence, experts, methods, and perceptions of science that constitute our beliefs about nature. To understand this important work, we must understand the workers. First, I discuss how fossil preparation inspires a new model for understanding science. This model highlights the crucial roles of work, objects, and craft in research. Next, I explain how I studied technicians who leave few written traces. Because scientists rarely describe fossil preparation or include preparators as authors in scientific

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papers, thereby making them "invisible" in print (Shapin 1989, 1994), I used ethnographic methods of interviews and observation. Finally, I outline how this book's chapters analyze how people prepare dinosaurs and other fascinating creatures, and what their work can teach us about scientific evidence, practice, and knowledge.

PREPARING KNOWLEDGE

Doing research comprises four component processes that work together. Specifically, evidence must be prepared into forms that can be studied. Workers must be prepared with skills and values to do good work in a research community. Tools and techniques must be prepared to help practitioners do that work. Research workers and their audiences must be prepared to engage with scientific knowledge based on a shared sense of what science is. These ongoing, interlinked processes simultaneously rely on and produce scientific knowledge. I follow the skillful, hands-on work of preparing fossils to investigate this system. To encompass the wide range of iterative interactions between research workers, nature, and society that makes science possible and meaningful, I conceptualize *preparation* as a fundamental feature of scientific work and knowledge.

This form of preparation expands on the theory of social construction, which similarly highlights the foundational roles of things, communities, practices, and social values in research. Philosopher Sergio Sismondo (1996, 66) explains, "Scientists inhabit a world in which both the social and many of the material realities that they encounter are constructed. Many of the social realities are supposed to take account of or mimic the material ones, and some material realities are constructed with help from the social ones." This cycle of constructing both the material and social worlds is crucial for making nature comprehensible. For example, some research communities conduct carefully controlled experiments on constructed materials (e.g., industrially purified chemicals or specially bred organisms) to investigate natural processes. How they define their questions and practices influences how they prepare their materials, and what they learn from those materials influences the questions they ask and how they work with the materials.

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This cycle allows scientific ideas, work, and objects to adapt to each other, and thereby align with and be useful in their social context.

The concept of preparation focuses on the adaptation and iteration inherent in this cycle. In comparison, "construction" implies an end point, an eventual finished product. Anthropologist Bruno Latour (1999, 115) worried that the metaphor of constructing scientific facts sounds too flimsy and therefore insulting to scientists by implying that "if it is constructed it must also be deconstructible." Preparation thus highlights the process more than the product, the journey more than the destination. Facts are constructed, and then some are deconstructed or renovated over time; preparation emphasizes how those changes happen from a longer-term perspective. Of course, one always prepares *for* something, which also implies an end point. But that end point is arguably more flexible and open, and less preplanned, than a construction project. Because research work is embedded in its time, place, and culture, the end points for which workers prepare their evidence, communities, technologies, conceptions of science, and knowledge change in response to their context. These moving goalposts may seem counterproductive, but actually this adaptability is crucial because knowledge can only make sense within its social world. When that world changes, as it is always doing, then knowledge—and the work of producing it—must change too. And after all, knowledge is rarely, if ever, truly finished. Rather, it is reexamined and reconfigured across time and cultures. Research workers will never reach their intended end point; it is a target to aim for instead of a permanent achievement. Crucially, that dynamic end point informs *how* workers do their work, which in turn alters the outcomes. The concept of preparing knowledge, then, captures the endless and critical interactions between research work, knowledge, and society.

Specimens are part of this cycle too, although some scholars of science and technology studies (STS) disagree. For example, Sismondo (1996, 67) names natural history specimens as an unusual exception to the social construction of material reality: "The material objects that scientists study are different from social ones in *some* interesting ways. They are made from other material objects, rather than just actions. Sometimes, if rarely, they are

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not even constructed or manipulated by people, as in the case of the objects that some naturalists, geologists, and early astronomers have studied." It is indeed hard to argue that stars and planets themselves are influenced by social factors (although how they are observed, documented, and interpreted certainly is). And of course, taxidermied animals, trimmed rocks, and prepared fossils contain plenty of material that exists due to factors beyond "just actions" of humans (unlike the socially constructed categories of race, gender, beauty, justice, and so on, that exist—and are powerful—because humans have decided that they exist).

Pieces of nature, however, are made into specimens by humans. Their naturalness becomes combined with social values as soon as humans deem them specimens. People develop scientific objects and interpretations in a social and material context that philosopher Ian Hacking (1999, 10) calls, in a wonderful double entendre, a "matrix." For example, a fossil forms in its geologic matrix, and later, when collected by a human, enters a social matrix of institutions, people, and beliefs. While Hacking (1999, 32) contends that nature does not "interact" with the categories that we assign to it, clearly this situation shows otherwise. If research workers decide that a natural object is a specimen, then they handle, process, and interpret that specimen differently from just any object. Classifying an object as a specimen therefore results in changes to its physical form, not just to how humans understand it. Hacking (1999, chap. 8) even chooses a case study about geologic knowledge to argue for the broad reach of the social construction of theories about nature. If social construction is more obvious in natural phenomena that are visible only indirectly or via technology (e.g., quarks, electrons, or microbes), then demonstrating that social values also shape scientists' interpretations of visible, tangible rock specimens is a powerful point. For the same reason, Latour uses paleontology to satirize an extreme view of the social construction of reality. In Latour's (1980) "fable," the actual past appearance and lifestyle of a dinosaur changes as scientists' beliefs about that dinosaur change; thus the scientists create reality in the process of trying to understand it. But nature is not created by people; specimens—as pieces of nature modified by humans for epistemic uses—are.

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Thinking about specimens as cultural objects with embedded social values (e.g., Haraway 1984; Alberti 2008), much like technologies (e.g., Mackenzie 1990; Bijker, Hughes, and Pinch 2012), reveals how they reflect issues of power between social groups. How preparators prepare fossils thus exemplifies the "entanglement of nature and culture in the specimen" (Alberti 2008, 85), such as how preparing specimens also defines the various groups of workers within a research community (chapter 4). Anthropologist Brian Noble (2016, 358–359) portrays this entanglement in the form of the many influences on the design of a dinosaur exhibit with a glass-walled preparation laboratory at the Royal Ontario Museum:

> The scientist's wish for conveying the dynamic process of palaeontological reconstruction, . . . the marketer's competitive goals to succeed in museums in the slipstream of *Jurassic Park*'s successes at the movies; the hopes invested in the meticulous action of a laboratory; the diplomatic efforts of the interpretive planner to translate across many knowledge experiences with special attention to those aligned with middling Canadian family living; the participation of audiences in constituting a fuller, if also more personal, vision of the living creature and its relations; the tensions of media and curatorial producers and their complex of tools and procedures. . . . This is the work of articulating dinosaurs.

The network of interactions between various groups, values, constraints, evidence, and kinds of knowledge defines—or in Noble's term, "articulates"—dinosaurs' appearance, behavior, and environment for the museum's visitors. Noble's analysis of the politics of display helps inform this book's analysis of the politics of research. The recursive craft of altering and interpreting pieces of nature, then, can be understood as a series of decisions and actions that "transform" natural objects into specimens to serve as what sociologist Chandra Mukerji (1989, chap. 8) calls "ostensive models" that combine description and theorizing. Preparing evidence and facts is not a singular transformation but rather an ongoing series of physical and epistemic changes through which research workers try to balance the priorities and influences of their various colleagues.

Preparing evidence involves "transform[ing]" materials to achieve physical and epistemic goals (e.g., a stable fossil with maximum completeness,

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a safe machine that produces reliable results, or a data set that has been cleaned and formatted for a particular study). This situated craftwork—and the technicians, students, and volunteers who do it alongside scientists—provides evidence about nature and thereby influences how scientists—and the rest of us—understand the world. Yet these tasks and workers receive little recognition in print, such as through authorship or methodological descriptions. Portraying research work as knowledge preparation recognizes all the "preparers" involved in this multifaceted process.

LABOR IN THE LABORATORY

Beyond Scientists

So who does the work of preparing knowledge by preparing evidence, communities, technologies, and conceptions of science? This question avoids the more exclusive job-based designations of "science" as done by scientists, "research" by researchers, "technical work" by technicians, or "support work" by support staff. In practice, all research workers—that is, anyone who contributes to research, including scientists, technicians, volunteers, and students—do various overlapping, recursive combinations of preparing evidence and interpreting it, making it difficult to extract which tasks count as "science" and therefore which workers deserve scientific recognition. By making most research labor "invisible" in print (Shapin 1989, 1994) and low status in institutional hierarchies, scientists effectively reify the more visible products and people of science: facts and scientists. Most ethnographies of laboratory life focus on *scientists'* labor. Sidelining the rest of the research workers, such as those who primarily do the skillful, creative, tailored work of preparing evidence, can portray scientists as lone geniuses, and scientific work as highly controlled, standardized, and predictable. This inaccurate view marginalizes all the other workers as well as overlooks the evidence crafting that scientists do themselves. Consistently including all research workers in STS analyses would enrich insights into scientific practice and knowledge. For example, an appreciation for nonhuman actors has broadened and enriched our understanding of participation in research (e.g., Latour 1987; Haraway 2000, 2016); all categories of

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human actors deserve analytic attention too. This book shows how the model of preparing knowledge guides us to follow the behind-the-scenes, between-the-lines activities of science in order to reveal the various kinds of people who do them.

Scientists in many contexts and time periods have endeavored to obscure the people and practices of research in order to promote the credibility of the resulting data and knowledge claims. This goal inspires efforts to make technicians "equivalent" (Yarrow 2003, 67), "interchangeable" (Lucas 2001, 9), or even "part of the 'instrument' to be calibrated" (Schaffer 1988, 118). Scientists in some fields closely supervise less skilled technicians, who "are required to act with machine-like regularity, keeping thought and creative variation to a minimum" (Lynch et al. 2008, 89–90). Scientists thus try to dismiss the relevance of low-status, nonscientist research workers to the output of their work (Shapin 1989, 1994). Nonetheless, even supposedly unskilled workers have unnamed, uncredentialed abilities that researchers rely on, such as technicians' expertise at building, operating, and repairing machines (Kusterer 1978; Mukerji 1989; Law 1994; Orr 1996; Sims 1999; Doing 2009).

This "machine-like" portrayal does not apply to all research workers. Scientists differentiate "support staff" who follow routine protocols from higher-skilled technicians, whose expertise some fields even acknowledge with authorship (Charlesworth et al. 1989, 82–89). The crucial indicator of technicians' skill, according to scientists, is "their reliability in producing certain types of data" (Latour and Woolgar 1986, 223)—that is, how well they achieve scientists' desired results. Technicians who produce desirable data then receive little supervision or instructions from scientists, thereby allowing them to carry out methods as they see fit (Latour and Woolgar 1986, 223; Mukerji 1989, 137; Lynch et al. 2008, 89–90). For example, skilled technicians and scientists work as de facto equals to ensure the safe operation of high-voltage electrical equipment for plasma physics research (Sims 2005). These workers believe that achieving safety relies on their own careful attention, experience, and "instinct" more than on academic credentials such as a PhD. Because of the indefinable nature of embodied know-how as well as many laboratories' reliance on

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diverse skills, scientists sometimes grant trusted technicians control over their techniques. This autonomy empowers research workers by implicitly asking them to apply their expert judgment to decide how they prepare evidence.

Furthermore, assigning research workers different levels of power enables some workers to do tasks that others cannot. For example, for one technician, "his low status and affable personality enabled him to move from lab to lab with materials, (often) inconclusive results, and ideas without provoking any controversy" (Rabinow 1996, 114). The technician's low institutional rank and categorization as a nonscientist made him nonthreatening, thereby achieving valuable information sharing for scientists. But how does this invisible role and work affect the technician? STS scholars tend to view laboratory laborers from scientists' perspectives. As a result, these studies don't tell us what the technicians think about scientists' expectations or how they experience their roles in research.

Fossil preparators offer important insights into laboratory labor because they don't fit the common views of technicians as standardized and "interchangeable" or as quasi-scientists. Preparators don't have PhDs or authorship on publications. They receive no formal training or methodological protocols. To distinguish themselves from low-skill, instruction-following technicians, preparators portray their practices as creative and artistic (chapter 1). Moreover, the majority of people who prepare fossils are volunteers, not staff. One might think that these skillful volunteers would threaten preparators' employment, yet the presence of volunteers actually empowers staff preparators by granting them control over selecting, training, and supervising a workforce. Thus preparators control their methods and communities, unlike most technicians, and lack the typical indicators of professional fields that most technicians have, such as official training and credentials (Abbott 1988; Barley, Bechky, and Nelson 2016). This combination of shared and divergent traits makes preparators and fossil labs valuable sites for studying how nonscientists shape science.

The fluidity of research tasks in practice complicates many distinctions we make about science. To shed light on the craft knowledge and "moral economy" of research work in the early twentieth century, historian Robert

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Kohler (1994) studied how scientists developed the *Drosophila* fruit fly as a "standard" organism for genetics experiments. The work of creating stocks of standardized flies might seem merely technical or perhaps even routine. Instead, it was deeply embedded in these scientists' group identity and knowledge about biology, such as generously sharing individuals' painstakingly bred fly collections to legitimize the emerging field's research and produce higher-quality knowledge for everyone (Kohler 1994). Similarly, sociologists Kathleen Jordan and Michael Lynch (1998, 776) argue that we can capture a more complete view of scientific practice and practitioners by "following the technique around," as exemplified by their work documenting how scientists, technicians, and students use polymerase chain reaction in various biological and forensics laboratories. I extend their analysis beyond one technique to follow the skillful practices of preparing evidence, communities, technologies, and conceptions of science, whose deep interconnection is a defining feature of research work and unifying force in research communities. So instead of worrying about the oversimplified and overstudied question of which processes and people are science and not science, here I study scientific work and workers in situ and inclusively.

Most scientific fields preserve at least some variability in who does which tasks. For example, paleoanthropologists and invertebrate paleontologists typically prepare fossils as well as study them. But workers in vertebrate paleontology enact a strict division of labor. They consider the work of processing data to be separate from the work of interpreting data—to the extreme that different people do those tasks. Few vertebrate paleontologists prepare fossils, and most don't even know how. This is not a case of routine work that scientists *could* do themselves but instead choose to outsource to lower-status workers. Rather, research workers consider fossil preparation to be a separate field from that of scientists, involving its own training, practices, and culture. Similarly, conserving, organizing, and displaying fossils are the primary responsibilities of other groups that consider themselves separate from fossil research, namely conservators, collection managers, and exhibit designers. This highly stratified social structure is reflected in how practitioners defend their domains from others' encroachment, such as cases of paleontologists forbidding preparators from doing research, and

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preparators hiding specimens to prevent paleontologists from preparing them (chapters 2 and 4). This crucial separateness enables each group's distinct contexts of (in)visibility and (dis)empowerment.

Most fields assign scientific recognition based on the perceived status of tasks, such that only people doing work deemed "research" (e.g., theory building) receive credit in the form of authorship and higher institutional rank. When scientists prepare samples or run experiments, their work often goes as unrecognized as when nonscientists do it. Likewise, if nonscientists such as technicians, students, or citizen scientists propose a theory that scientists deem credible, then they will typically receive recognition for it. Thus the *task* is deemed nonscientific, not necessarily the worker. In comparison, fossil research communities assign scientific recognition based on workers' job, such that anyone without a "scientist" job title does not receive recognition in print or power in institutional hierarchies, even if they propose theories or have a PhD. These stark divisions do not match workers' everyday responsibilities, which are interdependent to the point that everyone who works with fossils contributes to scientific knowledge by influencing evidence, communities, technologies, and/or conceptions of what science is.

A research community that defines its workers as separate and its categories of work as inviolable is somewhat unusual, and hence offers a clear demonstration of social processes that are usually more subtle and difficult to study. As such, vertebrate paleontology serves as a model in the sense that it amplifies specific attributes of a system; it is not a model *of* science but rather a model *for* understanding how research workers structure their social order (Creager, Lunbeck, and Wise 2007, 2). Its social structure highlights how communities define and practice power, such as by recognizing or sidelining certain kinds of work or people. As in the study of nature, exceptional cases in the study of society can help illuminate typical features. Like paleontologists examine the remains of a few individual animals in great detail as a way of learning about large-scale questions of adaptation and morphology, this study explores the social world of vertebrate paleontology to investigate aspects of scientific work, knowledge, and community.

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Cleaning or Sculpting Fossils?

So what do fossil preparators do, and what can their work teach us about science? When I talk with scientists and preparators, they describe fossil preparation with both realist and constructivist metaphors. For example, scientists say that preparators "clean" fossils—a realist and somewhat dismissive portrayal of the work, and one that preparators themselves rarely invoke. Cleaning implies preexisting evidence waiting to be revealed. The work therefore sounds clean in the sense of free from values, theories, and individuals' biases as well as simple, straightforward, and quotidian. In this view, practitioners' actions respond to reality alone. That reality, though, is not unyielding. Preparators subtly embrace constructivism more often than scientists do, such as by talking about their work as "creative" and, occasionally, "sculpting." This kind of language emphasizes the complexity of their work as well as their own power in defining fossils. Of course, supposed cleaners also make decisions that influence evidence (e.g., fossils' appearance, completeness, and stability; taxidermied animal skins' shapes and type of preservation; and data sets' selected information and organization). They thus constitute what that evidence is by altering its form. The cleaning and sculpting (and hence the realist and constructivist claims) are inseparable and simultaneous.

It may seem obvious how potential evidence should be cleaned, especially to nonexperts; however, distinguishing fossil from matrix, good data from bad, and signal from noise relies on skillful, experienced judgment, and nonetheless often provokes debate among experts. Historian Samuel Alberti (2008, 81) describes the processes of preparing specimens as that natural objects "are subject to physical processes to make them stable (such as conservation); a series of textual practices to order them (such as cataloguing); a range of spatial techniques to store them; and a variety of exhibitionary techniques to render them intelligible." By preparing a fossil, a preparator gives it a "social life" and a new meaning as a representation of an organism (Appadurai 1986; Alberti 2008; Rheinberger 2010; Daston 2004). Preparation, as arguably the most nature-altering process for specimens, is a crucial and little-understood component of how people make nature researchable. This book investigates the moments of recursive

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practice in which, to combine practitioners' words, people sculpt evidence by cleaning it.

The sturdy, complete fossils that we see assembled as beautiful, frozen-in-time animals in museum exhibits are an admirable product of human work and judgment. So too are the fossils that wait on museum shelves for scientists' eyes only. Fossils of vertebrate animals are usually rare and sometimes one of a kind, and every fossil bears the physical and chemical marks of its unique journey from a living bone to a fossilized one. Thus fossil animals are not Lego sets; they lack most of the pieces, the remaining ones are broken and deformed by geologic processes, there are no instructions, and even the finished-product image on the Lego box does not exist when research workers have no idea which animal a bone belonged to. Fossils are not replicable, unlike a chemical reaction or a synchrotron run. As a result, fossils are carefully stored for future reference. A preserved data source—unlike a written "inscription" of ephemeral experimental results (Latour and Woolgar 1986)—allows for the repreparation of evidence and renegotiation of knowledge (e.g., Cruickshank 1994; Wylie 2009), and as such, a long and dynamic life span of research usefulness for preparators' products.

Furthermore, vertebrate fossils vary significantly in fragility as well as size, anatomy, and scientific value. This diversity, which is shared by specimens of extant organisms, requires adaptable techniques to produce specimens with certain characteristics such that scientists can interpret and compare them. Fossils are visible and tangible without instruments, unlike many research objects (e.g., gravity waves, cells, and subatomic particles). This makes them more accessible to nonexperts like museum visitors, and means that research workers retain the embodied skills of directly handling and observing their objects of study (chapter 3). This interaction with material variations is the essence of craft (Paxson 2012, chap. 5; Ocejo 2017, chap. 6). Thanks to a craft worker's interventions, "rather than liabilities, irregularities become positive factors in the creative process" (Risatti 2007, 195, quoted in Paxson 2012, chap. 5). Working with the irregularities of once-living things is likewise a defining aspect of the craft of preparing evidence. After all, those irregularities may be why

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an object is scientifically important, such as to represent an unrecorded species, behavior, or environmental trend.

Scholars use the concept of craft to refer to the iterative exchange between materials and human action as well as the embodied skill of doing that action (e.g., O'Connor 2006; Paxson 2012). This feedback loop between action and assessment is common to a variety of craft workers, from potters to programmers (Sennett 2008). Craft relies on knowing an object well. This kind of knowing requires collecting data in the form of sensory inputs, such as the object's texture, colors, and weight. Anthropologist Heather Paxson (2012, chap. 5) calls this judgment "synesthetic reason," in that multiple sensory assessments merge to shape each other and inform the craft worker's decisions and actions. How research workers rely on embodied knowledge to assess how to work with a specimen exemplifies synesthetic reason.

Like craft, the cleaning/sculpting of fossils relies on embodied expertise about materials and epistemic expertise about the intended purposes for those materials. Like a carpenter shapes trees into tables in ways that celebrate the wood's grain while achieving a functional surface, research workers alter natural objects to serve as evidence. Craft, though, does not seek out an existing object as science does. The sculptor Michelangelo complicated this distinction when he apocryphally explained that to carve the *David* statue, he only had to remove all the marble that was not David. Two fossil preparators independently told me about Michelangelo's words (Wylie 2015), and historian Peter Galison (1987, 256) also used them to explain evidence selection. Fossil preparators appreciate this metaphor because they indeed remove the rock to reveal their desired product. In similar ways, Galison (1987, 256) argues, scientists remove "the background," such as "noise" or other irrelevant information, in order to define "the foreground" as the object or results they seek. This work entails careful, conservative actions followed by skillful assessment of the results to inform the next action. *David* did not emerge from Michelangelo's marble block all at once but rather via one precisely judged chisel stroke after another. The metaphor of the statue waiting hidden in the rock also captures a practitioner's expert sense of what is desirable about the material (e.g., a

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marble block's potential to evocatively represent a man with a slingshot, the traces of subatomic particles on a bubble chamber readout full of misleading "noise," a plant specimen covered in its accompanying but unwanted dirt and insects, or a fossil's edge peeking out from a heavy block of matrix) and how to achieve that potential. Craft and research workers have this skillful sense in common.

Craft workers, however, strive for somewhat standardized or at least similar products made from somewhat predictable materials, while research workers strive for products that are roughly similar enough to be compared despite a wide range of variation within and across materials. Research workers therefore conduct the ongoing, iterative design of objects and techniques to produce evidence that might undergo further future constitutive cleaning (e.g., repreparing fossils, sampling DNA from taxidermied animal skins, or reorganizing data sets for different analyses).

Research workers and STS scholars are well aware of the inseparability of investigating nature from constructing evidence. Yet they (and we) struggle to explain it, in part because the interconnection of these processes is deeply context dependent and can challenge the assumption that research is objective. Fossil labs, then, offer rich evidence about how craft can supersede the divisions of labor and power between scientists and nonscientists, and, perhaps, between research workers and the public.

OBSERVING "INVISIBLE" TECHNICIANS

To learn about research workers, I needed to go beyond exhibits and publications. So I followed the workers on the job by joining several vertebrate paleontology labs as a participant observer. I wanted to learn how different kinds of workers in these communities communicate, collaborate, make decisions, acquire and share skills and knowledge, and interact with these amazing ancient objects. Luckily I had a head start. As a high school student, I attended a summer program at the University of Chicago that included a week collecting fossils in the field with Professor Paul Sereno. The course didn't mention fossil preparation, but it was an eye-opening investigation of anatomy, evolution, geology, and the art of digging. After

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the course, I volunteered in Paul's Dinosaur Lab every Sunday of my senior year, learning to prepare fossils under an undergraduate student's tutelage. When I joined the University of Chicago as an undergraduate myself, I worked as a student preparator, pestering staff preparators for help and scraping rock—and sometimes, mistakenly, fossil—for about eight hours per week. I earned the admiration of other students, who begged for lab tours after spotting my dusty clothes and glue-stained fingers.

In my third year, I spent a term in London as a volunteer at the Natural History Museum's Palaeontological Conservation Unit. It was there that I witnessed the diversity of scientific practice. At the Dino Lab, I had learned to remove all the matrix from a fossil and then add cyanoacrylate (a kind of glue that bonds permanently through a chemical reaction) and epoxy (permanent self-hardening clay) to strengthen and reconstruct bones. The Palaeontological Conservation Unit preparators told me only to clear matrix from small specific areas of fossils and handed me a bottle of reversible (i.e., dissolvable and arguably removable) adhesive. When I asked for cyanoacrylate, they were surprised and a little offended. I didn't understand why until they kindly explained that British institutions value the approach of fossil conservation that includes doing only minimal preparation and reconstruction, and using only reversible materials.

This culture shock led to my revelation that fossils are not prepared in the same ways. Doesn't it matter to scientists' studies, I wondered, whether fossils are fully revealed and permanently strengthened with cyanoacrylate, or are still partly embedded in matrix and reinforced with reversible adhesives? Variations are not merely technical; US and British research workers also differ in behavior, hierarchy, and priorities. I returned to the Dino Lab and my major in the history and philosophy of science with a shaken view of scientific universality. Later, I wrote the first paper for a master's degree at the University of Cambridge about how my mentor at the Palaeontological Conservation Unit, preparator Scott Moore-Fay, reprepared an enormous fossil pliosaur skull that was first prepared in the nineteenth century (Wylie 2009). My experience in these two labs—at a US private university and British public museum—inspired this study by revealing that techniques, philosophies of fossil care, and technicians' roles can vary

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enormously without inspiring complaints from scientists or skepticism of fossil-based knowledge.

I am therefore somewhat of an insider to the fossil research community. I am familiar with preparators' lingo and practices. I can distinguish between fossil and matrix. I can discuss Monty Python and science fiction alongside tales of fieldwork adventures and disastrously broken fossils, as common topics of lab chats. This background informed my choices of research sites and facilitated conversations with research workers. My former bosses and coworkers were a crucial source of willing interviewees and generous invitations to visit institutions. I also met preparators and scientists at the conferences of the Society of Vertebrate Paleontology and the Association for Materials and Methods in Paleontology, where I wrote field notes and sometimes gave talks about my research. I designed a survey about preparators' demographics, training, work experiences, and opinions about methods that captured an informative snapshot of their community. Because of the relatively small number yet wide variety of fossil-preparing institutions, I conducted a multisited brief ethnography instead of the more traditional single-sited, long-term one (e.g., Falzon 2009). This approach brought me to six labs in universities (five of which are associated with university museums) and eight labs in natural history museums. Nine of the labs are in the United States, four are in the United Kingdom, and one is in Canada.

My goal was to investigate local cultures and work practices as well as identify concerns that span institutions. At each site, I interviewed and observed people who work with fossils, including preparators, scientists, conservators, collection managers, exhibit designers, and volunteers.[3] I spent one to three days at twelve of the labs and five weeks each at two labs. My goals for the short visits were to see what the labs look like and to learn workers' opinions on key issues about practices and social order. Typically, a staff member—almost always a preparator—would give me a tour, and then I would interview staff members and volunteers.[4] On the longer visits to two US natural history museums, I was in the lab full time to witness work practices and social interactions in addition to conducting interviews. These two museums, which I call the Northern Museum and

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the Southern Museum, are valuable for their significant vertebrate fossil collections, respected preparators and scientists, wonderful fossil exhibits, and glass-walled labs where visitors can watch preparators at work. I participated in the lab communities by attending social occasions (e.g., lunch breaks and bar trips) and institutional events (e.g., meetings), and doing some preparation work.[5] Ethnography proved a powerful methodology for revealing subtle mechanisms of social organization and everyday practice in these scientific workplaces.

I chose to assign pseudonyms to all the people and institutions in this study. All my interviewees except one agreed to be identified by name. However, I decided that the ethical necessity of protecting the participants from embarrassment or damage to their professional reputations far outweighs the benefits to my research of full disclosure. Being unnamed in publications thus can serve another purpose beyond scientists' pursuit of objectivity: protection from public attention. Even without tying quotations and actions to individuals, these interviews and observations speak volumes about the social and epistemic roles of research workers.

Based on these data, I suggest that we think about knowledge as the intersection of many interlocking and iterative processes of preparation, namely preparing evidence, communities of workers, technologies, and private and public conceptions of science. Thinking about science as all these kinds of work, done by scientists and nonscientists alike, offers a more comprehensive model of how we learn about the world.

PREPARING KNOWLEDGE ABOUT SCIENTIFIC LABOR

This book examines the everyday work of science. Each chapter asks how research workers prepare a component of knowledge: evidence, communities, technologies, and conceptions of science. What emerges shows that these kinds of work are inseparable from and more accurately understood to *constitute* epistemic work. The book concludes with a reflection on how acknowledging all these processes as parts of knowledge would usefully broaden the boundaries of scientific work and workers, thereby

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welcoming contributors with a wider variety of backgrounds, experiences, and identities.

Chapter 1 follows the unpublished work of making nature researchable by preparing evidence. Preparators practice constitutive cleaning by preparing rock-encased fossils according to their own and scientists' priorities. These aims include stability, completeness, and visibility as well as aesthetics and efficiency. Methods to achieve these goals are not standardized; instead, preparators tailor them to each fossil in a process that they call "creative problem solving." Preparing evidence, then, involves making decisions in ways that are situated, individualized, and expert.

Chapter 2 asks how technicians define and unite themselves, and thereby how they prepare their community. Preparators lack shared credentials, methods, and publications, and are dispersed in small groups across institutions. How, then, do they create a group identity and assimilate new members? One mechanism is mutual teaching and learning, as preparators supervise novices' hands-on learning as well as exchange advice and ideas on email list hosts and at conferences. Rather than imparting specific protocols, preparators help new staff members and volunteers develop an experiential sense of good work. Yet the craft of choosing and designing techniques is a privilege reserved for the staff. Volunteers prepare fossil evidence under employees' supervision and direction. How staff preparators define this social order despite their shared training and work with volunteers offers rich insights into how technicians conceptualize their skill and identity.

Chapter 3 studies how research communities prepare technologies—that is, techniques and tools. Specifically, preparators privilege their own skills over new technologies, and scientists prefer to rely on trusted technicians over new technologies. Thus preparators' tools have a strikingly long life; today's most common tools were invented over a century ago. A more recent technique, analyzing fossils with CT scanners, offers the appeal of high-tech machinery and digital specimens that can be manipulated on-screen. However, scientists are skeptical of it. They prefer physical fossils shaped by expert preparators to on-screen images produced by black-boxed

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machinery operated by unfamiliar people. This trust suggests that craft skill drawn from experience and relationships plays such an integral role in science that it has been—and is likely to continue to be—preserved.

Chapters 4 and 5 examine how research workers perceive science and their role in it. I investigate how research workers define their identities and work privately in the lab (chapter 4), and how they portray themselves for the public in museum exhibits (chapter 5). These chapters analyze situations in which preparators are empowered (i.e., as de facto leaders and decision makers in the lab as well as on display in glass-walled labs in museums) and disempowered (i.e., in publications and institutional hierarchies). These contexts suggest the important social functions of selective recognition, such as preserving both objectivity and craftwork by obscuring preparation in print, presenting paleontology as a transparent and accessible field through glass-walled labs, and dividing power between practitioners such that scientists control publications while nonscientists control the lab's work, workers, and public portrayal. Thus preparing knowledge about nature involves preparing knowledge about science.

To conclude, I consider how adopting the view of preparing knowledge enriches how we understand science and its place in our society. Preparing knowledge relies on methodological adaptation, skillful creativity, and ongoing feedback between nature and people, all of which are conducted by a variety of research workers. This work shapes scientific evidence, in the sense that how we learn about nature depends on who prepares it into evidence, the technologies they select and design, and their judgment of what counts as data. The paleontology community's social structure demonstrates how other sciences might incorporate nonscientists into research work, such as technicians and volunteers without typical scientific credentials. Highlighting the contributions of nonscientists to research can serve as a welcoming invitation to people who feel excluded from science due to discrimination based on race, gender, class, or ability. Calling attention to the wide variety of research work may also make science a more appealing educational choice or career for more kinds of people by disproving stereotypes about research work, such as that it is boring, difficult, lonely, or dependent on math. Crucially, creating a community of scientists and

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nonscientists can empower and educate both groups. Nonscientists can learn how science is done and apply their diverse skills, experiences, and values to propose socially relevant research topics and ways to investigate them, while scientists can learn what the public wants to know and cultivate fellow research workers as powerful supporters of scientific institutions and knowledge. As a form of improved transparency and inclusiveness, thinking about science as the process of preparing knowledge can help encourage broader participation and trust in science.

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