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What Fossil Preparators Can Teach Us About More Inclusive Science

In the vertebrate paleontology laboratory of a natural history museum, volunteer fossil preparator Keith was hard at work. He was searching for the dinosaur bones encased inside a "jacket"—a basketball-sized chunk of rock wrapped in plaster and burlap that had been collected by museum staff on a field expedition to Montana. Muted sunlight filtered through the lab's dusty windows, falling across fossils, tools, houseplants, toy dinosaurs, and other workers at nearby tables as Keith used a pen-sized steel pick to delicately scrape away the rock. Watching for any glimpse of fossil, his goal was to first discover and then painstakingly reveal the buried bones so scientists could study them. The problem, he lamented to me, is that "only the person who made the jacket knows where the fossil is."

As a preparator, Keith plays an essential role in finding and excavating fragile bones from the surrounding rock. A worker who is overeager, misinformed, or simply unlucky will break the fossils, destroying irreplaceable scientific evidence. Fossilized animals are shaped and defined by the skill and creativity of a variety of workers, including preparators, conservators, collection managers, students, and volunteers. The specimens they uncover serve as the foundation of scientific knowledge about life, environment, and evolution. As solid, permanent things that are carefully preserved in museums and university collections, specimens offer trustworthy physical referents for scientists' claims.

And yet these fossils do not spring from their rocky confines into scientific papers. Along the way, preparators do significant physical and epistemic processing to make fossils researchable, although their contributions to the forms that specimens take are rarely reported in institutional records or museum exhibits—and even less often in published papers. Not only do volunteer preparators like Keith rarely receive credit for their work, they aren't paid either. Keith donates a few hours of his skillful labor per week to wrestle knowledge out of rocks. It's a necessary but underappreciated job. Understanding how these workers turn nature into data offers insights into how other research disciplines could engage meaningfully with the public, make the research community more inclusive, and expand the definition of what constitutes scientific inquiry.

There is no specific training or certification required to work as a preparator; preparators teach novices on the job through informal supervision and advice. They draw on skills from their diverse backgrounds to free fossils from rock and piece them together. Keith, for example, is a veteran and retired businessman. He credits his home improvement projects and his love of puzzles and baking for honing his attention to detail, problem-solving skills, and fine motor dexterity, which he relies on to prepare fossils. During my study of Keith's lab, I often saw him—like many preparators—improvise tools and techniques, such as bending a wire to serve as a screwdriver and filling a specimen tray with sand to hold fossils steady while he glued them. Many professional as well as volunteer preparators credit their training in art or carpentry or their hobbies in crafting or model-making for their preparation skills. The many possible paths to becoming a fossil preparator demonstrate the importance of hands-on learning and highlight the fact that skills acquired outside traditional schooling can also be crucial for scientific inquiry.

When faced with a jacket, preparators must meet each fossil where it is. The attributes of what makes a "good" fossil vary widely based on the priorities and values of individual preparators and scientists. Every fossil bears the physical and

chemical marks of its unique journey from a living bone to a fossilized one. How animals die, become encased in sediment, are mineralized, and get compacted by surrounding rock layers shapes what that specimen is, including which body parts are preserved, in what condition, and how distorted they are from their shape in life.

Preparators use their skill and judgment to prepare specimens instead of following top-down instructions from scientists or carrying out predetermined protocols. Back at the workbench, Keith was happy to spot a fossil surface peeking out among the rock, putting an end to his nerve-racking digging. He set to work following the bone by scraping off rock around it with a tiny pick, thereby tracing out its shape. He soon found a nearby "floater," a thumb-sized fragment of bone he described as "not attached to anything." He said the floater might fit onto another bone or be informative to a scientist, so he set it aside for a later decision. Then Keith came across a swathe of small bone pieces, which he discarded into a bucket of rock dust. "Tiny, disintegrating debris—you can't do anything with those," he said dismissively. A specimen can only be a specimen if it is physically researchable—that is, visible and stable enough to handle—as well as trustworthy, which requires preparation by someone with expertise.

In spite of his unequivocal-sounding explanation, and possibly due to me asking questions about how he decides which bones to save, Keith asked a staff preparator, Amanda, whether to keep the debris. Amanda blew on the debris, assessing the size of the fragments, and told him to discard it. She deemed those pieces of dinosaur not useful. Then she picked up the floater and, turning it around a few times, matched its edge to a broken edge of the partly buried bone in the jacket.

"Want some glue on it?" Keith asked, watching.

"Yeah." Amanda scratched some sediment from the floater's broken edge with her fingernail, then put it in place against the other bone and dripped glue on it from the small bottle Keith handed to her. The glue bonded the two pieces into one larger chunk of a once-living animal. In the span of a minute or two, Amanda deployed several embodied skills: judging fragment size with her breath, removing rock with her nail, assessing the floater's fit with her eyes, adding a precise line of glue to the exact place she wanted it. Such expertise can only come with experience.

This everyday scene exemplifies the ongoing, high-impact decisionmaking involved in preparing specimens, including determining what is priceless (in this case, bone) or useless (rock, bone debris); which pieces fit together; and what counts as a specimen. None of this skillful judgment or these irreversible actions, though, are likely to be mentioned in papers, specimen records, or exhibits. Fundamentally, the purpose of specimen preparation is to satisfy scientists' desire to access pieces of nature—free of distracting context yet as complete as possible—so they can describe, identify, and compare them. But how are these values defined and carried out, and by whom?

Keith touches the dark-gray fossil inside the jacket, which only experts can distinguish from the surrounding lighter-gray rock.

When I talk with scientists and preparators, they describe fossil preparation differently. Scientists say that preparators "clean" fossils—a somewhat dismissive portrayal of the work. "Cleaning" implies preexisting evidence merely waiting to be revealed. The work therefore sounds "clean" in the sense that it seems free from values, theories, and individuals' biases, as well as simple and straightforward. In the scientists' view, preparators' actions only respond to reality.

Preparators, on the other hand, embrace their role in determining how fossils look and what data they can provide. They talk about their work as "creative" and, occasionally, as "sculpting." This language emphasizes the complexity of their work as well as their own power in defining fossil from rock. Of course, mere "cleaners" also make decisions that influence scientific evidence, including the appearance, completeness, and stability of prepared fossils, taxidermied animals, and dried plants. They define what that evidence is by altering its form. The cleaning and sculpting are inseparable and simultaneous.

Preparators' power over specimens is evident even in their jokes. While working on the same fossil a month later, Keith asked Amanda which species it belonged to. She answered that one of the museum's scientists believed the specimen belonged to *Eolambia*, a genus of herbivorous dinosaur.

"Supposedly," Todd, a paleobiologist, chimed in from across the lab, citing a lack of diagnostic evidence for the specimen's classification.

"Oooh, I'm in a controversy!" Keith joked. "One little slip [of my tool] and it won't be *Eolambia*."

"It'll be *Neo*-lambia!" Todd quipped. Everyone laughed.

This joke plays on preparators' profound work as shapers of specimens—despite their uncredited labor and low-status institutional role. Preparators' job, making natural objects into scientific specimens, is an unwritten secret that scientists, preparators, and all other paleontology lab workers know. Although they are unpublished and uncelebrated technicians, preparators have significant control over fossils, preparation tools and techniques, the community of preparators (through informal training), and even the public perception of paleontology.

This incongruity is telling. As invisible as preparators are in the scientific literature, they can be conspicuously visible to the museum-going public. Many volunteer preparators work in glass-walled labs in museum exhibit spaces, simultaneously providing prepared fossils and a performance of science in action for visitors to watch. Preparing fossils and teaching museum visitors about such work is imperative, and the fact that such public-facing and participatory scientific labor can go unacknowledged, especially within its own field, is striking.

What could other sciences learn from these volunteer preparators? To start, scientists, including paleontologists, could begin to include all contributors in publications and exhibits—if not as authors, then at least in the description of the research methods or as part of the acknowledgements. Another idea is that universities and other research centers could follow museums' lead by hosting glass-walled labs, volunteer programs, and other outreach efforts where people can meet research workers and perhaps get involved in scientific work. Members of the public may better understand and trust scientific knowledge if they know how it was produced, and by whom. For example, the movement for open science, which promotes open-access datasets and publications, could be expanded to include transparency about data preparation and all the workers who conduct it.

A museum visitor watches a volunteer prepare a fossil under a microscope at the Field Museum in Chicago.

Preparators are hired based on their skills rather than their training (since there is no official training); this is also possible for other scientific disciplines with, for instance, laboratory technicians. Such an approach dismantles the barriers to participating in scientific inquiry thrown up by degree requirements. It opens paleontology—and potentially other fields—to people who learn data preparation techniques as a hobby or who have transferable skills from other, more accessible endeavors, such as carpentry, crafts, and even Keith's puzzles.

Citizen scientists and undergraduate researchers demonstrate the potential for people without science degrees to influence the production of scientific knowledge by contributing their skilled labor. Recognizing the value of skills rather than credentials is a powerful way to celebrate diverse backgrounds and life experiences and can help confront the "leaky pipeline" problem of the marginalization of many racial and ethnic groups, women, and low-income students in science education.

Paying attention to all the workers in a research community reveals that there's more to the development of scientific knowledge, work, and community than PhDs and publications, and underscores the variety of skills and experiences that science relies on. This more complete view of science is fascinating for its own sake. It also invites more people to participate in research, since anyone can develop these skills, regardless of their success in school or expertise in science. Citizen science programs and museum volunteer opportunities abound, and their membership would grow further if more people knew how influential, fun, and accessible scientific work can be. That broader participation, and the appeal of the actual work involved, can then encourage people to pursue science education or careers. Crucially, it can help inspire greater public trust in science. And it can make science itself better by incorporating the perspectives, creativity, and skills of people who might not otherwise engage with research.

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