Timing Science: The Temporal Role of Scientists in the Construction of Data

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The processes of producing scientific knowledge rely on the temporality of data, yet they also obscure this relationship. Scientists hope that knowledge claims can stand relatively independent from their context of production. Instead, a more realistic and trustworthy view would be to embrace data's history and "journey" (Leonelli and Tempini 2020) as a component of the knowledge claims that these data inspire. These journeys describe how data and people interact and thereby influence each other's identity and epistemic worth. In this paper, I propose a model to help philosophers and other analysts pay closer attention to the people who work with scientific data, specifically by considering how these practitioners conceptualize time. I argue that how practitioners experience time reflects the personal, professional, epistemic, and ethical values that guide their decisions about how to do science. These conceptions of time differ by profession, career stage, identity, institutional context, and other factors specific to practitioners' lives as well as their scientific or disciplinary culture. I draw from two case studies of vertebrate fossils to illustrate how various conceptions of time co-exist for practitioners, as indicators of the values that guide practitioners' decisions as they do scientific work.

Keywords

paleontology • data • scientific practice • values • specimens

The processes of producing scientific knowledge rely on the temporality of data, yet they also obscure this relationship. Scientists hope that knowledge claims can stand relatively independent from their context of production. Instead, a more realistic and trustworthy view would be to embrace data's history and "journey" (Leonelli and Tempini 2020) as a component of the knowledge claims that these data inspire. In this paper, I define several notions of time that co-exist for scientists and other practitioners as they do the work of producing knowledge. These conceptions of time, I argue, represent the powerful epistemic, social, and professional values that define scientific practice. Recognizing these values' embedded presence in data, as well as in scientific work and workers, helps us understand how they influence what we believe about nature.

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Vertebrate paleontology illustrates the critical importance of understanding how data have encountered people, institutions, things, and ideas. I use this science to highlight the values that underlie the processes of making, processing, and interpreting scientific data. I launch my values-based analysis from Sabina Leonelli's (2018) argument about the temporality of data production (data time) as distinct from the temporality of natural phenomena (phenomena time) that scientists use those data to represent. Leonelli, too, takes historical sciences, such as paleontology, as hallmark examples of the epistemic relevance of data time as distinct from phenomena time, though she rightfully extends these concepts' applicability: "I argue that concerns around whether and how data maintain evidential value through time are not restricted to the historical sciences but are common to any field in which data acquired in previous periods can play a significant role as evidence for subsequent research" (2018, 742).[1] Here I similarly use paleontology to illustrate the critical importance of time to scientific practice and knowledge more generally.

However, knowledge construction involves more than data and phenomena. Specifically, I build on Leonelli's model by arguing for the inclusion of time as experienced by the people who construct data and phenomena, or what I call *scientist time*. Vertebrate paleontologists study fossils to understand such natural phenomena as adaptation and environmental change. Dating these phenomena is a critical, complex, and often contested component of knowledge production. In comparison, paleontologists tend to see data time, i.e., the journey of a fossil from a rock-embedded biological trace to a prepared specimen, as a slow, unscientific, yet necessary hindrance to their research (Watkins 2024; Wylie 2019a, 2019b). They typically want to think about Cretaceous Earth, for example, rather than about a fossil that was geologically smashed millennia ago and prepared as a specimen in 2024. Hence there is a need for an analysis of scientist time as a guiding force for understanding how scientists conceptualize data time and phenomena time, and thus how they act on those concepts in the process of producing knowledge.

Scientists can only interpret data and study phenomena in relation to their own context and professional journey. This context and journey include the expectations and norms of being a scientist, professional and individual notions of ethical research practice, and power dynamics of career stage and scientists with marginalized identities based on race, gender, ability, and class. These systemic trends and personal experiences are shaped by values regarding what it means to be a good scientist. These could be considered "contextual" values, in Helen Longino's (1983) distinction between broader social values surrounding science and the "constitutive" values that define what it means to do good science. But, as she argues, both kinds of values can and often do co-exist in scientific practice. For example, a vertebrate paleontologist cannot help but consider the timeline of her career requirements (e.g., the span of a graduate degree, a temporary contract as a researcher, or a tenure clock) when selecting a field site, specimen, or research question to investigate. This seemingly contextual value shows itself as a time constraint on more typical constitutive values of what makes a good scientific site, data source, or question. Phyllis Rooney (1992) further challenges Longino's categorization by arguing that the two categories are often so interlinked as to make it useless to distinguish them. Scientist time, then, refers to the temporal component of how scientists and other workers make decisions about research practices based on the values relevant to their particular situations.

Other notions of time, and thus the values that create them, interact with scientist, data, and phenomena times in formative ways for scientific practice and knowledge. Crucially, scientist time does not stand alone but rather is *negotiated* through ongoing interactions with the various people who make nuanced, expert decisions that define data time for fossil specimens, such as

1. Currie (2019) makes a similar claim that all kinds of knowledge rely on the history of their evidence, including how that evidence was produced, by whom, and in what context.

fossil preparators, conservators, and collection managers, as well as scientists who define phenomena time based on fossil data (Wylie 2019a). Analyzing these interactions calls attention to the values embedded in the production of fossil data by focusing on the values of the people who collectively transform fossils into data, as the foundation for knowledge claims about natural phenomena.

Next I analyze the data journeys of two fossil specimens to demonstrate how values form the foundation of conceptions of time, particularly scientist time as well as additional notions of time as experienced by institutions and specimens. The time-intensive process of preparing data in vertebrate paleontology is a powerful example of how these value-laden times influence each other as well as the times of data and knowledge. Understanding these interactions is key to understanding the people who do scientific work, how they do it, and the knowledge that they construct.

1 Why it matters to scientists *when* fossils are data

To illustrate the temporality of fossils' data journeys, let us follow an animal whose preparation as data was both quasi-experimental and performative. In this unusual case, a researcher timed his hypothesis and data preparation to convince his peers to support his way of thinking. Achieving social consensus is a key part of knowledge production and thus a key value that shapes scientist time.

Around 1800, deep in a gypsum quarry beneath the streets of Paris, a stoneworker unearthed a small, crumbling skeleton embedded in a rock slab. This creature found its way to the great fossilist Georges Cuvier (1769-1832), probably via a quarry worker whom Cuvier paid to notify him of any vertebrate fossils found in the quarry (Rudwick 2005, 409-410). Then Cuvier himself likely removed some of the overlying rock from this unfamiliar animal, especially to reveal its teeth as a distinguishing feature for mammals. Based on the teeth, he deemed it a marsupial. This was a controversial claim. It suggested that Paris had once been home to unthinkably strange animals like marsupials, which were then known only from specimens in Australia and North America. In particular, Cuvier argued that the specimen resembled extant American opossums, but that they weren't the same animal. (Note the use of what Currie [2024] calls "evolutionary profiles" as a strategy for scientists' comparative thinking across times, places, and organisms.) Cuvier proposed three striking knowledge claims based on this fossil:

1. opossums lived in Paris,
2. the methodological importance of comparing living and fossil animals, and
3. provocative ideas about extinction.

To investigate these claims, Cuvier invited several experts to watch him excavate the little skeleton's pelvis from its rocky tomb (Rudwick 2005, 409-410). He predicted that the as-yet-unseen pelvic bones would have the characteristic features of marsupials, which would confirm his identification and validate his approach of comparative anatomy between fossil and living creatures. His fellow fossilists gathered to witness Cuvier's painstaking chipping-away of rock, as well as his intentional destruction of a few of the animal's vertebrae that were blocking his view of the pelvis. This work did indeed reveal a marsupial's pelvis, thus achieving a victory both for Cuvier's theory about Paris' geological history and for his method of comparative anatomy.

This marsupial fossil already has three key temporal moments. The oldest is its life, which Cuvier dated as " 'thousands of ages' " ago (Rudwick 2005, 410) and which aligns with Leonelli's (2018) notion of phenomena time. The next (and very long) moment begins with the bones' mineralization into fossils and arguably ends with their excavation from the quarry and their identification as a scientifically interesting specimen around 1800; hence, Leonelli's (2018) data time. But how should we understand Cuvier's preparation of the pelvis for an audience? That is not a natural phenomenon, clearly (see Watkins 2024), nor is it a typical setting for slow, delicate fossil preparation. It could be considered an extension of data time, because it altered the physical data source as well as the data's epistemic meaning for contemporary fossilists. It wasn't even temporally far removed from the specimen's initial excavation, as it happened sometime between then and 1812 when Cuvier published about the Paris opossum.

However, the defining feature of the evidence Cuvier gleaned from this specimen was the *timing* of his visual access to the bones. The animal's anatomy itself was not the evidence in this case; rather, it was Cuvier's prediction of it without having seen the bones. The dramatic reveal that Cuvier performed for his expert audience, whom of course he expected to report on the results and serve as credible witnesses to their peers, was itself crucial evidence in support of Cuvier's method of comparative anatomy.[2] Cuvier's timing reflects a value for building credibility for himself and his method, by winning supporters through a somewhat outrageous hypothesis and a showy test of it. This approach also legitimized the fossil's data, heading off any possible claims of fraud, but I see this performance as more about Cuvier as a theorist and methodologist than about the opossum. What, then, can we learn from this kind of data-defining, knowledge-defining, reputation-defining moment as an example of scientist time? In brief: that there is more to science than data, phenomena, and the practices that make them. We must also follow the practitioners themselves, to understand how their values, norms, worldviews, and identities influence how they go about defining data and knowledge.

I propose extending Leonelli's (2018) insightful model to include these factors, specifically by adding a few components of how practitioners construct time so that we can better situate their value-driven decisions and actions with regards to data and phenomena. Crucially, we must understand the people who co-construct notions of time. Scientists work in a social system of collaborators, who have their own expertise, priorities, and constraints. For vertebrate paleontology, these crucial groups include fossil preparators, conservators, collection managers, and display designers. I have discussed elsewhere how these groups' perspectives and responsibilities shape their collective work as well as their notions of time (Wylie 2019a). Here I demonstrate several perceptions of time that are held by one or more of these groups of workers—i.e., scientist time, career time, specimen time, and institution time—and I consider how these temporal categories influence each other as well as inform data time and phenomena time.

2 How perceptions of time enable and constrain scientific practice and knowledge

I name these temporal categories not to claim they are all-inclusive, but rather to call attention to the values they represent and those values' influences on science. These features of what Steven Shapin (2008) calls "a scientific life" are deeply social, epistemic, and ethical; as such, they are the foundation of how scientists approach research questions, evidence, and knowledge claims. Leonelli (2018) argues that data time allows, informs, *and* constrains the study of phenomena time, because knowledge is tightly connected to the evidence that scientists draw on to inspire

2. Rudwick has documented Cuvier's preparation-as-experiment approach in another instance around the same time. In that case, Cuvier argued that a partially-prepared skeleton was actually a giant salamander rather than a human "witness of the Deluge" as an earlier naturalist had claimed (Rudwick 2005, 500-501). For an audience of experts, Cuvier removed rock around the animal to reveal its forelimbs and thus its anatomical similarities to extant salamanders (despite its comparatively enormous size).

and support it. I expand her model by considering how the times of career, specimen, institution, and scientist also influence times of data and phenomena.

All professional research workers are subject to *career time*, i.e., the expectations and norms of a scientific job, such as the time it takes to achieve particular kinds of training, accomplishments, and ethical research practices. The power dynamics of career stage and of marginalized identities such as race, gender, ability, and class crucially influence how individuals experience and are subjected to career time. For example, women and people of color are strongly underrepresented in vertebrate paleontology, particularly in the ranks of faculty and other professionals even as representation among students has been improving (Berta and Turner 2020, ch. 7; Plotnick 2022, ch. 12). These trends, which are common across many sciences, show that there are systemic barriers to the success of scientists from marginalized groups in research careers. Factors that Berta and Turner (2020, ch. 7) document for women vertebrate paleontologists also apply to scientists from other marginalized groups, namely implicit bias, harassment, widespread inequity in pay, challenges to finding research jobs for dual-career families, conflicts between timelines of research career expectations and parenting, inadequate mentoring, and impostor syndrome. Research workers in general tend to experience career time as rushed and therefore stressful, such as from the precarity of temporary and even unpaid jobs, the pressure to achieve within short time frames (e.g., for scientists to earn grants and write papers before their job contract ends, for preparators and conservators to make specimens useful in time for scientists' publish-or-perish schedules, etc.). These pressures are stronger for scientists from marginalized groups, particularly in disciplines with long histories of reliance on colonialism, racism, and resource extraction such as vertebrate paleontology (Monarrez et al. 2022).

Other notions of time relate to scientific objects, such as conservators' commitment to *specimen time* as the long-term view of a specimen's lifespan as useful data. Conservators specifically strive to minimize physical degradation to each specimen over decades and even centuries in an institution's collection. This goal can conflict with scientists' career pressure to publish about specimens, grants' short-term outcomes, and institutions' budgetary constraints.[3] Research institutions also follow their own *institution time*, which focuses on accomplishing their many goals alongside research. For example, most vertebrate paleontology happens in museums and universities, which respectively serve the public through displays of scientific objects and knowledge, and students through coursework. Scientists must contribute to these goals, which can limit their time and resources for research. Of course, those institutions also make scientists' research possible by funding them as employees, within the constraints and allowances of career time. Hence the interconnected nature of various conceptions and perceptions of time (fig. 1).

This explanation is certainly not all-encompassing. Instead, I intend to raise questions of how notions of time—and the values they represent—influence each other and knowledge. Similarly, these times are not mutually exclusive. For instance, specimen time and data time have much in common in terms of the labor of processing nature into researchable forms, but they also represent distinct moments in which people understand a particular object as data, i.e., as evidence for a knowledge claim as per Leonelli (2015, 2018), or as a specimen, i.e., as a potential source of evidence.

I focus here on scientist time because I think it is the least understood notion of time, and thus the one most often omitted from analyses of knowledge. Yet it plays a crucial role in bringing together the various other forms of time to produce data, knowledge, a scientific community, and a society that relies on science as a form of knowledge production. Scientist time is both an individual and systemic concept, which means we must keep it in mind to understand particular

3. Currie (2018, ch. 12) discusses funding for vertebrate paleontology, and particularly fieldwork, in a way that demonstrates the diverse values that shape funding decisions and project design, and thereby inform scientist time.

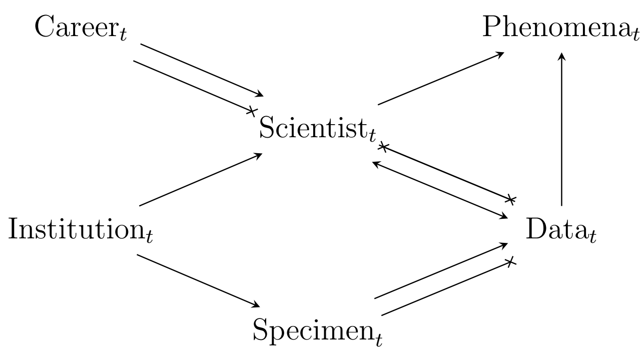

Figure 1: How various notions of time (t) interact. I simplify these relationships by focusing on whether they enable (shown by an arrow) and/or constrain (shown by an x) each other. I intend for this normative dichotomy to capture scientists' overall priority of producing knowledge about natural phenomena. This is not a comprehensive portrayal of these relationships, but rather a starting point for thinking through temporal influences on scientists and knowledge. (figure by Joe Johnson)

specimens and knowledge claims as well as across histories of disciplines.[4] Understanding the interactions between these various conceptions of time helps us better understand the data and the knowledge of natural phenomena that scientists and other workers produce under the influence of these value-laden conceptions of time. Let's follow the data journey of a more recently studied specimen to illustrate interactions among these times.

3 A horse's tale: how time matters for scientists, data, and knowledge

On the grassy plains of what would become Utah in the United States, a small four-legged, long-snouted mammal grazed beside meandering streams. Perhaps 45 million years later, in 1938, a human picked up this animal's fossilized skull, lower jaw, and fragments of its limbs. By 1955, someone had filed these bones in a museum collection, someone had removed the rock from them, and paleontologist Charles Gazin had studied the skeleton in enough depth to name it as the type specimen (i.e., the defining individual) of a new genus and species, *Mytonomeryx scotti* (Gazin 1955). Despite gaps in our knowledge of this specimen's data journey, its *data time* includes its collection, preparation, and cataloguing in a fossil collection. This time includes the specimen's removal from its geographic location and geological context, as well as its labeling as an object worthy of collection, storage, and study (i.e., as potential data) and as a particular kind of animal (i.e., *M. scotti* and its relations to other animals, including living horses). A scientist declared the *phenomena time* for this creature's life as the upper Eocene (Gazin 1955). The little ungulate's *specimen time* began when someone placed it in a cardboard box, labeled and shelved in a collection cabinet's drawer, where it bounced around against itself and its box until 2011. During this undocumented expanse of time, the edges of the bones shattered into ever smaller fragments, which occasionally someone repaired—more or less skillfully—with glue. This cycle of damage and repair mark important events in specimen time for *M. scotti*, as well as in its data time because these physical changes to the specimen influence the kinds of claims for which this object can serve as evidence.

In 2011, a scientist planning to study the deteriorating specimen brought its fragment-filled

4. This point is demonstrated by Erwin's study (2024) of individuals' influences on the kinds of questions paleontologists have asked.

box to the collection's fossil preparator to ask if it could be reassembled. (For more on this specimen's reconstruction, see Wylie 2021, ch. 1). The preparator undertook the project to reattach as many fragments as possible, in part to make the fossil more complete and in part to prevent continuing loss of its edges as well as the contextual information about where those fragments belonged on the skull, jaw, and limbs. He had to balance these values of specimen preservation and protection with values of work efficiency and time management. While this expert preparator was working on this project, I was observing him and his colleagues in an ethnographic study of how fossil preparators contribute to knowledge (Wylie 2021). I tried, unskillfully, to help him identify where the fragments' broken edges might match broken edges on the skull. When the preparator felt frustrated with our lack of progress (and perhaps waste of time), he visited the institution's library to look up the original specimen description (Gazin 1955). The preparator was hoping that the description and its associated photographs would inform how he should glue on the various pieces, particularly around the fragile eye sockets. This is a powerful example of the importance of legacy data, i.e., previously collected data that are analyzed for a new purpose (Wylie 2017, Currie 2021). In this case, these published data helped the preparator make arguably more accurate matches than his own guesses and saved him the time of puzzling out each piece anew, thereby serving his scientist-time values of preservation and efficiency.

The preparator drew from his knowledge of vertebrate anatomy, his judgment of which previously glued bone edges might fit together, and ideas from Gazin's publication to glue several fragments onto the skull. He deemed his work finished when the remaining pieces were too fragmentary or mysterious to justify spending time figuring out where they might belong. At that point, the skull's eye sockets generally matched the form they had in Gazin's photos. A new feature was a canine tooth protruding down from the animal's upper jaw. This tooth is not in the 1955 photos or text descriptions, but it had a glued edge on its broken shaft that matched a glued edge on the jaw. The preparator trusted whoever had previously attached that canine, most likely a fellow fossil preparator sometime in the preceding decades.

As a result of these decisions by the preparator, as well as his many decisions along the way of which fragments to adhere and where, the skull was arguably more complete in 2011 than it had been in 1955. This completeness makes the specimen more informative for scientists. It also means that the skull looks different from its 1955 description, the official definition as the type specimen of its genus and species. This reconstruction work, then, is a crucial moment in the specimen's *data time*, in that the preparator's reconstruction work potentially changes how scientists interpret the specimen as evidence. The preparator made decisions based on his intention to improve the quality of data that a specimen can provide for a knowledge claim.

Another value guiding the preparator's work was protecting the specimen from future damage (and thus data loss) by uniting many of its broken pieces. This value makes this reconstruction work also an example of *specimen time*. Furthermore, the preparator also protected the specimen by creating a custom plaster base molded to fit the skull, thereby holding it in one place and preventing it from banging into the sides of its storage box when someone opens its drawer. Thus, the preparator cared for the specimen's current and future evidential value by caring for its current and future physical condition. He also tried to use his time wisely by leaving some unidentifiable fragments loose in the specimen box, perhaps for a future preparator to try their hand at.

These judgments and actions by various people throughout the specimen's data journey reflect how various forms of time influence one particular piece of potential evidence. For example, *institution time* balances specimen care with knowledge production by dividing labor (e.g., preparators vs. scientists) and resources to allocate to each. These decisions make research possible in the long term by prioritizing *specimen time*, such as by making specimens accessible and protected. They also slow down research in the short term, such as by making *M. scotti*'s skull unavailable to scientists—including the one who reported its damage—while the preparator worked to repair and protect it. This can be stressful for scientists who are subject to *career time*, such as time pressure to transform specimens into data that inform knowledge about natural phenomena. *Scientist time* is thus both enabled and constrained by *institution* and *specimen times*. Documenting *data time* can help scientists (and philosophers of science) better understand the relations between the social and ethical values that "constitute" the other dimensions of time, in Longino's (1983) and Rooney's (1992) conception.

4 The long lives and times of specimens

The case studies of Cuvier's predictive public possum preparation and the preparator's repair of *M. scotti* illustrate what I mean by these categories of time. They demonstrate why I argue that these temporal categories are essential for understanding data, knowledge, and the social and epistemic processes of producing both by including more aspects of practitioners' priorities in our models of scientific practice. There are also other reasons why it matters to scientists *when* fossils are data. For example, there are vast numbers of vertebrate fossils that sit unprepared in collections, waiting for workers to make them available and legible for study through, for example, fossil preparation, collection management, conservation, and curation of metadata. Vertebrate fossil preparation is time-intensive, extremely skillful, and carries critical implications for the usefulness of prepared specimens as potential data; hence this backlog of specimens-in-waiting amidst the typical cash-strapped budgets of museums and universities. This situation is why scientists occasionally make spectacular fossil "discoveries" in dusty specimen cabinets. The time must be right for a specimen to be accessible, i.e., thanks to processes that occur during *data time*, *specimen time*, and *institution time,* to someone with particular knowledge. Then that someone must mobilize data from the specimen as evidence for a knowledge claim, based on Leonelli's (2015) relational view of data. To become knowledge, that claim must be worthy of other scientists' attention (*scientist time*), such as for being new, surprising, or otherwise publishable.

Times show the ways that contextual values constitute practices necessary for most sciences, in that any kind of data must be properly "prepared" in whatever sense that takes for various kinds of specimens as well as for data derived from experiments and observations (Wylie 2021). Examples include the critical importance of data curation to make it possible for scientists to reuse research data shared in open-access databases (Levin and Leonelli 2017), and standardized ways of documenting experimental and observational methods and results, such as the use of what Latour (1985) calls transcription devices to create trustworthy data sources from measurements of experimental results. Preparing evidence generally involves transforming specific, local observations into data that can be compared across places and times.[5]

Another key factor that makes notions of time matter for making sense of vertebrate fossils in particular is the permanence or irreversibility of fossil preparation techniques. Unlike reorganizing a genetic dataset or repeating an experiment, removing rock from a specimen cannot be undone. This can be interpreted as destructive, if you consider the data that can sometimes be gleaned from sediment that surrounds fossilized bone, such as impressions of feathers or skin,

5. For example, consider how scientists transform soil samples into data tables (Latour 1999), and how scientists capture geological landscapes and natural history specimens as maps and drawings that other scientists can interpret thanks to discipline-specific conventions (Rudwick 1976, 2000).

fossilized pollen grains, and geological features.[6] However, scientists—and thus preparators—have long prioritized visual and physical access to bone surfaces over preservation of surrounding rock. One example of this "bone bias" is acid preparation, in which preparators soak fossils in weakly acidic solutions over several weeks to dissolve away certain kinds of rock. This approach reveals minute details and is particularly popular for exposing the many tiny bones of fish fossils, but it also weakens exposed bones and can actually eat through them if a specimen is left too long in the acid. All techniques for making fossils visible rely on the skill and judgment of individual practitioners, who do not share common training or use standardized techniques or materials.[7] This diversity of skill and practices is evident in prepared fossils themselves, whose physical stability and appearance reveal their preparators' levels of expertise even though those preparators and their work are rarely documented in specimen records or research publications (Wylie 2021, ch. 4).

Typical methods of strengthening and repairing fossils can also have irreversible effects. For example, cyanoacrylate is an adhesive that bonds materials together instantly through a chemical reaction. This means a preparator's decision about where bone fragments belong in a specimen is final and cannot be altered. The use of cyanoacrylate also alters a fossil's geochemical makeup, making some analyses useless (e.g., carbon dating for more recent fossils). There are other adhesives that practitioners consider "reversible" (i.e., removable, impermanent) because they can be dissolved out of a fossil with a solvent. However, they are weaker and take longer to set than cyanoacrylate. Preparators fiercely argue about the merits and harms of these materials, and particularly their own right to choose between them as appropriate for the physical and scientific situation of each individual fossil (Wylie 2021, ch. 1). In terms of scientist time, these everyday decisions about glue contend with the crucial values of shorter-term data access and longer-term specimen preservation.

How these techniques impact the physical integrity and thus the epistemic credibility of vertebrate fossils is a key component of data time, specimen time, and institution time, and thus of career time and scientist time and, finally, of phenomena time. Crucially, institutions store vertebrate fossil specimens indefinitely. As we saw in the case of the horse skull, specimens undergo ongoing physical changes, both from passive degradation and from well-intentioned attempts to preserve them (conservation) and make them accessible for study (preparation). So to understand fossil-based knowledge claims about phenomena, it is crucial to know *when* scientists studied particular fossils. The data they interpreted from those fossils dates to a specific moment in each fossil's life as a specimen, based on what happened to it beforehand and what may happen to it afterwards. For *M. scotti*, for example, Gazin did not write about its long thin canine tooth in his 1955 description because it was not attached to the skull, although it was assumedly in the box with the rest of the skeleton. But a scientist who studies it after the 2011 reconstruction work would of course document the tooth and perhaps offer interpretations for

6. Some methods of accessing fossil data are particularly destructive, such as slicing specimens very thinly to reveal their interior structures (known as serial sectioning). In the similar approach of serial grinding, a thin layer of a specimen is polished off and then the revealed surface is captured by a wax impression, photograph, or drawing. Then that surface is ground away to reveal the next cross-sectional view. These approaches are rarely used for vertebrate fossils now because they reduce a specimen to a stack of fragile slices or a pile of dust, but they were long used as the sole way to see inside fossil skulls and eggshells, for example. CT scanning has replaced this technique for some fossils by creating non-invasive digital "slices" of x-ray views through specimens that can then be manipulated on-screen (Wylie 2018, 2021 ch. 3). Prioritizing long-term specimen preservation over short-term data access is an example of how these sometimes conflicting values constitute practitioners' methodological choices.

7. I argue elsewhere that the need for this skill is evidence that fossil specimens are underdetermined by their surrounding rock (Wylie 2019b).

what it tells us about that animal's behavior, ancestry, and role in evolutionary relationships. So to understand knowledge claims made at different stages of specimen time (i.e., a specimen's data journey), scientists and philosophers must know that time and what it entailed—including how it relates to scientist time experienced by the *people* involved—to be able to understand its implications for that fossil as a source of data and knowledge.

5 Discussion: the times of science

Considering how scientists and other research practitioners experience time enriches how philosophers understand scientific practice and, crucially, the data and knowledge that it produces. It is easy to think of data as standing alone or speaking for themselves, and in some ways scientific norms promote this idea, such as through passive-voice writing in research publications, the absence of non-scientist workers in publications and institutional records, and simplified published descriptions of methodologies that no one can reproduce without the tacit knowledge of how to actually perform them. Yet acknowledging the journeys, histories, and lives of data gives us more nuanced, accurate, and interesting perspectives on the knowledge claims that those data support. It also provides a key window into the journeys, histories, values, and identities of the people who do this work. We—as philosophers, social scientists, and general audiences for scientific knowledge—must understand the practitioners to understand their work and the knowledge they produce.

To better center practitioners, I proposed a model that goes beyond Leonelli's concepts of data time and phenomena time to define other temporal factors that influence decisions about data and knowledge, specifically career timelines, institutional priorities, specimen care, and scientists' experiences and identities (fig. 1). These factors (and the values embedded in them) are all interconnected and interdependent, among each other and with data time and phenomena time. Their detailed implications for each other and for data and knowledge deserve further study. I hope this model provides a useful framework for philosophers, scientists, and others to analyze the temporal structures of various sciences, and to pose normative questions about which times and values are better for scientists, scientific practice, and knowledge.

For vertebrate paleontology, I hope this model expands philosophers' and practitioners' attention beyond studying "deep time" to also focus on the people who make it possible for the rest of us to imagine past creatures and their worlds.[8] Recognizing the influences of specimens, careers, and institutions on the practices and thought processes of research workers empowers them to be more intentional about what they prioritize. For example, perhaps elevating the realities of discrimination against scientists from marginalized groups would inspire strategies to better support these scientists by improving their career stability and their access to specimens and data. Similarly, embracing the importance of specimen conservation for knowledge production could perhaps challenge the short time frames expected for funded research projects and career publication trajectories, thereby protecting specimens from rushed care and helping scientists realize their work's dependence on conservators and preparators. These changes would lessen power inequities between scientists and non-scientists and encourage more documentation of specimens' data journeys, both of which would in turn improve the quality of data that fossil specimens can yield.

A more comprehensive view of how conceptions of time influence scientific lives, practices, and knowledge can enrich philosophers' and social scientists' analyses of science, inform practitioners' decisions and priorities about how they do their work, and encourage more transparent

8. Historians of paleontology already do this well (e.g., Rudwick 2005, Sepkoski 2012, Rieppel 2019, Manias 2023).

access to how knowledge is made for other groups, such as people who admire vertebrate fossils in museums. We can only know about "deep time" and other natural phenomena, after all, if we first know our own times as scientists and knowers.

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Literature cited

Berta, Annalisa, and Susan Turner. 2020. *Rebels, Scholars, Explorers: Women in Vertebrate Paleontology*. Baltimore: Johns Hopkins University Press.

Currie, Adrian. 2018. *Rock, Bone, and Ruin: An Optimist's Guide to the Historical Sciences*. Cambridge, MA: MIT Press.

———. 2019. *Scientific Knowledge and the Deep Past: History Matters*. Cambridge: Cambridge University Press.

———. 2021. "Stepping Forwards by Looking Back: Underdetermination, Epistemic Scarcity and Legacy Data." *Perspectives on Science* 29 (1): 104–32. https://doi.org/10.1162/posc_a_00362.

———. 2024. "Fossils, Modality, & Central Subjects in Palaeobiological Reconstruction." *Philosophy, Theory, and Practice in Biology* 16 (2): 6.

Erwin, Douglas. 2024. "Quo Vadis, Paleontology?" *Philosopphy, Theory, and Practice in Biology* 16 (2): 7.

Gazin, Charles Lewis. 1955. "A Review of the Upper Eocene Artiodactyla of North America." *Smithsonian Miscellaneous Collections* 128 (8).

Latour, Bruno. 1999. "Circulating Reference: Sampling the Soil in the Amazon Forest." In *Pandora's Hope: Essays on the Reality of Science Studies*, edited by Bruno Latour, 24–79. London: Harvard University Press.

Latour, Bruno, and Steve Woolgar. 1986. *Laboratory Life: The Construction of Scientific Facts*. Princeton, NJ: Princeton University Press.

Leonelli, Sabina. 2015. "What Counts as Scientific Data? A Relational Framework." *Philosophy of Science* 82 (5): 810–21. https://doi.org/10.1086/684083.

———. 2018. "The Time of Data: Time-Scales of Data Use in the Life Sciences." *Philosophy of Science* 85: 741–54. https://doi.org/10.1086/699699.

Leonelli, Sabina, and Niccolò Tempini, eds. 2020. *Data Journeys in the Sciences*. Cham: Springer. https://doi.org/10.1007/978-3-030-37177-7.

Levin, Nadine, and Sabina Leonelli. 2017. "How Does One 'Open' Science? Questions of Value in Biological Research." *Science Technology and Human Values* 42 (2): 280–305. https://doi.org/10.1177/0162243916672071.

Longino, Helen. 1983. "Beyond 'Bad Science': Skeptical Reflections on the Value-Freedom of Scientific Inquiry." *Science, Technology, & Human Values* 8 (1): 7–17. https://doi.org/10.1177/016224398300800103.

Manias, Chris. 2023. *The Age of Mammals: Nature, Development & Paleontology in the Long Nineteenth Century*. Pittsburgh, PA: University of Pittsburgh Press.

Monarrez, Pedro M., Joshua B. Zimmt, Annaka M. Clement, William Gearty, John J. Jacisin, Kelsey M. Jenkins, Kristopher M. Kusnerik, et al. 2022. "Our Past Creates Our Present: A Brief Overview of Racism and Colonialism in Western Paleontology." *Paleobiology* 48 (2): 173–85. https://doi.org/10.1017/pab.2021.28.

Plotnick, Roy. 2022. *Explorers of Deep Time: Paleontologists and the History of Life*. New York: Columbia University Press.

Rieppel, Lukas. 2019. *Assembling the Dinosaur: Fossil Hunters, Tycoons, and the Making of a Spectacle*. Cambridge, MA: Harvard University Press.

Rooney, Phyllis. 1992. "On Values in Science: Is the Epistemic/Non-Epistemic Distinction Useful?" *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association* 1992 (1): 13–22. https://doi.org/10.1086/psaprocbienmeetp.1992.1.192740.

Rudwick, Martin J. S. 1976. "The Emergence of a Visual Language for Geological Science 1760–1840." *History of Science* 14 (3): 149–95.

———. 2000. "Georges Cuvier's Paper Museum of Fossil Bones." *Archives of Natural History* 27 (1): 51–68.

———. 2005. *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution*. Chicago: University of Chicago Press.

Sepkoski, David. 2012. *Rereading the Fossil Record: The Growth of Paleobiology as an Evolutionary Discipline*. Chicago: University of Chicago Press.

Shapin, Steven. 2008. *The Scientific Life*. Chicago: University of Chicago Press.

Watkins, Aja. 2024. "When Are Fossils Data?" *Philosophy, Theory, and Practice in Biology* 16 (2): 9.

Wylie, Alison. 2017. "How Archaeological Evidence Bites Back: Strategies for Putting Old Data to Work in New Ways." *Science, Technology, and Human Values* 42 (2): 203–25. https://doi.org/10.1177/0162243916671200.

Wylie, Caitlin D. 2018. "Trust in Technicians in Paleontology Laboratories." *Science, Technology, and Human Values* 43 (2): 324–48. https://doi.org/10.1177/0162243917722844.

Wylie, Caitlin D. 2019a. "The Plurality of Assumptions about Fossils and Time." *History and Philosophy of the Life Sciences* 41 (21): 1-21.

Wylie, Caitlin D. 2019b. "Overcoming the Underdetermination of Specimens." *Biology and Philosophy* 34 (2). https://doi.org/10.1007/s10539-019-9674-2.

Wylie, Caitlin D. 2021. *Preparing Dinosaurs: The Work behind the Scenes*. Cambridge, MA: MIT Press.

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