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Trust in Technicians in Paleontology Laboratories

Caitlin D. Wylie (wylie@virginia.edu)

Abstract

New technologies can upset scientific workplaces' established practices and social order. Digital imaging of rock-encased fossils is a valuable way for scientists to "see" a specimen without traditional rock removal. However, interviews in vertebrate paleontology laboratories reveal workers' skepticism towards computed tomography (CT) imaging. Scientists criticize replacing physical fossils with digital images because, they say, images are more subjective than the "real thing." I argue that these scientists are also implicitly supporting rock-removal technicians, who are skilled and trusted experts whose work would be made obsolete by widespread implementation of CT scanning. Scientists' view of CT as a sometimes-useful tool rather than a universal new approach to accessing fossils preserves the laboratory community's social structure. Specifically, by privileging "real" specimens and trusted specimen-processing technicians over images and imaging experts, scientists preserve the lab community's division of labor and skill, hierarchy between scientists and technicians, and these groups' identity and mutual trust. Scientific workers may therefore prefer preserving skilled manual work and the social status quo to revolutionary technological change.

In 2000, a paper in *Science* announced an unprecedented discovery: a dinosaur's fossilized heart (Fisher et al. 2000). A team of experts on imaging technologies and paleontology used "computerized tomography" (CT) to make cross-sectional density measurements through the dinosaur. Then they digitally processed these measurements into three-dimensional onscreen images, which "resemble a four-chambered heart" (Fisher et al. 2000, 504) (figure 1). This interpretation makes dinosaurs more similar to birds and mammals than reptiles in metabolism and phylogeny. However, ten months later, two fossil researchers and a geologist challenged this claim. Their paper, titled "Dinosaur with a Heart of Stone," argued that it is geologically unlikely for soft tissue to fossilize in this specimen's locale and that the CT images show few anatomical features of a heart (Rowe et al. 2001). The authors did not criticize CT as a research method. In a response published on the same page, Fisher and colleagues refuted these claims and defended the concretion as a preserved heart (Russell et al. 2001). This case exemplifies fossil researchers' belief that CT can offer useful but epistemically problematic views of specimens. In general images can seem self-evident and inherently convincing, especially those made with impressive high-tech machines. Interpreting images, however, requires expertise about the pictured object to judge what the images actually show.

In this paper, I investigate how digital imaging affects the knowledge-making practices and social roles of a research community that has long relied on direct visual observation of physical specimens. I interviewed researchers, technicians, and other workers in several vertebrate paleontology laboratories in universities and museums in the US, UK, and Germany in 2009-2013. In semi-structured qualitative interviews, I asked workers about their lab practices, training, workplace hierarchy, and roles in research, knowledge making, and specimen display. CT was not included in my interview questions, but interviewees mentioned it and, following grounded theory, I added it to my question list. I assumed that people who work with fossils would be impressed by CT, with its interactive onscreen 3D models of fossils that are buried in rock. But, to my surprise, practitioners express skepticism about CT. They prefer working directly with fossils, not with digital tracings of them alone. This preference makes sense for researchers with a long history of physical interaction with specimens and, accordingly, with technicians who skillfully remove rock to make those specimens visible. These researchers value data that are handmade by people they know.

The construction of CT data, digital images, and physical specimens is intricately tied to the construction of social roles. I argue that the link between the production of data and social order is *trust*. Specifically, trust in data-making workers enables trust in data. Trust in machines alone is not enough to inspire trust in machine-made data. In general, users' excitement at previously inaccessible information can result in celebration of the technologies that provide that information. This can also encourage the assumption that new technologies are always better. This case challenges these beliefs by crediting social relationships over technology as the foundation for the production of reliable data.

Innovation as a threat to social equilibrium

This case could be a story of the automation of technical work. The sole way to access rock-covered fossils has been to chip off the surrounding rock, a process known as fossil preparation. Since the early twentieth century, technicians called fossil preparators have done this specimen-revealing work (Brinkman 2010), based on no shared training, credentials, or protocols. Preparators learn skills on-the-job and adapt and design techniques in response to local, situated goals. CT, however, offers researchers the possibility of viewing a fossil *inside* rock. Skipping preparators' rock-removal process—with its time-consuming nature, dependence on individual skill, and risk of damaging the specimen—seems like an improvement. Braverman's (1974) classic theory of deskilling—capitalism's drive to replace human skill with mechanical automation—could apply here. Braverman suggests that capitalism distrusts workers (for their propensities for inefficiency and revolution) and promotes trust in machines instead, as cost-saving devices. The workers who prepare fossils have very different skills from the workers who make and analyze CT scans. In the theoretical outcome of CT use replacing fossil preparation, fossil preparators would be deskilled because scientists would no longer value their expertise. In many cases, after all, changing technologies and techniques requires changing technicians.

Changing work practices, such as through deskilling, shifts a community's established divisions of labor, group identities, and hierarchies. These systems of social order are underlain by trust, which is a foundation of all social relationships (Shapin 1994, chap. 1; 1995). In scientific communities, trust is required for credible knowledge making (Lynch et al. 2008; Porter 1995). In medical imaging, hierarchy developed between image-makers (technologists) and image-interpreters (doctors), despite their work's interdependence (Barley 1986; Rystedt et al. 2011; Saunders 2008). Similarly, groups who work with fossils perceive their skills and tasks as distinct from each other's. They vary in training, from graduate degrees for researchers, conservators, and often collection managers, to preparators' on-the-job learning. Researchers have the highest institutional status and salaries, but each group has practical control over their claimed area of expertise, i.e., the researcher's publications, the preparator's rock removal and fossil repair work, the collection manager's database, the conservator's specimen protection projects. Abbott (1988) argues that groups define their area of expertise by competing for "jurisdiction" or control over certain tasks. The groups who work with fossils have carved out separate jurisdictions, even though their work is interdependent. If researchers were to favor CT data over prepared fossils as objects of study, then conservators and collection managers would shift to preserving and organizing digital images. In comparison, learning how to run CT scanners or process data into images is too different from preparators' current work for them to join that field without a significant investment in re-skilling through training.

Therefore, using CT images instead of specimens would upset the balance of jurisdictions within the fossil laboratory, requiring a new social order. Negotiating new systems of jurisdiction, hierarchy, and trust takes time and effort. Upholding the current, functional social order would benefit the community by preserving its successful "social equilibrium" (Durkheim 2006). In addition, CT scanning cannot image all fossils.

These are high social and epistemic costs for replacing preparation with CT. As a result, researchers prefer to study CT images alongside prepared fossils, as an additional view rather than the only view. They distrust this convenient-seeming digital view in favor of the risky and time-intensive work of chiseling out specimens in part because studying the "real thing" (i.e., physical specimens) rewards their existing skills and, accordingly, supports their expertise-based social status quo. They see no threat to preparators' jobs or their labs' social order from CT, because they believe digital and physical fossils should coexist. In cases when only digital fossils (i.e., onscreen images made from CT data) are available, they are an acceptable but somewhat suspect proxy. Agar's (2006, 873) three models of how computerization affects science suggest that, if fossil researchers adopt computer-produced data (e.g., CT images), computerization will either 1) imitate and assimilate into current techniques and social structures, 2) reorganize but coexist with previous sociotechnical practices, or 3) create a truly new way of studying fossils and therefore a new organization of scientific work. Fossil lab communities' views on CT share aspects of all three models, perhaps because Agar (2006, 870) found that computerization only occurs in science after work practices have been routinized. Preparators' diverse and flexible methods of preparing fossils, in contrast, may inspire skepticism to potential computerization.

This then is an illustrative example of 21st-century skepticism of technology in favor of skilled manual work. Considering practitioners' explicit and tacit reasons for rejecting the complete replacement of physical specimens with digital images—and therefore the replacement of fossil preparators with imaging specialists—sheds light on crucial questions of how practitioners build skills, social order, and trust around different ways of representing nature. To investigate these questions, first I contextualize CT images in theories of visual and material culture. The second section examines how researchers and preparators perceive the role of CT in their work. Next, practitioners' opinions on whether CT images can and should replace fossils as research subjects reveal how these workers want to work. They justify their insistence that CT images should not replace specimens—or, by association, preparators—with claims that the "real thing" is somehow different from images and should be the primary data source. Finally I analyze how this case reshapes notions of objectivity and skillful judgment with regards to data processing. Overall, I suggest that the benefits of conserving skills and community structures—which are built on trust—can explain why a community might prefer the coexistence of old and new techniques over replacement, with its accompanying processes of deskilling and social instability.

Seeing through rock

Communities' reactions to new technologies often reveal tacit practices and beliefs, because practitioners articulate what is exciting, questionable, or threatening about a proposed change in method and therefore in social organization. CT is a recent solution to an old problem: how to study a specimen encased in rock. One fossil researcher told me, "Before modern times with CT scanning and things like that, you couldn't do anything with a vertebrate fossil until it's out of the rock." The typical approach is to remove that rock, using hand tools (e.g., dental picks, chisels, handheld jackhammers). Thin-sectioning and serial grinding are "an early form of CT," as one preparator put it, because they create cross-sectional views through objects. Agar (2006, 873) argues that computerization can follow the same social and technical organization of previous scientific work. This preparator reverses the typical pattern of likening computerized to manual methods by comparing "early" techniques to an up-and-coming computerized technique, but still suggests a continuation rather than a revolutionary break in practices.

Besides their similarities, there are important differences between CT and sectioning and grinding. Crucially, the latter methods destroy a fossil by reducing it to slices in thin-sectioning, often each embedded in resin to hold it together, and photographs in serial grinding.[1] In comparison, CT scanning "sections" specimens noninvasively, by sending x-rays through a specimen and recapturing them to measure the specimen's density. Then the x-ray source and the recapture sensors rotate to release and recapture x-rays from a new angle, eventually rotating 360 degrees. Each of these angles produces a cross-section—a "slice"—of density readings through the object. A fossil researcher or imaging technologist then uses software to compute the density measurements into images. These images are of two kinds: each individual slice and a compilation of slices into a three-dimensional digital model of the whole object. Users can adapt the images to distinguish between densities and even remove certain densities (e.g., to show only fossils and not rock) (figure 2). However, CT cannot image all fossils: it requires distinct densities between fossil and rock, x-rays can't penetrate all rock types (such as ones containing metals), and high-resolution micro-CT scanners can only fit small specimens (though industrial scanners can be large enough to scan even *T. rex* skulls [Brochu 2000]). Researchers access CT scanners at their own university or museum, or they pay for scanner time at other institutions, or some hospitals donate scanner time.

In addition to technical limitations, CT measurements and compiled images require fossil researchers to learn new ways of understanding, analyzing, and manipulating data. CT data and images can function as "proxies" by standing in for specimens (Hineline 1993 cited in Rudwick 2000, 57), in part because they can be manipulated and shared electronically, unlike physical fossils. Fossils, though, can be physically rotated, prepared, and transported too, suggesting that CT images are often used in comparable ways as fossils. Likewise, naturalist Georges Cuvier's solution to the problem of rare and geographically dispersed fossils in the 18th and 19th centuries was to accumulate "paper fossils"—specimen drawings—to complement the Museum d'Histoire Naturelle's collection of physical fossils (Rudwick 2000).

Cuvier's situation of geographically inaccessible specimens is similar to that of particle physicists, astronomers, molecular biologists, doctors, and other researchers who rely on imaging technologies to provide visual access to their subatomic, light-years-distant, microscopic, or internal research objects. Turner (2007) argues that dinosaurs are inaccessible and unobservable because they are extinct; in comparison, fossils exist in our historical epoch and therefore can be accessible and observable, depending on their location and state of preparation. CT images can reveal physically

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[1] In serial grinding, a technician grinds off a millimeter of the specimen, photographs the exposed surface, and then grinds away another millimeter.

inaccessible fossils, such as views inside eggshells (e.g., Balanoff et al. 2008) (figure 2) and skulls (e.g., Brochu 2000) (figure 3) and views of fossils hidden in rock (e.g., Fernandez et al. 2013) (figure 4). In 1990, a team of paleoanthropologists framed CT as a solution to "a catch-22 situation—a beautifully preserved, but unapproachable, endocast" of a brain inside a fossil skull (Conroy et al. 1990, 838-9). The authors lamented that the natural brain cast couldn't be reached or studied without destroying the skull. So they used CT, introduced to fossil studies in the 1980s (Kevles 1997, 159), to make damage-free braincase images. Researchers also use CT to generate high-resolution images of a prepared fossil's exterior that can be rotated, experimented upon, shared, and 3D-printed. But this information is visible to the naked eye, without CT. Instead, I'll focus on cases in which a CT image *is* the specimen; i.e., there is no comparable view with which a researcher can validate the image. Physical and digital preparation do not coexist in these situations, which somewhat invokes Agar's third model of computerized work that "would be impossible to accomplish by manual or mechanical means" (2006, 873). Although a fossil could be physically sliced or ground to show its interior, lab workers rarely perform this technique because it's destructive. It's not physically "impossible" to prepare that specimen, but it is socially rejected in most cases. Agar (2006, 873) describes this process as "hypothetical" and believes it may never occur; this case may offer a way to understand this model of the replacement of manual work practices by new, discontinuous computerized methods.

"Incredible" images

How then are digital fossils, only visible onscreen, legitimated as reliable information about an organism? Like all data, images derived from CT scans require community acceptance and trust, as well as a shared method of making, interpreting, understanding, and publishing the images (e.g., Coopmans et al. 2014; Frow 2012; Lynch and Edgerton 1990; Lynch 1991). Fossil researchers' and preparators' descriptions of CT express amazement at its images inside rock and skepticism about its widespread utility. They share doctors' and patients' views of the "magic" of imaging techniques (Joyce 2008, 149-50; Saunders 2008, 175), as evident in researcher Wayne's wonder at CT images of both fossil and extant specimens:

> We've got this tomography business that allows us to reconstruct a skeleton without ever taking it out of the rock… They can take an animal with all its flesh and fur and scales and whatever and they can just take its skeleton right out. And then they can roll it around, they can turn it in any direction. They can make a model of any of the elements out of plastic. They can enlarge it, they can reduce it to any size you want. They can duplicate one side to the other, and it's just incredible.

Wayne's admiring description of CT focuses on its ability to allow users to digitally expose, manipulate, and reconstruct unprepared specimens. For him, CT enables actions that can't be done directly to specimens, such as changes in size. But preparators can build different-sized replicas of fossils out of plaster, though this process is not as exact or quick as CT analysis. Nonetheless, Wayne's concept of an "incredible" technology captures CT's rich data as well as the mystery of "that tomography business" to its users in paleontology as well as medicine. Radiologists, patients, fossil researchers, and preparators rarely discuss or even know the details of CT technology (Joyce 2008). They assume that information is the realm of physicists, material scientists, and imaging technologists—groups Wayne refers to vaguely as "they"—and thus they are generally uninterested.

The typical cause of researchers' "wonder" is CT's otherwise impossible views, which preparators also admire. Preparator Mary explained, "The things you see in the scan are the things you can't really get to with preparation. You're limited to where the [preparation] needle can get to and it's a straight line. You can't really do ninety-degree bends back in space." Mary points out the limitations of preparation, such as that hand tools—e.g., steel needles—cannot reach certain spaces. For example, for an extinct crocodile whose jaws had fossilized while closed, CT data revealed information that the preparator, Tim, couldn't access:

> You couldn't see any teeth on the lower jaw… because of how the skull was overhanging it… [But] I looked at the slices of CT data… and I could see that there were little teeth along the back of the jaw... We never saw those, we still don't really know what they look like, but at least from the data we have this concept that they're there and that they're sharp, they're small, they're evenly spaced. So that was really neat.

Tim is struck by the absence of direct views of the teeth, in comparison with his vision-centric work of preparation. He distinguishes ideas of vision based on teeth "I could see" on a scan but that "we never saw" in reality. Tim trusts CT data as reliable and impressive information, but he is also wary of "seeing" a fossil indirectly, with CT as an intermediary.

A digital fossil, after all, may be a clearer and more complete view of the specimen than is achievable through preparation. For example, Fernandez and colleagues (2013) described two animals fossilized inside a burrow based only on synchrotron scans, a CT-like use of x-rays to measure density (figure 4). The burrow is a rock nodule with only one skull's edge showing. Two animals fossilized inside the burrow remain there, though their bones, positions, and even injuries are visible in scan data. The scans *are* the specimen; they are the only access researchers have to the fossils. Preparation, after all, would destroy the skeletons' rare three-dimensional preservation.

Researchers and preparators trust CT images as digital fossils in cases of invisible, unpreparable fossils. Researcher Wayne called the CT scanner "the truth machine," "because you can see everything.

It's like looking at something in a glass box." He meant that looking at scans is like looking at a fossil, but inside "a glass box"—a computer screen. He portrays studying fossils and images as arguably the same process. Wayne's trust in machines as truthful, a belief that Daston and Galison call mechanical objectivity (2007, chap. 3), echoed many researchers' belief that a digital image can be treated—and trusted—like a specimen. But working with digital fossils requires new ways of thinking, as preparator Tim demonstrated in his confusion about teeth that a CT scanner "saw" but that he could not. Researchers accept CT images but prefer to study physically referable fossils, which preserves their existing skills, practices, and workplace social structure.

Subjective images

Despite their amazement, fossil researchers almost universally criticize CT images as not sufficiently detailed, reliable, or "real" to replace prepared specimens. They thus blame the machine but also, implicitly, their own perception of data. They are wary of the decision-laden complexities of making images, including crucial and rarely-obvious judgments of what is specimen and what is not. Researcher Wayne articulated the skillful nature of making CT images by describing a student's construction of a digital fossil: "He didn't do a very good job of Photoshopping. These things [onscreen images of individual bones] are ragged around the edges." CT data can be digitally isolated into separate bones, but doing so with software like Photoshop is difficult and has critical implications for how research images look. Likewise, preparator Steve complained about the significant processing and skill required to make useful CT images: "You don't just get a lovely three-dimensional image, you have to take all that information and then merge it all together and decide on the resolution." Image making as expertise is similarly discussed among astronomers (Lynch and Edgerton 1988; Vertesi 2015) and cell biologists (Cambrosio and Keating 2000); these communities, like fossil lab workers, use images to judge the quality of *workers* as well as of evidence and knowledge claims. Thus how images and specimens are made and used depends on workers and their social structures.

One criticism of CT is that it isn't effective for all specimens. Researcher Kyle had an unprepared skull CT-scanned, but was disappointed with the results:

> The specimen and the sediment had very similar compositions... So when you're looking at the image of CT slices it's very hard to say, alright, this is where the bone ends and this is where the sediment begins.

If a fossil has the same density as the surrounding rock, then CT data—i.e., density measurements–cannot distinguish the two. Kyle explained that one option is to use software to manually draw this boundary into the onscreen model, but he rejects that process as inaccurate. Interestingly, he trusts the machine's distinction between fossil and bone, but he does not trust himself to determine that distinction based on CT images. Again, studying CT data draws on different skills than a fossil researcher typically has. Only by seeing the fossil himself, not an image compiled from CT data, can Kyle trust his own judgment of fossil and rock.

Defining specimen vs. not-specimen is a crucial and complex decision in arguably all data processing methods. Galison writes of this definition task as a crucial application of workers' "laboratory judgment" in particle physics: "The task of removing the background is not ancillary to identifying the foreground—*the two tasks are one and the same*" (1987, 256, original emphasis). By removing—digitally or physically—information deemed "background" or "noise" or "rock," a practitioner thereby defines the remaining information as "foreground," "event," "data," "specimen," etc. Biologists distinguish and count mixed populations of cells by defining parameters for a flow cytometer machine. Flow cytometry readings of cells have "no original topographical referent," because the machine measures chemical tags that researchers add to the cells, not innate cell parts (Cambrosio and Keating 2000, 247). Flow cytometry therefore measures "a purely instrumental feature, and creates a new representational order with no necessary correspondence to the anatomical or even morphological organisation of the biological entities under investigation" (Cambrosio and Keating 2000, 247). CT measures an object's pre-existing density, not an artificial tag; however, the argument that imaging techniques are distanced from their objects of study applies in both cases, particularly when imaging techniques *create* representations to make objects accessible to researchers.

How then do researchers distinguish between background and foreground, data and noise? Because these are often nonobvious judgments, researchers worry that their control over how images look may challenge the objectivity of their data and knowledge claims. This may seem striking, since most scientific fields revere images as mechanically objective and trustworthy ways to capture nature in its most useful form, e.g., clear, detailed, portable, reproducible. The sudden "inversion of credibility" in forensic science, from fingerprinting to DNA identification as the most reliable evidence, reflects trust in machines that analyze and compare DNA samples over people who analyze and compare fingerprints (Lynch et al. 2008). Likewise, astronomers (Lynch and Edgerton 1988), molecular biologists (Frow 2012; Lynch 1991; Stevens 2013), physicists (Galison 1997; Pickering 1999), and others rely on images to make stars, cells, genomes, and particles researchable. Yet even these image-dependent groups are somewhat suspicious of images. For example, astronomers claim that they process digital telescope readouts into "pretty pictures" only for public view, not for research; however, ethnographers Lynch and Edgerton witnessed such processing for both public and research images (1988, 192-6, 202). Practitioners did not want to acknowledge, perhaps even to themselves, the control they held over images as data sources. Likewise, particle physicists advised against physics training for the supposedly unskilled "scanners" (humans) who searched cloud chamber images for tracks of subatomic particles, for fear that the scanners would then "see" imaginary evidence to please the physicists (Galison 1997, 200). Scanners were considered more objective if they couldn't interpret the tracks, reflecting researchers' fear of subjectivity when selecting data from noise. For nanotechnology, which similarly relies on machine-made images, Ruivenkamp and Rip (2010) note the growing standardization—and thus rarer published descriptions—of image-processing methods for scanning tunneling microscopy. They predict that as this trend continues, "the distinction between artist's impression and pictures linked to data may become invisible, and the image of nanotechnology becomes like a work of art" (2010, 30). Because researchers agree that image making is subjective, variable, and potentially fraudulent, scientific communities try to standardize it for publications. But practitioners have trouble defining acceptable and fraudulent images, as well as enforcing those definitions (Frow 2012). This fear of creating the very phenomena they want to see drives practitioners either to standardize image making or to reject images altogether, as researcher Kyle did, to avoid the risk of influencing their data.

This view, though, overlooks the fact that lab workers must select *all* data, not just in images. Preparators decide every few minutes whether material is fossil or rock, which is often difficult because of shared color and texture, and they act on their decision irreversibly by destroying what they deem rock. Researcher Nathan described processing CT data as deciding what is "something versus nothing, just the same as fossil prep." But a crucial difference, according to Nathan and other researchers, lies in replicability, which CT images have because "you can reassess it" by re-analyzing the scan data or re-scanning the fossil. The conception of data as entirely unprocessed or objective is of course misleading (Rasanen and Nyce 2013), because all scan data are selected by the mechanism of CT (i.e., density measurements) as well as by the CT expert's initial scan parameters. In comparison, fossil preparation is not replicable because, Nathan said, preparators "throw away the crap"; a prepared fossil cannot be unprepared. Rieppel (2012, 490) describes fossils, with their selectively removed rock, added adhesives, and handmade replica components, as "mixed-media sculpture." Researchers of course know that fossil preparation is irreversible and relies on skilled judgment, but they question its legitimacy much less often than CT images. For example, despite CT's supposed replicability, Nathan believes images will never replace specimens, because "specimens are the truth in the end of it." Most researchers therefore are not skeptical of the *machine's* objectivity, but rather the *people's* who select and edit the machine's data.

Researchers often list examples of information that CT cannot provide, as a way to both criticize the technique and promote direct observation of specimens. For example, researcher Tobias admired the "sensational" images of the fossilized burrow (published in Fernandez et al. 2013, a study which did not involve Tobias) for being as clear and detailed as "a line drawing." Despite these images that impress colleagues, the paper's authors admit the scans cannot answer some questions, such as the cause of two holes in one animal's skull (*Broomistega*, an amphibian). The authors argue that the holes' size do not match the other animal's (*Thrinaxodon,* a mammal-like reptile) teeth, so they are not a result of predation. The holes are in a thin-boned area, suggesting disease or chemical changes during fossilization. "Unfortunately, the resolution of the scan does not allow further investigation," they conclude (Fernandez et al. 2013, 5). Perhaps researchers could better study the holes' cause through direct inspection, but that's impossible without preparing—and destroying —the burrow. Researchers express frustration that scans cannot always yield the information they want to study, from Kyle's completely "failed attempts" to Preston's and Kirk's concerns over questionable features to missing details of the *Broomistega* skull holes. I suggest that these complaints are not purely technical; they also express researchers' trust in and value of their—and preparators'—existing skills. Thus decisions about how to understand different kinds of data, such as images and specimens, rely on and shape beliefs about work, workers, and knowledge.

Skillful eyes

Researchers consider the lack of direct observation a significant problem with digital fossils. They blame the machine's lack of detail, but I argue that they are implicitly defending their existing research skills, which focus on interactions with specimens and not images. Researcher Preston explained, "One of the things for example that [researchers] are not able to discern is the difference between an actual suture between two bones and a crack, maybe an artifact. If you have [the fossil], you can look at it and say, okay, well, that's a crack." If CT images are not detailed enough to allow distinction between natural sutures, cracked bones, and random "artifacts" caused by scanning, that could severely limit their reliability and usefulness. Researcher Kirk finds CT scans insufficient for his work:

> I can spend hours staring down a microscope … trying to figure out if … this shallow depression on the surface of the bone… is actually where a nerve or a blood vessel used to run … I can only do that because I've done it before lots of times and because I am looking at the real thing in extraordinary detail. It's very difficult with current technology, and probably with technology for a long time to come, to actually be able to see that.

Kirk criticizes CT's inability to record the anatomical details that he studies. He may also disapprove of studying CT images because it doesn't draw on his long-practiced skill of observing "real" specimens. For Preston, the solution is to view a fossil as digital and physical: "When you work with CT scans it's quite important to actually have the 3D object too, to be able to relate some of the structures." In this view, CT images cannot entirely replace fossils, because the fossil should serve as a check on the images. As a result, Preston explained, CT "is not a panacea for what we do… It gives you a lot of power to do things, but it's not a complete answer." The missing factor is researchers' expert eyes interpreting fossils.

By questioning CT, fossil lab workers indirectly promote their own expertise in interpreting physical fossils through touch and sight. Daston and Galison's concept of "trained judgment" is relevant here, in the sense that only from experience do researchers and preparators learn to identify and "judge" important information (2007, chap. 6). The achievement of objectivity thus relies on a social consensus on how to construct and interpret images. Interpreting CT images requires trained judgment that fossil researchers typically lack and that imaging technologists, material scientists, physicists, and medical clinicians have. But prepared fossils, like images, are made "by (and for) the trained eye" (Daston and Galison 2007, 355). By extending trained judgment to objects as well as images, we can understand "seeing" fossils as a learned skill. Grasseni's (2004) idea of "skilled vision" captures these learned, social practices of visually interpreting objects. Twentieth-century scientific communities valued image-interpreting expertise over image-making techniques (Daston and Galison 2007); similarly, today's fossil lab workers seem to value specimen-interpreting expertise more than making new kinds of images.

Researchers struggle to articulate the power of studying real fossils and why digital images cannot match that experience, except for the unscannable fossils and insufficient detail that they blame on CT's technical limitations. Researcher Frank explained that it's important to "evaluate with your own eyes" for elements that CT scans can't capture, such as fossil texture, color, and trace fossils, e.g., skin impressions. For researcher Maurice, CT is a poor substitute for a specimen:

> I have never seen a CAT [CT] scan that didn't make me feel like I wanted to see it prepared. Sometimes when you can't see it prepared you can use the CAT scan and you think, okay, I can get sort of what I need out of this. But I never had one that was like, oh, that's fine, we won't bother [to prepare it]. [laughs] … It's just not the same as seeing the thing for real.

CT images *heighten* Maurice's interest in seeing a prepared fossil. By not articulating this mysterious quality of direct experience and thus preserving it as tacit knowledge, researchers make it even more mysterious and thus in some ways black-box and protect their practices. Collins (2010) categorizes different types of tacit knowledge based on whether or not they can be articulated; however, he does not explore reasons *why* certain knowledge might be preserved as tacit instead of made explicit. Perhaps fossil researchers are not consciously aware of what they do with a fossil that cannot be done with a digital image, and therefore cannot articulate it. Another interpretation would consider this knowledge as a trade secret, an ability that defines a community while also claiming an area of control for that community. Jackson (2003) contrasts eighteenth-century instrument makers' closely guarded trade secrets—which are tacit by purposeful omission—with the openness claimed by the scientific community. By not defining how their trained judgment of objects compares to images, fossil researchers promote their own mastery and thus control of this process. Therefore they stand to benefit from *not* explaining why fossils are better data sources than images.

Researchers do not reject CT outright; most researchers I interviewed said that CT should be used alongside specimens, in a mixed-methods approach. Preparator Steve observed that even with high-quality CT images, "people like to handle the real thing. Researchers still want to see the real thing." For researcher Sam, the most "fruitful" method is a combination of "CT and the human eye, an expert eye" on a physical fossil. For researchers, "expert eyes" also belong to preparators. For example, researcher Maurice worries that CT cannot replace the information a preparator gains about specimens:

> [A preparator] might say, "Do you want this cleaned out?" And it's like, "What is that? I never saw that before." [laughs] And that kind of thing happens a lot, so it's hard to imagine not having that anymore.

Researchers believe that preparators' trained judgment—e.g., their attention to detail and recognition of unusual features—provides valuable insight into fossils' morphology. Thus researchers criticize CT in favor of the flexibility and reliability of visual observation by trained, skillful eyes—their own and preparators'. As a result, preparator Bill described a strong tie between preparators and researchers:

> It's almost like you do need to see the fossil and have a CT scan at the same time. I don't think we'll ever really be able to get rid of preparators… I think there always will be a need for them as long as there's paleontology—paleontologists.

Bill first draws on researchers' "need to see the fossil" to justify why preparators and paleontologists are interdependent. But when he changed his response from "paleontology" to "paleontologists," he indicated an underlying connection specifically between these kinds of workers, rather than between preparators and fossil *research*. These workers' roles are defined *relative to each other*, rather than as relative to a research process. If CT were to replace preparation and thus preparators, this network of social roles, divided labor, and established trust would collapse.

Workers' social order

By rejecting CT as a universal "panacea" for fossil research, lab workers reinforce the technique's perceived status as exterior to the fossil lab community, because it requires different skills, training, and tools. For example, Cuvier, who studied drawings of fossils, was an accomplished draughtsman (Rudwick 2000, 54-56). In comparison, today's fossil researchers are not trained in digital imaging techniques. By arguing that CT images are insufficient for research except when accompanied by an expert's direct observation of a specimen, researchers promote their own expertise—much like Cuvier did by professing the reliability of drawings, which he could make. I argue that this change in perspective between 18th-century paleontologists and today's is not a rejection of imaging techniques, but rather a way to promote researchers' existing skills. This trend is further evidenced by researchers' and preparators' tendency to distance themselves from CT's actual operation. Preparator Max echoed a common view that if researchers want to CT-scan a fossil, "be careful with it. [laughs] Yeah, I don't know anything about the techniques and the technology." His only concern was that the fossil he prepared not be damaged during scanning; CT itself is outside his expertise and his interests. Likewise, when I asked researcher Tobias how different CT scanner models work, he told me that he doesn't know: "I'm not a physicist" implying that it's not his responsibility to know. Expressing disinterest in CT's mechanisms may serve to protect the status quo of lab workers' tasks, skills, and social order.

Researchers' preference for the "real" fossil, whose processing relies on preparators' expertise, is perhaps surprising based on preparators' low institutional status and lack of shared credentials. Preparators and their work are rarely mentioned in publications about fossil research. The common explanation is that researchers omit "invisible technicians" from publications to promote the objectivity of scientific work, thus benefiting researchers (Shapin 1994). However, I argue elsewhere that invisibility can benefit *technicians*, by distinguishing their work from researchers' and thus allowing them the freedom to choose and control their practices without researchers' interference (Wylie 2015). In addition, invisibility may allow researchers to deem preparation a separate jurisdiction, in Abbott's term (1988), or a separate field, in Bourdieu's term (1993). CT experts, in comparison, perhaps can't be ignored as invisible technicians because they are often researchers in their own right, with PhDs in physics or material science. They have equal scientific status with fossil researchers, unlike preparators who have no common training and rarely have PhDs. If preparators have social and technical practices distinct from researchers', in addition to lower status, then researchers can safely overlook them and, as a result, overlook the many subjective and skillful decisions that preparators make to produce a fossil specimen.

Researchers believe that CT is a "great tool" (Sam) and "will become a standard method in paleontology" (Tobias); however, they believe CT is "not going to replace the preparator" (Sam). Lab workers value each other's skills of seeing and interpreting fossils, and they resist the obsolescence of those skills by technology. However, this case is also not an example of Ludditism. Practitioners promote CT use on fossils to enable otherwise impossible data access, such as the fossil burrow. They just don't consider CT a "panacea" for all fossil research. The technical disadvantages of CT that practitioners discuss, however, are not the only reasons why they believe CT cannot fully replace prepared fossils and preparators. The social structures of scientific communities rely on workers' divisions of labor and identity as well as networks of trust, which would have to be laboriously renegotiated if one group were removed. Likewise, I don't think fossil lab workers intend to challenge the validity of scientific images by celebrating a prepared specimen as the "real thing" and thus the gold standard of evidence and "truth." Instead, they promote their current specimen-based laboratory skills and, accordingly, their skill-based social order. These seemingly contradictory assessments of the products of human work—i.e., objects and images—reflect practitioners' trust in their own and their fellow lab workers' trained judgment.

Conclusion

For today's science workers, the reliability of images and objects depends on the people who make them. For fossil researchers, CT technology and technologists are outside their social and epistemic domains and thus suspect, while fossil preparation is done by their fellow lab members, whom researchers trust and, therefore, can ignore. Researchers and preparators do not question mechanical objectivity; however, they trust the products of each other's expertise over images produced by CT experts' decision-laden processing of digital data into images. This trust, I suggest, is a sign of the successful negotiation of jurisdiction (Abbott 1988) over different areas of work within fossil research. These workers have divided their expertise, labor, and power in ways that are currently clear and uncontested. New techniques that alter the role of one group of workers threaten the social system of carefully balanced jurisdictions and conceptions of trust. When paleontology lab workers criticize CT and exalt "real" fossils, they promote their own expertise and the status quo of their workplace's social structure.

This case exemplifies how social context and existing work practices shape users' responses to new technologies. Lab workers value better access to data, but they decide what "better" means in terms of a data source's form (e.g., images vs. objects) and production (e.g., made by scientists or technicians). CT can provide views of fossils that fossil preparation cannot; however, studying those views instead of fossils threatens the lab workers' practices, skills, and therefore social structure. Agar argues that computerization was "deepening the division of labour" in science (2006, 900) by distancing lab workers from computing and by creating jobs centered around computers instead of the lab's research field. It is this deeper division that fossil researchers want to avoid, I argue. They prefer to have trusted local technicians make fossils into physical data sources, rather than hiring imaging scientists to process CT data into digital fossils. This preference relies on desires to practice and preserve their own skills at studying physical fossils as well as to protect their current, stable social order. For now, these two work processes coexist, such that researchers recommend studying CT images alongside prepared fossils. When that is not possible, such as when preparation would destroy a fossilized egg, skull, or burrow, then researchers study digital fossils but with reservations about their reliability.

The dinosaur heart/rock controversy illustrates the power of trust among colleagues over trust in machines, even when colleagues' interpretations of data differ. A 2011 paper re-examined the specimen with several techniques, including long-established manual methods (e.g., histology) and "advances in technology not available at the time of the original study" (e.g., higher-resolution CT scanning) (Cleland et al. 2011, 204). None of these techniques produced evidence that the concretion in the dinosaur's chest was biological. The authors conclude their paper not with a harsh rejection of Fisher and coauthors' claims, but instead with a celebration of technological progress: "While the original hypothesis of cardiac origin was consistent with the data presented by Fisher et al. (2000), new technologies and methods allowed retesting of this controversial hypothesis" (Cleland et al. 2011, 210).

Cleland and coauthors have a good reason for blaming technologies and not the researchers: they are colleagues, at the same university, of four of the six original paper's authors. The acknowledgements section further frames the paper as an application of new techniques rather than as criticism of Fisher and coauthors' work: "We also gratefully acknowledge D. Russell [second author of the 2000 paper and first author of the 2001 defense paper] for his willingness to propose the original hypothesis and his fundamental advances to the field of vertebrate paleontology, and we are honored to work with him" (Cleland et al. 2011, 210). By blaming imaging technologies, the authors avoid criticizing their colleagues' expertise and thus damaging their trusting relationship, even while rejecting those colleagues' claim.

Trust among workers is a crucial force in shaping a community's support or suspicion of new techniques, technologies, and, accordingly, technicians. Fossil researchers' trust in preparators is strong enough to overpower fears of subjectivity in favor of skillful, nonstandard, unpublished data preparation work. Science practitioners typically favor standardization and mechanical objectivity to promote scientific knowledge as reproducible and universal, regardless of individual skill. But the introduction of a new technique—and the accompanying new workers, skills, ways of working, and social roles—requires a foundation of trust among workers. Fossil researcher Larry Witmer explained this well in a news article in *Science* titled "Learning to dissect dinosaurs—digitally": "It's not going to be the technology that provides the insight… It comes down to humans who can understand the complicated and voluminous information that comes out of the scanner" (Stokstad 2000, 1732). The success of technology—no matter how advanced or impressive or "magic" it is—relies on humans' willingness to change their practices, skills, and social roles accordingly.

Author Biography

Acknowledgements

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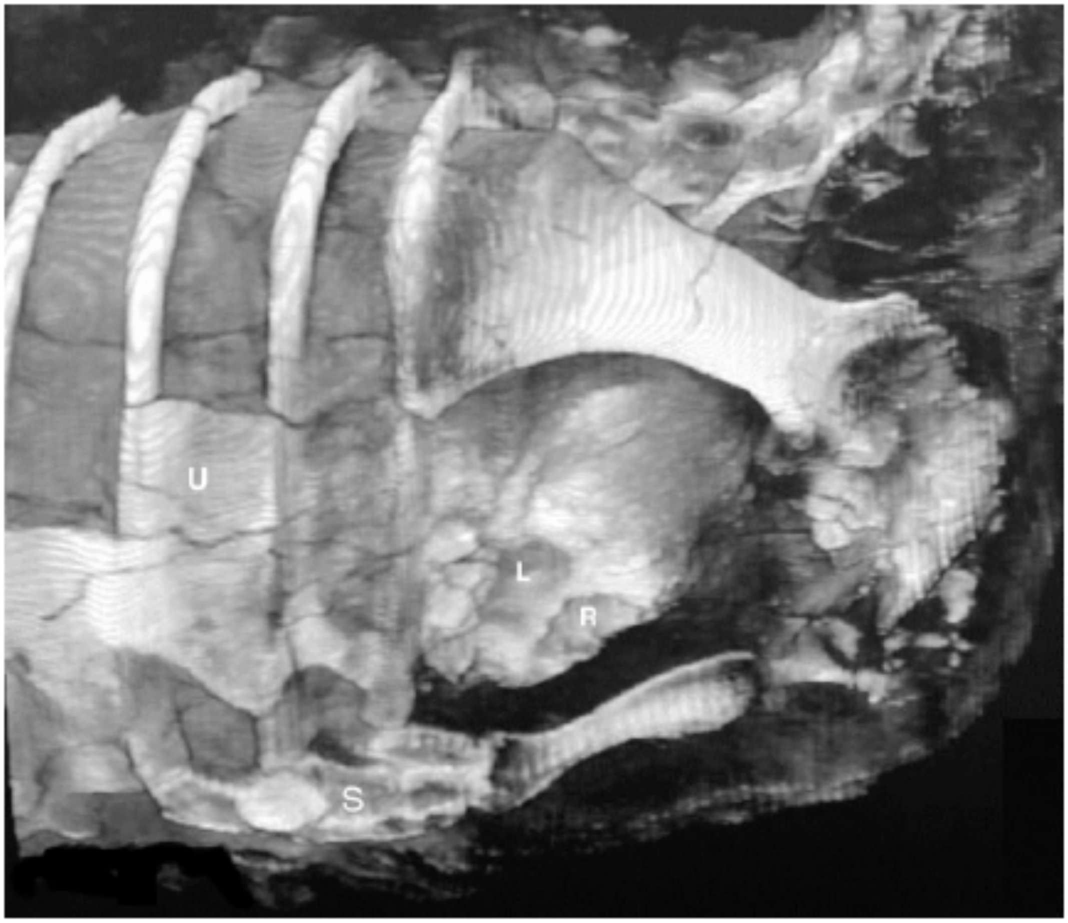

Fig. 1. Right lateral view of a 3D reconstruction of CT images of the *Thescelosaurus* specimen showing the right (R) and left (L) ventricular cavities, preserved sternal ribs (S), and plates resembling uncinate processes (U) attached to thoracic ribs. The apex of the heart has been temporarily removed.

Figure 1: An image made from CT scans, which the authors argue show a dinosaur's heart ventricles ("L" and "R") (Fisher et al. 2013, 504).

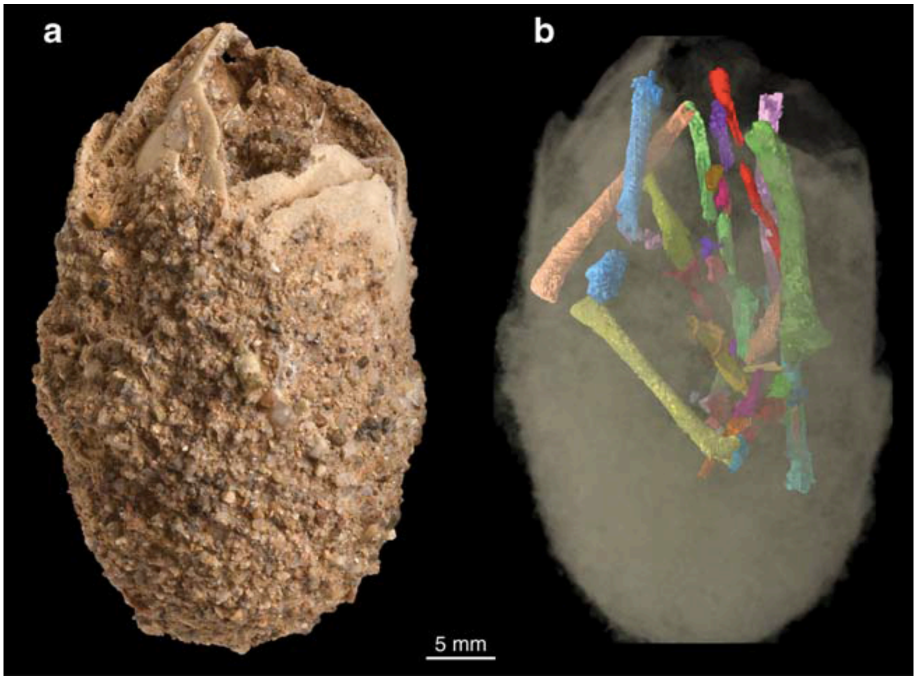

Figure 2: Photograph (a) and CT image (b) of a fossil dinosaur egg, with eggshell shown as translucent and embryo bones as various colors (Balanoff et al. 2008, 494).

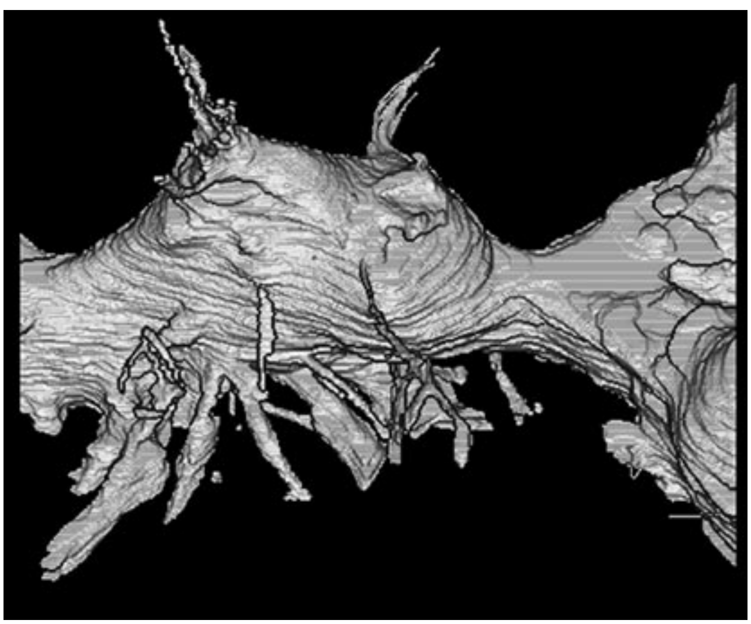

Figure 3: ‘Digital endocast’ of a *T. rex* skull, made by digitally removing the skull to reveal the space once occupied by the brain (Brochu 2000, 2).

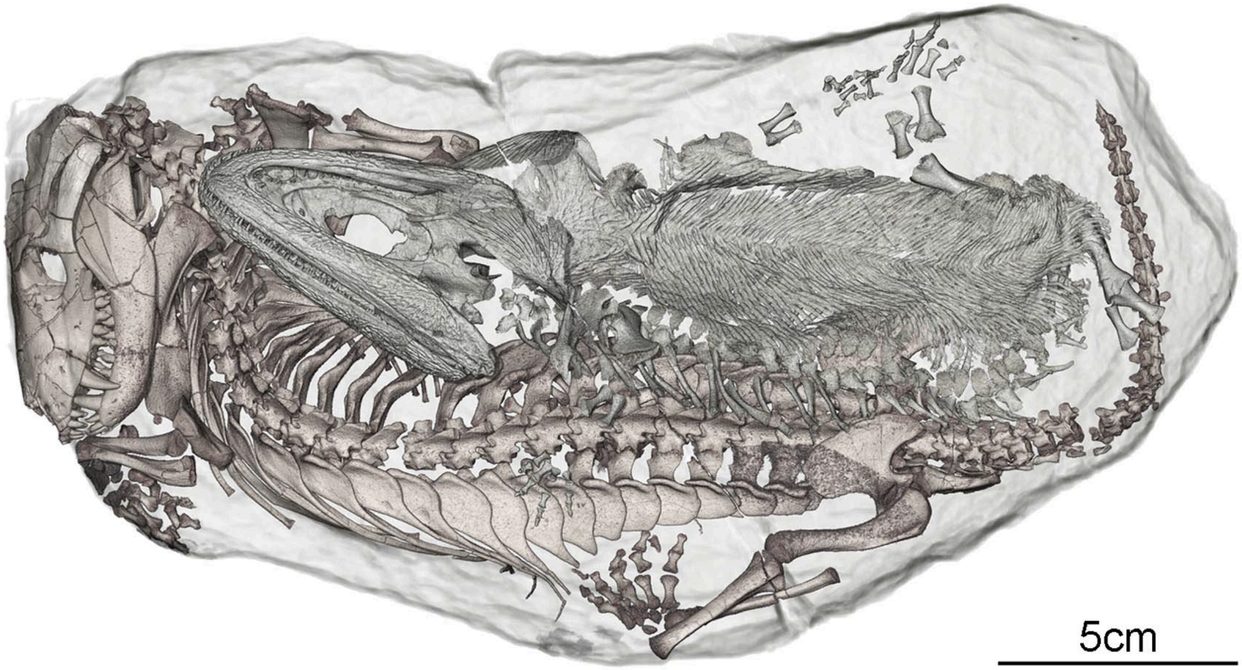

Figure 4: Synchrotron image of a burrow containing two fossil skeletons (Fernandez et al. 2013, 2).