

THE SCIENCE OF LOST WORLDS

Adrian Mitchell Currie

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Imagined Worlds

A member of the public raises a claw: “Uh, you painted Broadfoot a kind of browny colour—do we know Broadfoot was brown?”

Prof. Ichthy laughs, “Well, maybe we don’t know Broadfoot was brown, but we can certainly imagine Broadfoot being brown.”

Noting the suitably nonplussed reaction from the crowd, Ichthy becomes a little more serious: “Let me explain. There are a lot of things we’re not yet sure of, such as Broadfoot’s colouration. However, we are in a position to make pretty educated guesses. I’m sure some things in the past were surprising. Some mammals, I’m sure, sported wonderful and weird colouration. After all, a bunch of the animals around us have surprising colours. However, the browny colour we’ve speculated for Broadfoot is both the kind of colour you might expect an animal who lived like that to have, and it tracks the colour of most mammals we know of today. So, although we’re not certain, there are constraints on how we imagine. And while I probably wouldn’t stretch that to count as bona fide knowledge, I think these constraints matter.”

Scientists confronted with putatively lost worlds are confronted both with the limits of their imagination and, at the same time, the tools needed to expand it.

In the introduction, I boldly claimed that this book is about the scientific imagination, but at this stage, you’d be forgiven for scepticism on that score. Thus far, all I’ve said about the imagination is to argue that imagination fails to play a special epistemic role in grounding modal knowledge in science. It’s time to give a positive characterization of imagination in science, or at least the imagination involved in uncovering knowledge of lost worlds.

My account of scientific imagination will be rooted in artifactualism: I’ll argue that perspectival tools underwrite, expand, and extend scientific imagination; indeed, those tools partly constitute scientific imagination. I’ll

not deny that the psychologistic aspects of some scientists' imagining play important roles, but will claim that for the majority of the time, imagining is best understood as carried by perspectival tools. The tool is often required for the imaginative act, often carries the imaginative act's content, and is necessary for the act's spread and development among scientific communities. In arguing for an artifactualist account of the scientific imagination, then, I'll soften the focus on scientists' individual psychologies.

Imagination so understood, then, does play a justificatory role in our knowledge of the past; however, imagination is significantly de-psychologized as compared to the views discussed in chapter 6, and I retain the position that imagination doesn't play a *special* role in uncovering modal knowledge: as we'll see, it is just as necessary for knowledge of the actual past.

Before presenting my view on imagination, I'll discuss the role of imagination and modality in palaeoart, that is, attempts to provide artistic representations of the past worlds that historical scientists hypothesize about. I'll focus on a case from recent history: "shrink-wrapping." I understand this kind of palaeoartistic practice as the combination of two different "modes": both representing extinct taxa *as* living organisms, as associated with natural history illustrations, and being epistemically responsible via being constrained by contemporary palaeobiology. The demand to represent them as living organisms requires the "concretization" of various hitherto abstract ideas. And this requirement sometimes clashes with the expectation that palaeoart should be epistemically responsible. I will, then, articulate a dilemma for palaeoartists—a clash between the demand to represent extinct taxa as natural-history organisms and the demand to be epistemically responsible—and I'll then suggest a particular way out of that dilemma, one that is reflected in how palaeoart is often practiced now. In particular, I'll suggest that palaeoartistic representation ought to be pluralistic and take diversity in representation, thus exploring epistemic possibility as a central motivator.

This chapter, then, has two major parts. First, a side path into palaeoart. There, I'll both make some direct arguments about palaeoartistic practice and provide the contours for the more general account of imagination in the second part. Before any of that, however, we need some further preliminaries about imagination.

1. The Poverty of Imagination

“But why care about what I can imagine?” Ichthy asks, reflectively. “Prior to discovering Broadfoot, such a weird little creature existing wouldn’t have occurred to me. My imagination is terribly, terribly restricted. But also, if I had imagined Broadfoot, such imagining would be rightly dismissed as so much fancy. After all,” Ichthy shrugs, “I can imagine whatever I want, so of what scientific import is me happening to imagine something?”

“As a scientist, my imagination is in a somewhat paradoxical bind. It is both too restricted and too free.”

Uncovering lost worlds requires imagination: at a minimum we must conceive of denizens differing from those that are familiar to us. Beyond mere conception, we often attempt to represent them in various ways: with linguistic description, various abstract representations, attempts to generate various of their properties, such as what they sounded like and looked like. The imagination involved in uncovering lost worlds is deeply driven by empirical discovery: Prof. Ichthy is fond of emphasizing that it is only in virtue of the fortuitous discovery of Broadfoot’s fossil that they even conceived of such an organism. As James McAllister has put it: “In empirical discoveries . . . scientists are repeatedly confronted with phenomena that cannot be comprehended in terms of the familiar. Far from outstripping the range of empirical experience . . . imagination is broadened by empirical input: Scientists learn after having made discoveries how limited their imaginative powers have been” (McAllister 2012, 15).

My aim is to provide an account of scientific imagination geared toward understanding this feature of the science of lost worlds. To get there, I need to situate myself within the voluminous discussion of imagination.

As you’d imagine, there is a *lot* of work across the academy on imagination. And this work approaches the imagination, both conceptually and empirically, in a variety of different ways (e.g., Forgeard and Kaufman 2015). One advantage of this diversity is that, in tackling imagination, one is fairly free to stipulate which aspect interests you in the relevant context. What, then, is the appropriate conception of imagination for considering the science of lost worlds?

Arnon Levy has distinguished between *thin* and *thick* conceptions of imagination. Where thicker notions involve some kind of mental imagery, “a kind of off-line sensory experience” (Levy 2024, 100), a thinner account

of imagination “is to merely entertain, to take under consideration without presuming the truth” (Levy 2024, 100). Similarly, James McAllister distinguishes between notions of imagination that focus on *mental imagery* and another—thinner—usage that cross-cuts it. “Mental imagery” isn’t restricted to images but includes other sensory imaginings, such as imagined tactile feel, smell, or taste. The focus on mental imagery is highly psychologized: imagination is that thing that makes use of sensory phenomena in your head. The other sense of imagination, which McAllister and I are broadly interested in, is concerned less with mental images but instead with the unknown. He understands “imagination” as involving “a mental capacity for conceiving entities, states of affairs, events, and phenomena that have not previously been observed. In a generic sense, imagination plays a role whenever someone originates novel output of any kind (McAllister 2012, 11).

This is a fairly minimal conception of the imagination: the mental capacity for originating novel output. This differs from mental imagery in obvious ways. First, mental imagery need not be novel—consider visual memory, for instance (this is one way that McAllister’s conception departs from Levy’s). Second, novelty need not involve mental imagery. No doubt, conceiving of lost worlds sometimes includes mental imagery, as it does the production of images. However, sometimes discovery takes more strictly symbolic forms, from narrative to mathematics. McAllister’s notion is further constrained by being about scientists’ use of mental capacities “when they conceive possible features of the world that they have not previously encountered empirically” (McAllister 2012, 11). This combination of mental capacity and the unknown is common in accounts of imagination. Both Sheredos and Bechtel (2020) and Mike Stuart (2020) define imagination in terms of creativity and imaginistically. As I’ll provide reasons against tying imagination—*creative imagination*—to mental imagery per se, the account is somewhat at odds with these. However, this doesn’t mean that notions of the cognitive are left out. As we’ll see, I’ll understand mental capacities in an extended or situated (de-psychologized) way suitable to an artifactualist account.

So, when I’m interested in the *scientific imagination*, like McAllister, I’m interested in the capacity to generate novel conceptualizations of the unfamiliar, specifically lost worlds. This concept of imagination is closely related to work on speculation and creativity, and I take myself to be expanding on previous work on those topics (Boden 2004; Hills and Bird 2019; Stuart 2022; also Currie 2019e, 2021c, 2022).

It is worth noting that my focus departs a fair bit from much of the work on imagination in the philosophy of science, which tends to target scientific thought experiments (Brown 1991; Meynell 2014; Stuart 2016; Murphy 2020). Surprisingly often, particularly when introducing novel theories, scientists employ fictional—often impossible—scenarios to illustrate or make sense of the ideas they explore. Philosophers disagree on whether the mental imaginings involved in such thought experiments play a role in justification properly speaking. Nancy Nersessian (2007), for instance, argues that sensory imagination is necessary for the persuasive force (and indeed the justification) of scientific thought experiments, while John Norton (1996) has it that every scientific thought experiment can be stripped of its imagery and presented as a formal or semi-formal argument (see Stuart 2020 for more). This dispute turns on whether the act of imagining itself is necessary for the thought experiment's persuasive force.

The importance of this argument expands dramatically if, like some in the debate, we take there to be an equivalence between the kind of imagination employed in thought experiments and in scientific modelling. Salis and Frigg (2020) are especially explicit about this: “TEs [thought experiments] and SMs [scientific models] involve the same kind of imagination. The imaginative activities involved in SMs and TEs can be analysed together” (Salis and Frigg 2020, 22). When I get to sketching an artifactualist account of imagination, I'll agree to some extent with this: insofar as mental imagery and, say, computational systems can be media that accommodate modes, they can do imaginative work in similar ways. However, “perspectival tool” is a broader category than “model,” so it doesn't follow that the same treatment will work across all cases that interest us. And, indeed, when we're interested in McAllister's conception of imagination, thought experiments and models are just a subset of the varied ways in which we might conceive of the unfamiliar (see Skaf and Stuart 2025 for further discussion of the differences between thought experiments and scientific models).

McAllister describes two contrasting objections to the use of scientific imagination. The first is the *arbitrariness objection*. We are, in some sense at least, free to imagine what we like. Not in the sense of being able to imagine anything at all, but in the sense of our imaginative capacities being insufficiently constrained for us to have good reason to think imagining tracks what there is, or even what there relevantly might have been. As McAllister puts it, “An entity or state of affairs conceived by an act of imagination is just one among many that could be imagined: None of these has any more claim to

reality than any other” (McAllister 2012,13). The second is the *poverty objection*: “The fact that it is impossible or difficult to rule out that our imagination is insufficiently creative to apprehend reality” (McAllister 2012, 15). There are a lot of weird things out there, so why think that we’ve imagined all of them?

Arbitrariness and poverty together are especially troubling for uncovering lost worlds. Consider the plethora of explanations posited for pizza-disk fossils. They have been imagined as jellyfish, arthropods, microbial colonies, and false taxa. By the arbitrariness objection, our merely being able to conceive of these interpretations as such doesn’t seem to carry much weight, given the other ways in which we might imagine. We can imagine them in a bunch of ways, so why think any particular imagining is important? By the poverty objection, our *inability* to conceive of the range of options undermines the importance of our imagining of pizza disks as they could have been. Considering how surprising the past often turns out to be, why think that the space of what we do imagine maps in any interesting way onto how things were?

Both arbitrariness and poverty have a common source—one that has been prominent in recent philosophical discussions of the epistemic power of imagination—a lack of *constraint*. As Amy Kind has put it, there are roughly three reasons folks give for thinking that imagination cannot give us knowledge: “First, imagining is typically under our voluntary control. Second, imagining is not world-sensitive—the content of an imagining is determined by the imaginer, not by the world. Third, imagining is uninformative—an act of imagining can provide us with no new information” (Kind 2016, 145).

Each of these problems, especially linked with arbitrariness and poverty, lends support to the idea that imagination needs to be constrained. *Voluntariness* feeds into arbitrariness: if we can imagine what we want, then imagination isn’t sufficiently constrained to be epistemically relevant. *World-sensitivity* can relate to both poverty and arbitrariness: our imagination’s partial freedom from the world makes it insensitive to it, but also, what we *can* imagine is apparently set by our mental prowess, not the potentially much weirder world. Finally, *uninformativeness* is due to imagination requiring us to reshuffle knowledge we already have: the poverty of our current information thus restricts what we might imagine. Together, these form a challenge regarding *epistemic relevance* (Kind 2018; Rucińska and Gallagher 2021). We can imagine a bunch of things, but why think the possibilities we imagine relate to past worlds? Our imaginations are extremely limited, so why think what we do imagine relates at all to what the past was like?

The challenge of epistemic relevance asks how we might constrain imagination in the right way, that is, find epistemic principles that, if imagination followed, would solve this set of objections. As Kinberg and Levy put it: “To the extent that one’s imagination abides by appropriate principles one can use it to generate knowledge—including, in particular, knowledge of concrete actual, worldly facts” (Kinberg and Levy 2023, 327). Philosophers tend to be somewhat circumspect about what these constraints are supposed to be (although we’ll see a suggestion appealing to embodiment later in the chapter), but are much clearer on what the constraints are supposed to do. First, the imaginer begins with a setup that sufficiently captures the real-world scenario that interests them. Second, the imaginative scenario should then unfold as it would were the scenario to occur in the real world. At base, then, whatever the constraints might be, they should ensure that the imaginative exercise tracks worldly events.

However, there are two recent arguments suggesting that appeals to constraint—or at least systematic appeals that are supposed to underwrite the particular power of imagination—cannot be had. Mike Stuart (2020) has argued from something like a pessimistic meta-induction that, for any attempted general claim about the proper constraints on imagination such that it can be epistemically viable, there will be examples of scientists breaking those rules in epistemically valuable ways (and, presumably, cases of scientists *obeying* those rules in ways that are disvaluable). For Stuart, then, scientific imagination is anarchic in the Feyerabendian sense. That is, there is no systematic story to tell about the successful use of imagination in science. Second, Kinberg and Levy point out that the epistemic stories we might give in constraining imagination are never particular to imagination; rather, they pick out general epistemic rules of thumb, in particular, hypothetical reasoning more generally. As such, they cannot be solutions to problems particular to imagination. I’ll return to these challenges later in the chapter.

In previous work, I’ve characterized some palaeoscience as *phenomena-driven*, that is, their models and explanations are built, examined, and interpreted in continual conversation with the past as revealed by traces (Currie 2019d; Dresow 2021). This feature of the palaeosciences provides initial answers to how scientific imagination might be constrained in epistemically relevant ways. The scientific imagination of palaeoscientists is not so arbitrary, but directed and underwritten by real traces. The scientific imagination is not so impoverished, but boosted by unexpected empirical discoveries and extended by perspectival tools. I think this character is best understood by

an *artifactualist* account of scientific imagination. To get there, I want to first tackle a broad case study from the recent history of palaeoart.

2. The Palaeoartist's Dilemma

"Can we go back to that illustration of Broadfoot, please?" Ichthy waits patiently while the grad student at the OHP fumbles through the slides, dropping a few on the floor, before finding the right one and slipping it into the projector. Ichthy considers the image, peering at it through their spectacles, before continuing. "Some of this reconstruction we're quite sure of, particularly the anatomical details, that is, the bone and muscle. Others we're less sure of. The colour, as we've discussed, is speculative. Not wholly so, of course: again, the mammals around these days tend towards rather drab browns, and that makes sense for camouflage."

One of the keener grad students jumps into the conversation: "This troubles me, though, in illustrations like this, both what we know really well and things we—or the artist—basically made up are presented with the same confidence. This makes it seem like we know a lot more about them than we really do. It would be better to represent them less realistically, I think."

"Maybe," Prof. Ichthy responds, a slight grimace across the jaw indicating some discomfort at the interruption, "but without the realistic interpretation, people would find it harder to imagine Broadfoot as a real, living creature, and I think that's important too . . ."

Lost worlds are times in the past that played by different rules, that contained differing denizens than now, and that are eerily unfamiliar. Learning about them, then, both extends and challenges the scientific imagination. In this section, I want to explore how lost worlds might be represented in vivid, powerful ways in what we might call *science-oriented art*, that is, art that is in the business of seriously representing scientific knowledge, such as we might see illustrating scientific books, sculpted in museums, and in animations accompanied by David Attenborough's voice-over. I'll thus dip my toe into what Victoria Cain has called "the ongoing dilemma of picturing what can never be witnessed" (Cain 2010, 285).

"Dip my toe," indeed. Work on the relationship between artistic illustration and science (to say nothing of the relationship between art and science generally) is an enormous topic (Ambrosio 2014; Daston and Galison

2021; Ambrosio and Sánchez-Dorado 2024) that I can't hope to do justice to here. Similarly, the historical, social, and political elements underlying representations of the historical and Earth sciences are rich (Rudwick 1992; Cain 2010; Rieppel 2012, 2019; Jones 2019; Tamborini 2024). I'll restrict myself to a recent historical episode that highlights a particular epistemic and aesthetic challenge for palaeoart, a dilemma that emerges from the requirement to represent extinct taxa as concrete organisms (in characteristic poses, in characteristic environments) on the one hand, and the requirement that palaeoart be epistemically responsible on the other. This will involve articulating what this kind of palaeoartistic representation affords, which will set us up for a more general defence of an artifactualist account of scientific imagination.

As we saw in chapter 1, a crucial part of 19th-century naturalists' arguments for the importance of palaeontology and the Earth sciences was the discovery of deep time. Throughout the history of palaeontology, the spectacle of various forms of visualizations—from Henry De la Beche's *Duria Antiquior*, to the Crystal Palace sculptures, to Charles Knight's murals, to *Walking with Dinosaurs*—has played an important role in popularizing and shaping these discussions. Understood broadly, “palaeoart” has been produced across multiple institutional and professional contexts, from formal relationships between professional artists and museums in the early 20th century, to today's expansive online fan communities (Romano and Manucci 2023). However, the term itself was only introduced in 1986 by Mark Hallett (Ansón, Fernández, and Ramos 2015), and has a somewhat narrower use, restricted to what I'll call “science-oriented art,” representing extinct organisms and other elements of past worlds. Summarizing Hallett's view, Romano and Manucci put it as follows: “[Palaeoart] would be linked to the reconstruction process starting from available material, a process for which an entirely hypothetical component is essential and unavoidable. A ‘palaeoartist’ must be able to merge congruently aesthetic and scientific knowledge” (Romano and Manucci 2023, 7).

Debus and Debus (2002) helpfully distinguish between “palaeoart” proper and *palaeoimagery*, a broader category that includes any representation inspired by palaeontological knowledge. I'm interested in that former, more restricted, category.

I'm here interested in approximately the period from the 1980s to today. The repositioning of palaeontology into palaeobiology in the 1970s and '80s also reinvigorated palaeoart toward representing the lost worlds palaeobiologists sought to understand, especially in the “Dinosaur Renaissance” where

the public and palaeontological perspective of dinosaurs went from, as palaeontologist Robert Bakker said in the 1970s, “the epitome of extinctness, the prototype of an animal so maladapted that it dies out . . .” to “. . . more interesting creatures, better adapted to a wide range of environments and immensely more sophisticated in their bioenergetic machinery than had been thought” (Bakker 1975, 58; see also Ansón, Hernández, and Saura Ramos 2015; Monnin 2023). Bakker’s and others’ palaeontological illustrations drove the Dinosaur Renaissance by representing dinosaurs in the dynamic ways they hypothesized.

Considering how prominent representations of extinct animals are in the popular imagination, palaeoart is a surprisingly idiosyncratic “discipline.” These days, palaeoartists are very rarely palaeontologists and are typically self-trained with input via informal advice through informal channels. The relationship between palaeoartists and palaeontologists could perhaps be understood analogously to how Caitlin Wylie describes the relationship between palaeontologists and fossil preparators: they play different roles in knowledge production and follow differing incentive structures (Wylie 2009, 2015). Palaeoartists are fairly disconnected, then, from the kinds of institutional structures, training, and activities we might identify with “science.” And yet, palaeoartists are often deeply informed by science: palaeoart is as much an epistemic activity as it is an aesthetic one.

I will focus on palaeoart that (1) attempts to represent extinct taxa *as concrete organisms* and (2) intends primarily to represent the best current scientific knowledge (I’ll explain what is meant by these in due course). This excludes a lot of palaeoart. Karolina Twardosz, for instance, represents extinct taxa *as cartoons*, that is, using the symbolic forms, tropes, and techniques of cartoon drawing as opposed to those of natural history. Jim Robins’ illustrations of Prof. Ichthy are also partly cartoonish and non-natural-historical in mode. They thus adopt different “modes,” and this makes a difference to their representational capacities. To foreground future arguments and jargon: although both Twardosz and Robins communicate scientific details in part, the “cartoony” mode affords significantly more “implicit non-committal” representation; they are significantly less powerful as objects of “virtual witnessing” in light of this.

Many representations of dinosaurs are purely for entertainment, or at least willing to sacrifice accuracy for other values (Michael Crichton swapping the more accurate “Deinonychus” for the cooler-sounding “Velociraptor” being an infamous example). Regardless, I’m interested in the kinds of illustrations

that often accompany journal articles, press releases, museum representations, and palaeobiological books: those that primarily aim to communicate scientific knowledge of the deep past.

My discussion in this section will somewhat isolate palaeoart from its interaction with palaeontology. Especially in light of my emphasis on iterativity, this is unfortunate: no doubt there are many instances of palaeontology influencing palaeoart and palaeoart in turn influencing palaeontology. And in addition to the bountiful historical work already on this topic, I think there is a lot of philosophy to be done in this arena as well. But for my purposes, I'm interested in palaeoart for its own sake because, as we'll see, it provides a rich inroads to thinking about how artifactual modes enable and constrain various epistemic activities.

I'll argue that for science-oriented palaeoart, popular in the wake of the Dinosaur Renaissance, a dilemma arises between the two requirements listed above: first, that extinct taxa be represented as organisms, that is, as concrete three-dimensional living creatures; second, that palaeoartists be epistemically responsible, that is, not misrepresent scientific knowledge. The dilemma coalesces around the practice of "shrink-wrapping."

2.1 Shrink-Wrapping: What Went Wrong?

Taking inspiration from the scientifically-informed palaeoart common in the United States in the early 20th century, especially Charles Knight's work, palaeoartists in the 1970s onward began shifting from what pioneering palaeoartist Greg Paul called "a damaging laissez-faire attitude about constructing dinosaurs" (Paul 1987, 6) toward a more scientifically-informed approach. Part of this new seriousness was due to progress in science: "In some cases dinosaurs can be restored with remarkably high fidelity, almost as accurately as some recently extinct animals" (Paul 1987, 40).

Paul and his fellow travellers (such as Mauricio Antón) have a somewhat ambiguous legacy. As we'll see, on the one hand, they have been hugely influential in demonstrating just how powerful and how scientifically informed images of lost denizens can be, but on the other hand, they brought to prominence a particular style of representation, often called "shrink-wrapping," which carried some epistemically damaging consequences.

To get a sense of how scientifically-informed palaeoart proceeds, it is useful to start with the information typically emphasized in how-to guides.

Instead of beginning with how to draw, these often dive into rigorous anatomical detail. Sticking with Paul, here he is discussing the skulls of archosaurs:

Archosaur skulls are like those of reptiles and birds, and unlike those of mammals, in lacking facial muscles and having the skin directly appressed to the skull . . . These features make them much easier to restore. Easily the most prominent skull muscle is the powerful posterior pterygoideus that wraps around and deepens the back third of the mandible. Jaw muscles bulge gently out of the skull openings behind the orbit and in thecodonts and saurischians also out of the preorbital opening and depression. (Paul 1987, 6)

Scientifically-informed palaeoart starts from a *musculoskeletal* reconstruction, which represents the basic skeletal anatomy and musculature of the taxa. The artist then layers *integument* upon their reconstruction: skin, feathers, fat, colour, and so on. The skeletal reconstruction is, more or less, taken as given, and the integument is as informed by modern science as can be.

The style that Paul popularized, “shrink-wrapping,” is “the colloquial term for paleoart that squeezes the bones and muscles under a gaunt layer of skin” (McDermott 2020). Illustration 7.1 shows a shrink-wrapped Prof. Ichthy.

Shrink-wrapped Ichthy reveals significantly more skeletal detail than standard Ichthy. The structure of the fins, ribs, and backbone is plainly visible. Why represent extinct organisms like this? The aim is betrayed in Paul’s own advice: “It is more important to execute the distinctive profile of each dinosaur than to meticulously add hypothetical details” (Paul 1987, 42). That is, the palaeoartist should emphasize the well-understood skeletal and muscular anatomy, not the highly open integument. This was motivated by an effort to be *epistemically responsible*, that is, to not speculate too far beyond what is scientifically established. Science writer Amy McDermott reports this in her interviews with palaeoartists: “Shrink-wrapping is the conservative approach to imagining an entire animal based on fossil bones rather than speculating about soft tissue as well, says New Mexico-based freelance paleoartist Matt Celeskey; Ugueto believes that shrink-wrapping caught on simply because artists and palaeontologists have been so focused on the form suggested by bones” (McDermott 2020, 2729).

The thinking here is straightforward. To be epistemically responsible, palaeoartists ought to emphasize the parts of their representations that are

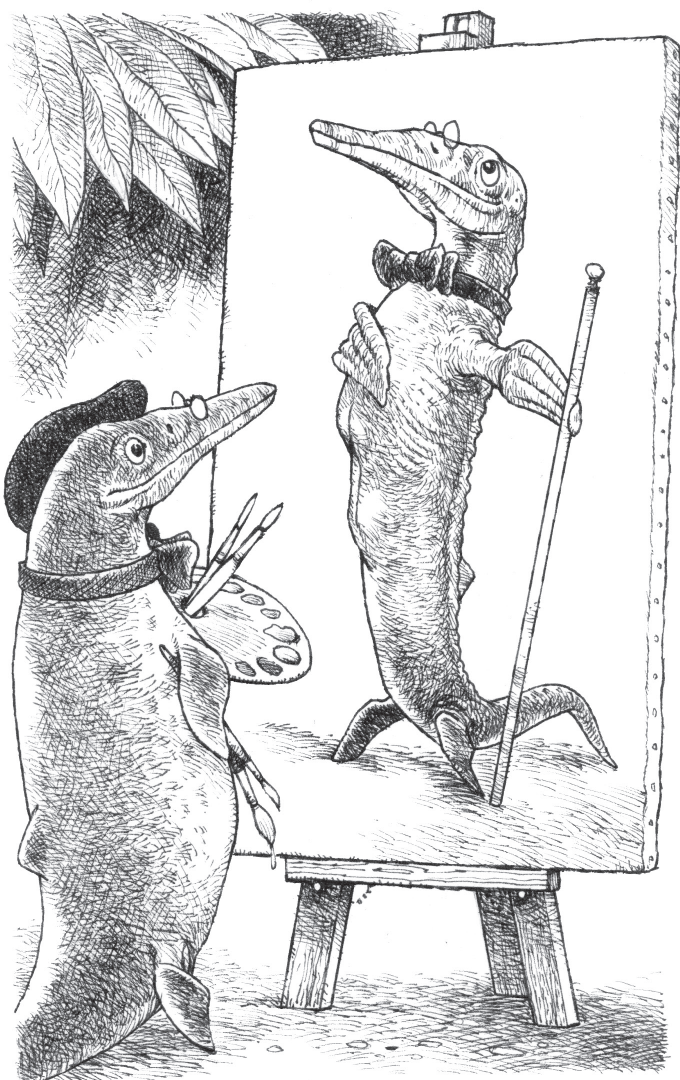


ILLUSTRATION 7.1 Prof. Ichthy, Shrink-Wrapped

scientifically well-established. And with some exceptions, integument is highly underdetermined by scientific knowledge: “Integument is the great unknown for many fossil animals; its preservation is rare and infrequent, and even when it’s preserved, it may be massively distorted or rearranged relative to position in life” (Conway, Kosemen, Naish, and Hartman 2013, 11; see also Eriksson 2014, 100–101). It’s worth noting that the shrink-wrap style was influenced by more than attempts to avoid speculation. First, there were (and are!) some empirical reasons to think that the anatomy of some dinosaurs, particularly the head, is fairly shrink-wrapped. Second, the clear representation of muscles and anatomy harkens to the idealized, heroic human forms of classical sculpture. It is a style that lends itself to the more dynamic vision of dinosaurs pushed by Bakker, Paul, and other Renaissance palaeontologists and palaeoartists. As Victor Monnin has put it, Bakker’s style, in particular, involved:

A powerful visual rhetoric speaking to the reader’s imagination learning about dinosaurs’ physiology and behaviors. If the dramatic scenes and acrobatic poses can easily be criticized as exaggerated, it is mainly because they do not serve as plain decoration to the written argumentation. On the contrary, their apparent exaggeration serves to create an even clearer contrast between a “traditional” dinosaur iconography and the author’s own vision of dinosaurs as warm-blooded animals. (Monnin 2023, 9)

So, aspects of the style played a rhetorical function, but nonetheless, avoiding speculation about integument is the most prominent justification for the style.

There is an interesting similarity between shrink-wrapping and styles of visual representation from the 18th and early 19th century, which Daston and Galison (2021) characterize as following the virtue of “truth to nature.” In these cases, illustrations strive not to represent specimens as they genuinely looked, but rather in a “perfected” way that brings out the underlying truth among nature’s frustrating variability. Linnean description, for instance, “singled out those features common to the entire species (the *description*) as well as those which differentiated this species from all others in the genus (the *differentia*) but at all costs avoided features peculiar to this or that individual member of the species” (Daston and Galison 2021, 60). These are “reasoned

images”: not faithful representations of how the plant literally looked, but images that capture the morphological features that distinguish Linnean categories.¹ As in Linnean representation, shrink-wrappers highlight particular features of their subjects, namely, the bone and muscular anatomy. But they do so for different reasons: instead of representing the “underlying truth” revealed by careful study of nature’s variability, their primary epistemic aim is to avoid speculating about that variability.

So, here is the first constraint on palaeoart, which led to the influential “shrink-wrapped” style: only represent properties that are sufficiently scientifically established (or, perhaps, *emphasize* well-evidenced properties). This is an instance of the second component of palaeoart, above: represent the best scientific knowledge, that is, be *epistemically responsible*. However, being informed by palaeontological science is not the only aim of this kind of palaeoart.

In his palaeoartist’s handbook, Mark Witton emphasizes the necessity of “the skills of a natural history artist, such as being able to produce realistic scenes of the natural world, to arrange interesting compositions, and predict how light and shadow would play out on alien, ancient forms” (Witton 2018, 8). Palaeoartists are expected to represent extinct taxa like dinosaurs *as if they were living organisms*, specifically, using the same techniques used to represent extant organisms. This is one way in which the palaeoartistic cases I’m interested in depart from other public-facing scientific representations and science-oriented art (think of representations of galaxies, atoms, genes, viruses, and so on). While these sometimes employ techniques that imply realism, palaeoartists explicitly make use of natural history techniques that are also used for extant—even familiar—animals. This has a proud and long tradition. The first real attempt at a pictorial representation of a palaeontological scene, De la Beche’s *Another Dorset*, “belongs squarely in a well-established pictorial tradition, namely that of natural history illustrations” (Rudwick 1992, 46). This, then, is the first requirement above: represent extinct organisms as concrete, living organisms.

The term “abstract” and its converse “concrete” are, to say the least, vexing across the philosophies of both science and art. In practice, processes of

1 Fascinatingly, Jim Robin’s depiction of a theropod graduate student with a toy Broadfoot from chapter 3 isn’t a representation of any particular theropod taxa, but rather of a generic theropod, including the paradigmatic features of the group, rather than of a particular species.

abstraction should not be understood as simple acts of omission (Leonelli 2008) but can be actively generative and creative (Stuart and Kozlov 2024; Sánchez-Dorado 2024a). As such, “abstract” and “concrete” are not necessarily mutually exclusive terms. Instead, one useful way of understanding abstraction is in terms of *framing*. This refers to what is included, excluded, and emphasized in the representation, especially when combined with conventions concerning the function of the representation. Abstraction is one way of providing a “prescriptive frame” that encourages certain kinds of viewing, interaction, and interpretation (Walsh, Roberts, and Currie, forthcoming). Consider Catherine Elgin’s example: “A fabric swatch exemplifies its pattern, color, texture, and weave. It marginalizes other properties of the cloth—its shape, location, age, and so on” (Elgin 2017, 20). A fabric swatch is certainly concrete—it’s a physical object, after all. But there are conventions about what swatches are *for* (giving one a sense of the fabric’s aesthetic properties for design purposes), which, in combination with its physical properties, lead it to be taken as representing the fabric more generally. Below, I’ll provide an artifactualist gloss on these elements. For now, the point is that palaeoartists represent extinct organisms using the genre conventions and techniques that are used for natural history illustrations of extant animals. Part of the prescriptive frame is an assumption of *realism* by the audience.

One useful way of understanding the function of the realism implied by the prescriptive frame of natural history illustration draws on Shapin and Schaffer’s notion of *virtual witnessing* (1986). They developed this idea to make sense of the literary devices used by early modern natural philosophers, who attempted to describe their experiments in ways that ideally lead readers to have an experience approximating having been there—hence, to “virtually witness” the experiment. Historians of palaeontology have deployed the notion in visual contexts (Rudwick 1992; Cain 2010). In the case of post-palaeobiological-revolution palaeoart, extinct taxa are presented *as if* they are subjects of natural history portraits of living taxa. The animals are presented *as concrete living animals*. We might think the same of computer-animated visual media like *Walking with Dinosaurs*, which make use of the techniques and tone of natural history documentaries (although these sometimes have a somewhat tongue-in-cheek parodic undertone). To see how natural history illustration might act like virtual witnessing, consider this portrait of Misty ShadowFang.

Robins’ image of Misty ShadowFang isn’t photo-realistic, but it is *concrete* in the sense that it represents Misty as a particular, individual organism. It is

a *portrait* and, as such, aims at both sufficient accuracy and to capture her “essential air” (Freeland 2007).² There is a sense in which the portrait could serve as a stand-in for seeing Misty herself, and hence lead to *virtual witnessing*. This is achieved by various artistic tricks and techniques, as well as by the genre conventions—and thus the prescriptive frames—of portraitists and natural history illustrators.

Presenting extinct taxa similarly to illustrations of concrete living organisms leads to similar implications. That is, similarly to how seeing this image—or even a photo—of Misty could approximate truly witnessing her, so also examining

palaeoart could approximate virtually “seeing” extinct taxa. Virtual witnessing is afforded by the organism not being presented abstractly, but as a concrete object. Thus, in creating natural-historical concrete images of extinct taxa, palaeoartists deploy a combination of deep anatomical knowledge with a set of artistic techniques to display the organism vividly.

To get to the palaeoartist’s dilemma, and to see what went wrong with shrink-wrapping, we can follow Catherine Elgin in distinguishing between two ways in which a representation might be *non-committal*.

A representation is implicitly noncommittal with respect to a property if it makes no commitment as to whether the represented object has that property. A stick figure is implicitly noncommittal with respect to its subject’s girth. It simply does not go into the matter. A representation is explicitly noncommittal with respect to a given property if its representing the



ILLUSTRATION 7.2 Misty ShadowFang

2 Freeland argues there is an essential tension in portraiture between *revelation* (being faithful to the topic) and the *creativity* of artistic freedom. I take this to be a different tension than the one I’m interested in.

having of one feature precludes its taking a stand on the having or lacking of another. A representation of a man wearing a hat is explicitly noncommittal with respect to whether he is bald, because representing him as hatted makes it impossible for the picture to commit itself on the question of his baldness [*italics in original*]. (Elgin 2017, 154)

Explicit non-commitment involves masking some properties via the representation of other properties. An example from palaeoart is a common trick in representing *Tiktaalik*, a late Devonian fish that is often considered a transitional fossil from fish to terrestrial animals. We only have fossils of the organism's front half. By representing it as coming out of the water, half-submerged, palaeoartists are both able to highlight its land-and-sea transitional status, and make an explicit non-commitment about the critter's unknown back half. Figure 7.1 is a sculptural example from the Royal Tyrrell Museum.

So, with dim lighting, half-submersion, foliage-afforded obscurity, and so forth, palaeoartists can use explicit non-commitment to avoid speculation.

Implicit non-commitment involves forms of representation that make no commitment to some properties in virtue of the mode of representation deployed. Under usual circumstances, a stick figure is just not in the business of representing girth.³ Skeletal-muscular reconstructions are similarly abstract: they don't make any claims about integument. The "cartoon" approach Robins adopts in representing Prof. Ichthy, similarly, affords implicit non-commitment (otherwise we'd get our knickers in a twist over Ichthy's bowtie). However, implicit non-commitment clashes directly with the requirement that palaeoartists represent extinct taxa as concrete natural-history objects.

Representing an organism in the shrink-wrapped style is an attempt to be (something like) implicitly non-committal about integument. But, as palaeoart, it also involves representing extinct taxa as whole, concrete organisms. As such, it represents the extinct taxa as in fact being a shrink-wrapped organism. The commonality of this style led to the common perception of dinosaurs and other extinct taxa as somewhat ghastly, monstrous, skeletal beasts. And it did so apparently with the backing of up-to-date scientific evidence.

Worse, shrink-wrapped organisms are also implausible.

3 Although, as Rose Trappes points out to me, they are tacitly committed in various ways vis-à-vis our expectations of "default" girth, gender, and so on.



FIGURE 7.1 Royal Tyrrell Museum's *Tiktaalik* Sculpture (from r/NatureWasMetal)

In 2013, Conway, Kosemen, Naish, and Hartman published *All Yesterdays: Unique and Speculative Views of Dinosaurs and Other Prehistoric Animals*, a fascinating book that both argues against the then-prevalent shrink-wrapped style and provides examples of more diverse palaeoart. We'll turn to that positive project in the next subsection. A major aspect of the book is an attempt to represent living animals as shrink-wrapped, including domesticated cats, swans, and so forth. The results are very different from the morphology of these extant animals. And they are profoundly cursed.

So, in attempting to be epistemically responsible, palaeoartists in the shrink-wrapped style inadvertently generated misleading representations of extinct taxa. We have, then, all the pieces needed for a dilemma:

1. Palaeoartists are expected to depict extinct taxa *as whole organisms*.
2. Palaeoartists are expected to be *epistemically responsible*.

3. Depicting taxa as whole organisms is necessarily speculative.
4. Speculation is inconsistent with epistemic responsibility.
5. Therefore, palaeoartists face a dilemma between two requirements: holistic depiction and epistemic responsibility.

By “whole organism,” I’m referring to the techniques of natural history illustration, which imply a realist framing. “Speculation” is a tricky term in science with many meanings (Currie 2021c). In this instance, the idea is that in shrink-wrapping, palaeoartists present at best speculative, and likely false, elements of their subjects in a realist mode. It is that element, representing extinct organisms as truly shrink-wrapped, that amounts to an epistemically irresponsible representation.

In the next subsection, I’ll argue against premise 4: done right, palaeoart can be speculative but remain epistemically responsible.

2.2 Diversity of Representation as an Aesthetic/Epistemic Virtue

The answer to the palaeoartist’s dilemma is to speculate more, not less.

Recall the artifactualist machinery of “medium” and “mode.” Palaeoart, as I’ve described it, works across a range of media: from drawings to paintings to three-dimensional sculptures to moving images. The palaeoart I’m interested in does more or less have a unified mode: representing extinct taxa as living organisms (following the practices of natural history representation) epistemically responsibly (informed by palaeobiology). However, there is an apparent clash within this mode: the concreteness required to represent extinct taxa as living organisms seems to undermine attempts to be epistemically responsible. I suspect that Greg Paul was well aware of this:

I disagree with photographic-image restorations. Extinct animals cannot be restored with complete confidence or be photographed. Art is the use of visual cues and creative licence to convince people that they are seeing a version of reality. Paintings and other restorations should be just what they are, aesthetic and realistic illusions of how the subjects may have appeared in life . . . [artistic techniques can] create a work that may even verge on the surrealistic but that is based on facts

and possibilities. Such works not only inform, they challenge the viewer. (Paul 1987, 44)

I doubt Paul's comments about art apply generally, but for this version of palaeoart, the techniques of the visual arts use various tricks to "convince people they are seeing a version of reality." They are tools of virtual witnessing. However, I've argued these tricks undermine implicit non-commitment. This led shrink-wrapping to fail in its aim of epistemic responsibility.

As Paul implies, however, we should not give up on virtual witnessing outright, that is, get around the dilemma by denying the first premise. Although less realist representations of extinct lineages are welcome and often powerful, there are both epistemic and aesthetic reasons to sometimes represent extinct taxa as concrete organisms. Aesthetically, at least some of the power of palaeoart is in its concretely revealing the past to us. Visual representation makes lost worlds salient, both to practitioners and the public. It is the sense of virtual witnessing which, plausibly I'd think, leads to much of the awe and other aesthetic attitudes and affect that palaeoart provides us. More epistemically, concretizing our ideas can aid in exploring these relationships, finding consistency or otherwise among them. In other words, exploring epistemic possibility. Given some musculoskeletal reconstruction and other known contextual features of an organism, what behaviours and integument are possible? Similarly to how Butterfield's narrative grafting pulled together the various perspectives involved in explaining the emergence of the metazoan-filled, well-oxygenated Mesozoic, a good piece of palaeoart can do the same for anatomical, ecological, phylogenetic, and energetic traits interpreted from fossils.

This kind of palaeoart, then, has distinctive epistemic and aesthetic power in uniting natural history representation and palaeoscience.⁴ Doing this epistemically responsibly, I think, does not involve avoiding speculation, but instead generating as many different images that accord with contemporary science as we can. The answer is not to be conservative but to be diverse. This lesson is well-represented in *All Yesterdays* (Conway, Kosemen, and Naish 2013): Conway, Kosemen, and Naish experiment not only with integument

4 There is a lot more to be said about the aesthetics of palaeoart, and the relationship between the aesthetic and epistemic generally. For recent discussion of aesthetics in scientific practice, see Ivanova and Murphy (2023); for palaeoart-specific aesthetics, see Xhignesse (2024); for discussions of aesthetics geared toward the historical sciences, see Turner's *Palaeoaesthetics* (2019a), Caitlin Wylie's work (especially 2015), and my own contribution (Currie 2023).

but with various behaviours and environmental contexts. A striking example is their reconstruction of aquatic long-necked *Elasmosaurus*, thrusting their necks high out of the water in an ornate and energetically expensive mating display. Their commentary is revealing: “No record of such behavior could possibly exist—it is wholly and unashamedly speculative—and yet things equally spectacular must have happened throughout the history of life” (Conway, Kosemen, and Naish 2013, 20).

In chapter 6, we discussed *mere-how-possibly* explanations, explanations that pick out one way things could have gone. I don’t think that Conway, Kosemen, and Naish mean exactly the same thing here. The point of concretizing one possibility among others isn’t merely to show one way things could have gone, that is, to demonstrate possibility, but to aid the reader in realizing just how many wild and wonderful denizens could have occupied past worlds. *All Yesterdays* was followed by *All Your Yesterdays*, in 2017, a project that brought together a wide array of differing palaeoartists at a global scale and at various levels of notoriety and professionalism to further represent the possible variation.

Vividly representing some of the diversity of forms and behaviours that could have existed in the past makes salient just how broad epistemic possibility is, and how surprising lost worlds might turn out to be.

So, in addition to (1) whole-organism representation and (2) consistency with science, I’d add a third requirement to palaeoart: (3) palaeoart should strive to collectively generate *a sufficiently diverse* set of representations. Within these constraints, it strikes me, the dilemma is resolved. The dilemma was generated by the idea that concretizing to achieve virtual witnessing was not epistemically responsible. But if we switch our attention to a group-level property—diversity—we see that *variation* in how the integument is filled out comes with epistemic benefits, not costs. Most obviously, it involves exploring epistemic possibility, that is, what is open given current palaeontological knowledge. Thus, observing that variation both communicates what is well established, via what doesn’t vary, and what is not, via what does vary.

The upshot of an appeal to diversity is not unbridled speculation. The arguments of *All Yesterdays* don’t license, as Darren Naish has put it, “people to speculate away and do whatever the hell they liked, evidence, conservatism and critical thinking be damned” (Naish 2017, 7). Rather, the combination of diversity and coherence with science leads to exploring epistemic possibility. The edges of what is “coherent” with up-to-date science are, I take it, controversial, as is what counts as “up-to-date.” But this just makes creative and

speculative use of palaeoart an excellent forum for productive discussion of those porous boundaries.

One complaint about whole-organism representation, parodied by Ichthy's graduate student, is that it represents little-known organisms with as much confidence as those for which we have excellent specimens. We know what mammoths look like—we have frozen examples—but integument is much rarer for dinosaurs. Yet whole-organism representation renders both as virtual-witnessing material. Following the second two requirements, above, we should expect representations of mammoths to be significantly less diverse than many of the dinosaurs. As the constraints of scientific consensus tighten, the open diversity decreases. Thus, although any individual reconstruction will be concrete, the relevant information about certainty and open epistemic possibility would be communicated across reconstructions.

An upshot of this meta-variation, wherein well-known critters are represented in narrower sets of ways than less-well-known critters, is that those observing the art will likely come to know about current constraints on scientific knowledge. It further undermines what Witton, Naish, and Conway (2014) decry as the “culture of copying” in palaeoart. Instead of relying on what have in effect become tropes of palaeontological representation that lack scientific grounding, palaeoartists are free to explore epistemic possibility (see Turner's (2019a) discussion of a mounted *T. rex* and *Triceratops* in the Smithsonian).

An odd luxury of many philosophical prescriptions is our getting to ignore the economic, cultural, and social realities of the practices at hand, and I'm fairly blatantly doing that here. There are plenty of realities on the ground that restrict palaeoartistic imagination (see Witton, Naish, and Conway 2014). In the wake of *All Yesterdays*, *All Your Yesterdays*, and other projects, and with the internet affording much further democratization, communication, and dissemination, palaeoart has become, as Chris Manias has put it to me, “a large-scale amateur-dominated field” (personal communication). No doubt, there's a lot to be said both positively and negatively about this, but so far as I can tell palaeoart has taken up something similar to my third requirement.

In that spirit, let's give the last word to Greg Paul: “We need to be daring and bold. Not only are traditional concepts of dinosaur appearance no more intrinsically valid than controversial ones, more often than not they are incorrect. The reasons for illustrating alternative views of dinosaurs are excellent” (Paul 1987, 40).

3. Artifactualist Imagination

The next question is from one of Prof. Ichthy's relatives: "Where do you get your ideas?" Ichthy only pauses for the briefest moment: "I look at things and build things."

In section 1, I articulated a set of challenges to taking scientific imagination seriously. Given imagination's arbitrariness and poverty, why think that imagination is epistemically relevant? As we saw, one strategy seeks principles by which imagination might be *constrained* and *enabled* such that imaginative acts are not mere fancy and yet are able to extend beyond our meagre resources. However, we also saw arguments against our chances of finding legitimate constraints. As Kinberg and Levy argue, suggested constraints on imagining are not about the powers of imagination per se; as Mike Stuart argued, imagination in science is anarchic: that is, there is no set of informative principles that range systematically across scientific uses of the imagination.

In section 2, we dived into some recent palaeoart history. As we saw, the mode of representing extinct taxa as living organisms and the requirement to cohere with up-to-date science place significant constraints on palaeoartists' imagining. The *whole organism* constraint precludes the ability to be implicitly non-committal about organismic traits: the organism is to be shown as a concrete object. Cohering with science requires that palaeoartists, insofar as they can, restrict their representations to what is epistemically possible. As we saw, this involved intimate knowledge of anatomy derived not only from living animals but also from fossils. In artifactualist terms, the imagination of the palaeoartist is constrained by the mode and medium of their practice. Palaeoart is neither special nor unique in this regard; indeed, mainstream palaeontology involves a diverse array of visual practices, from fossil illustration to digital visual techniques and more (e.g., Cunningham et al. 2014), all of which are similarly constrained by mode and medium. This also isn't limited to visual practices, but includes epistemic practices geared toward lost worlds generally.

In this section, I'll bring these together to develop an *artifactualist* account of the scientific imagination. In answer to Kinberg and Levy's point, I'll argue that restricting ourselves to a *mentalized* conception of the imagination is a mistake; therefore, imagination, as it plays out in the human mind, not having special powers, is a feature, not a bug. To Stuart's complaint, I'll argue that the informative principles cannot be generally constrained because they

are constrained by the *material conditions* in which imagination plays out. As material conditions—modes instantiated across various media—are so diverse, so too are the constraints on imagination. As with palaeoart, scientific imagining of lost worlds is best understood in terms of the mode and medium (and *combinations* of modes and media) through which imagining occurs. That is, the perspectival tools—including traces and interpretations of traces—don’t merely constrain our imagination. They *are* our imagination.

Rucińska and Gallagher (see also Jones and Schoonen 2024; Savojardo 2024) argue that the imagination can be constrained via a commitment to strong embodied cognition, that is, “the role the extra-neural body plays in cognition—its postures and movements, and the history of bodily interactions that make up a bodily habit, skill or knowhow” (Rucińska and Gallagher 2021, 8144). The idea is that if we think, and thus imagine, through our bodies and through our movements, then large constraints come into play for some imaginative activities. Perhaps a disembodied brain, if such a thing could imagine, imagines whatever it wants, but an embodied agent imagines through the affect, proprioception, and phenomenology of its body as it interacts with the world.

Imaginings may be closely coupled to the dynamic constraints involved in interacting in the world just so far as bodily movement and action are constrained by how we relate to our environment and engage with others. When we imagine with movement, we can’t imagine anything we want, as our movements are constrained not just by the actual parameters of the body and developed body schema, but by ongoing environmental situations. (Rucińska and Gallagher 2021, 8166)

Rucińska and Gallagher are not primarily interested in the scientific imagination: they’re interested in both day-to-day imaginings, say, my imagining lifting a heavier kettlebell than I have before, and imaginings that concern analytic metaphysicians (e.g., Kung 2016). Recall that I’m interested in imagination similar to how McAllister had it: the (mental) capacity of conceiving of previously unobserved entities, in particular, as it plays out in the science of lost worlds. Here, the embodied imagining of scientists is potentially very important (when, say, approaching the physicality of a fossil specimen), but to capture how lost worlds are imagined we need to go further, and also consider the varied perspectival tools that are employed. To do this, I think, we best develop an *artifactualist account of the imagination*.

Here it is:

What can be relevantly imagined scientifically is a function of the constraints and enabling conditions set by the modes and media of the perspectival tools at hand.

Note that this is not a claim about what the imagination *is*, but about what *can* be imagined. However, there's not much distance between a claim about imagination's capacities and imagination's nature. It is further not about imagining per se, but *relevant* imagining, that is, imagining that is epistemically linked to the target. In the instances I care about, these targets are lost worlds and the denizens that comprise them. As we've seen, the palaeoartistic imagination is deeply constrained and enabled by the mode and by the medium. Similarly, the palaeoscientific imagination is constrained and enabled by the various artificing, grafting, and anchoring activities that historical scientists employ. Phylogenetic contexts require that the histories of extinct taxa are rooted in the analysis of fossil and extant characters, various statistical techniques that hypothesize their evolutionary relationships, and are understood in terms of interactions among historical individuals. Mitchell et al.'s imagination is rooted both in the spatial relationships of Avalonian rangeomorph ecologies, as well as information gleaned from the various anchors they bring into play. Cuthill and Conway Morris' imagining plays out in the construction and exploration of geometric models of rangeomorph growth, as well as in the results of re-contextualizing these with rangeomorph fossils and what we've inferred regarding their developmental processes and environments.

In each of these examples, scientists rely not on a single mode or medium, but work across them to both enrich imagining and further ensure and develop relevance to past worlds.

There are at least two related complaints you might have regarding an artifactualist account of imagination. First, isn't imagining primarily a mental activity? One might be happy to say that scientific imagination is situated and scaffolded by artifacts, but still insist that the *real* imagination is in humans conceiving of, or perhaps even engaging in immersive (Kinberg and Levy 2023) mental imagery. Even though McAllister's notion of imagination isn't tied to mental imagery, it is nonetheless tied to mental capacities: is dropping that, as I appear to, a step too far? Second, if we give up on mental conceptions of imagination, what, then, carries imaginative content?

If one wishes to grant our mental activities a special place, perhaps in embodied terms as Rucińska and Gallagher do, one can still say something very much like what I have said by appealing to scaffolding or similar metaphors.⁵ Mike Stuart's account of *imaginative tools* is extremely close to, and partly inspirational to, the view I'm trying to develop here. In a very artifactualist turn, he distinguishes between tools of the hand—say, a sewing needle—and tools of the mind: “Tools of the mind (calculators, white boards, computer simulations, artificial intelligence, etc.) are really tools in the same sense that tools of the hand (forceps, pipettes, pumps, particle colliders, etc.) are tools. That is, tools of the mind ‘promote or regulate’ the ‘motion’ of the mind, by supplying suggestions and cautions that improve scientific reasoning” (Stuart 2022, 451).

Tools of the imagination are that subset of tools of the mind that “promote or regulate” our imaginings. Stuart is, perhaps responsibly, somewhat non-committal about whether tools of the imagination should be better understood as *aids*, that is, physical objects that increase our natural capacities, or whether they are the *bearers* of those activities. In his discussion of the function of visualizations to aphantasic scientists, he claims that such scientists “use and create visual images . . . to explore ideas in an imaginative way that they cannot do inside their own minds” (Stuart 2022, 451). The artifactualist would phrase this in a slightly stronger way: it is not that the image is being used “in an imaginative way,” but rather that the scientist is imagining (I have no quibbles with Stuart's further claims about the consequentialist justification of imaginative tool use).

I think the artifactualist can accommodate the minds of scientists, perhaps even claim they are special. The move is just to say that scientific minds are *themselves* artifacts. The process of becoming a scientist involves both practical and theoretical training over a long term—this is how “paradigms” are built, after all. How scientists think are products of their broader cultural context, idiosyncratic individual differences, and the work they have undertaken as a scientist-in-training and as a scientist. Years of labour shape the practical, epistemic, aesthetic, and moral sensibilities of scientists (Currie 2023b, 2023c). And further, these sensibilities and forms of understanding are often deeply embodied and entangled with material context (see Myers' 2008 on *body work*). A scientist with exceptional capacity for mental imagery,

5 As, for instance, Sterelny does for cognition (2010) and Krueger and Colombetti (2015) do for affective states.

say, might be able to run Cuthill and Conway Morris' geometric models in a purely mental environment. This would just be to say that they use a different medium but the same (or very similar) mode, just as we switch mediums but not necessarily modes, as we switch between a pen-and-paper medium and a computational medium in thinking through an ecological model. And just as switching from paper and computers brings various different affordances and epistemic dangers, so too might switching between a mental perspectival tool and one built of silicon.

In recent work, Kirsten Walsh, Tom Roberts, and I apply so-called "4E" cognition to scientific contexts (Walsh, Roberts, and Currie forthcoming). We distinguish between views whereby scientific apparatuses are considered part of, aids to, or extensions of, the scientists' senses and cognition (e.g., Toon 2014), and views whereby we consider the scientist's cognition as situated or distributed, that is, part of the system that does the science. I take it that an artifactualist would find the latter set of views attractive, and indeed, need not deny scientific agency by doing so.⁶ Further, I've been speaking in largely propositional terms about this modal knowledge, but I think less propositional accounts appealing to "pragmatic understanding": knowledge by acquaintance, know-how, or skill (e.g., Stuart forthcoming) fit nicely within a situated framework. I don't take myself to be committed one way or the other to how exactly we characterize the relevant epistemic good here. The crucial element is the relationship between artifacts and imagination in the production of epistemic goods. As Brandstetter says of models in geology, "They liberated the imagination of the scientist, enabling him or her to literally see processes that were essentially outside the grasp of human perception" (Brandstetter 2011, 136). While I'm not sure what to make of the appeal to literal sight, here, the point is that artifacts like models generate bountiful epistemic goods, and some of these involve enabling and carrying out imaginative acts.

In this context, I do think there is reason to resist claims about mental imagination's in principle priority. Consider the *diversity* of scientists' mental

6 There are various ways one might cash out a "situated" view about scientific work. For instance, you might conceive of it in terms of ecological agent-environment dynamics (using something like dynamical systems theory), à la Anthony Chemero's work (2011). A more intentionalist approach could be drawn from my work with Kirsten Walsh and Alice Murphy (Murphy, Currie, and Walsh forthcoming), which considers how experiments instantiate and afford various forms of scientific agency. Hopefully, one's preferred direction here shouldn't make much difference for my purposes.

imaginative abilities. Mike Stuart has examined these across various studies, summarized in Stuart (2024). Scientists vary in their reported and tested abilities in terms of mental imagery (visual and otherwise). I don't think we should say that those with more capacities in this sense are thereby more imaginative scientists. Let's suppose that Cuthill and Conway Morris were utterly bereft of the mental imagery required to perform anything like the geometric transformations described above—let's imagine they are *aphantastic*. That doesn't seem to block them from generating the model that they did. It strikes me that scientists who generate the same modelling work, where one is *aphantastic* and the other isn't, should be considered equally imaginative. Further, our scientists with rich mental imagination still must *communicate* their work: science is a fundamentally social activity, and this requires the use of artifacts beyond mental imagery.

None of this denies that, in some contexts, we may want to study mental imagination in science, or that we may wish to argue that highly agential epistemic goods, such as understanding, require according special status to the “internal” mind. Nor is it to say the scientists do not deserve praise for their imaginative work. Rather, an artifactualist account of imagination that considers imaginary content to be carried across various media and modes can make sense of scientific imagination's poverty and constraints, at least in the context of lost worlds.

So, where does imagination *happen*? Should we say that imagination occurs within the scientist's mind—properly scaffolded—or does imaginative content sometimes occur in the objects they construct? Although the artifactualist is led to say that imagination is extended in this sense, I'm not so sure whether answering this question, that is, unambiguously identifying “where” imagination happens, is so important. To see why, I want to provide an analogy with another human practice: making music.

Consider the solo human voice, singing a melody. Here, we're likely to agree that the music comes from the singer. Although the voice was likely trained, the song was written by somebody else, or at least drawn from a musical tradition, it is still pretty clear that it is the singer who generates the music. Now, let's add instruments and other musicians. We'll likely agree that the *musicians* collectively play the *music*, although some of the aspects of the sound come from their scaffolded interactions with each other and their instruments: these afford, to crib from Joel Krueger, acts of “musicking,” which generate experiences inaccessible without them (Krueger 2014). Now consider procedurally-generated music, often associated with Brian Eno: this

music is generated according to a set of systematic rules. Or consider music developed “in collaboration” with artificial intelligence. Here, we might disagree about whether AI is a collaborator, or, as Roberts and Krueger have argued, might take it as a fiction that the AI truly collaborates (Roberts and Krueger 2022). These questions about *agency*—about who is truly *acting* in the music-making—aside, we can still agree that *music is happening*.

I think we can say the same of the scientific imagination. Shifting from the scientist sitting in a dark room using their rich mental imagery to consider what the world might be like, to scientists as we’ve seen them in this book, in rich interaction with multitudes of perspectival tools, to—perhaps—the automated generation of ideas and experiments, we might have reasonable disagreements about who or what is doing the imagining. But *imagination is happening*. And, crucially, how the imagination occurs, the mode and medium, makes a difference to what it might do. As Mike Stuart points out, AI-designed experiments are often ugly in the sense that they do not follow the kinds of elegant norms and principles that human-designed experiments at least aim for. This is because their algorithmic mode explores the space of possible design options very differently from how humans do, and their media afford highly precise, high-speed information processing compared to our wetware. As Stuart puts it, “The reason that AI-designed experiments are ugly *and* epistemically good is due to a common cause: the nature of the algorithms involved” (Stuart 2023, 227).

Thus, just as understanding the aesthetic achievements of music requires attending to the various affordances of musicians, their instruments, and the musical tradition they follow, understanding acts of scientific imagination—where their ideas come from—requires careful attention to the modes and media at play. Who is imagining, or where imaginary content lies, are open questions. But in the present discussion, they are secondary.

Artifactualism’s main competition links scientific imagination with *make-believe*. This view is developed from a powerful form of fictionalism about models that understands them as props in games along the lines that Kendall Walton has argued (Walton 1993; for modelling views, see Toon 2012; Levy 2015). In brief, make-believe occurs when some combination of props and conventional rules prescribe that we imagine things to be thus-and-so. Say some children have constructed a sandcastle and are together telling a tale of medieval gallantry and the intrigue of castle politics. Here, the sand and its shape, and the conventions the children develop (one of them declaring a shell to be a knight, say) together prescribe their imagining that, say, the

seawater crashing into the sandcastle is a spell cast by an evil witch. Similarly, on such views, Mitchell et al. use a set of ecological models as props, which, in combination with the construal of that model, prescribes imaginings such as taking the two-dimensional Euclidean space of the spatial point analysis to represent ecological locations. As with fictions, propositions are generated by a combination of *primary truths*, roughly analogous to what would be explicitly stated in the text, and *principles of generation*, the rules of inference grounded in the conventions and props.

An immediate problem with using this form of fictionalism to analyse imagination is circularity: make-believe is understood as a prescription to imagine, and so trying to analyse imagination in terms of make-believe doesn't seem to get us very far. Fictionalist accounts of modelling explain idealization and other confusing elements of modelling practice by *appeal to imagination*. As Arnon Levy put it recently, "A central motivation for treating models as fictions is their shared imaginative, concrete-hypothetical character" (Levy 2024, 100). But explaining models or fiction with imagination—defining them as acts of imagining, say—requires an independent definition of "imagination" to avoid circularity.

Happily, Salis and Frigg do provide an independent definition of imagination. They commit to *propositional* imagination, that is, imagination that can be understood in terms of some attitude toward a proposition, *p*. For them, some mental act counts as imagining just when the act is (1) *free*, which is to say we're under no obligation to believe what we imagine,⁷ (2) *mirrored*, that is, the inferential rules work more or less the same as belief, and (3) *quarantined*, that is, the propositions we imagine and inferences we make on this basis do not directly affect our behaviours or other propositions, except when they are transported beyond the quarantine.

Following Salis and Frigg, the idea is that scientific imagining is an act of make-believe where props in combination with a set of conventional rules prescribe free, mirrored, and quarantined mental propositions. This account has a lot going for it. As Salis and Frigg argue, the view satisfies many desiderata of an account of scientific imagination: it is *constrained*, both by props and by the rules of generation, and it is *social*. "It has an objective content that is normatively characterized in terms of social conventions implicitly or

7 I take it that this doesn't conflict with the poverty of the imagination: we're not free to imagine whatever there is, I assume. This is a little ambiguous in Salis and Frigg: "We can decide freely what to imagine" (Salis and Frigg 2020, 30).

explicitly understood as being in force within the relevant game” (Salis and Frigg 2020, 44). It is also, as Levy (2024) explains, *normative* in the sense that models have content: one might be *wrong* about a model by, say, misconstruing the props or entertaining the wrong mental propositions.

What is the difference between artifactualism as I’ve described it and fictionalism? I suspect that we can quite happily map talk of *mode* onto social conventions, that is, the rules of the game, and talk of *medium* to props. I’m quite happy to think that a claim like “Mitchell et al. use a computational medium and statistical mode to generate a neutral result” is intertranslatable with “Mitchell et al. use a computer running a set of software as a prop which, in combination with statistical rules, prescribes imagining a neutral result.”

Like a fictional account of imagination, artifactualism can provide normativity. This is because artifacts are, well, built and used intentionally. I’ve previously distinguished between an object’s *physical* and *functional* properties (Currie 2017b). Functional properties are those physical properties that contribute to the intended purpose of the artifact. Take the PVC pipe that Woodruff and Varricchio used in their artficed dinosaur burrow. Here are two of its physical properties: it is *rigid*, and it is *white*. The former is a functional property because it is required to deliver the sediment to fill the burrow; the latter is not a functional property insofar as the pipe’s colour doesn’t make a difference to its purpose. As such, artifacts can have better or worse functional properties, can be misused, and, in contexts where the functions are representational, can be right or wrong. Note that I don’t think the functional properties should always be delineated via the intentions of the builder or designer of the artifact, but sometimes also in the context of use: the pluriptency of perspectival tools involves fruitful flexibility as to their use, and hence context-sensitivity as to which physical properties are functional, and how. Thus, functional properties are sometimes set by makers and sometimes set by users (Knuuttila 2024, 118).

Thus, fictionalism and artifactualism are very close. Indeed, Fiora Salis (2021) has incorporated an artifactualist element to a Waltonian account of modelling by emphasizing the material nature of “model descriptions” (approximately, the props). Salis might well be right that perspectival tools function as Waltonian fictions in some contexts, but as we’ll see, these don’t exhaust our interests here.

One difference between the views, recalling our discussion of artifactualism in chapter 6, is that make-believe is representation-first while artifactualism is not. However, this difference loses much of its import if we buy their

intertranslatability, becoming more of a matter of emphasis than anything else. And indeed, the use of props well captures the central motivation of the account I'm pushing: lost worlds reveal the poverty of the imagination, and this is overcome by the use of strategic perspectivalism, which in fictionalist terms would involve the construction and exploration of props and conventions.

However, I think there are two reasons to prefer artifactualism over make-believe fictionalism (see Friend 2020 and Thomasson 2020⁸ for other anti-fictionalist accounts of models).

First, and speculatively, on the face of it, make-believe fictionalism takes the propositional content of imaginings to be mental events, and although this might be plausible for scientific thought experiments, this is less obvious in modelling cases. In thought experiments, the props are linguistic descriptions or other representations that we then "play out" in our minds, coming to some judgement or understanding. Modelling cases might well involve a lot of mental action, but it is the model that generates the content on which the judgment is based. When Cuthill and Conway Morris generate rangeomorph morphology out of a computational system following a geometric three-part self-branching system, it is that computational system that generates the results. This process *could*, in principle, be done within someone's head, at which point it would take on the appearance of a thought experiment. But it doesn't. This suggests there is an analogy to the functional equivalence claim that infamously underwrites arguments for extending the mind (Clark and Chalmers 1998). If, in principle, diaries might play the same functional role as memory, and memory is defined functionally, then, in principle, diaries are *part* of memory. By analogy, if *imagining* is prescribed propositional content derived from props and rules of generation, then when the act of making inferences from props is carried out in a model, well, it seems as if the model is doing the imagining.

So, if we are functionalists about aspects of imagination, then we might be tempted to extend the imagination beyond mental acts. But this move appears to break elements of the view: I'm not sure, for instance, what it would mean for freedom and quarantining to apply to a model, as I'm not sure how to make sense of the difference between what a model "believes" and what it merely "entertains." The fictionalist, then, faces a dilemma: either models

8 I leave open whether Thomasson's artifactualism about *fictions* is consistent with artifactualism about *models*.

somehow prescribe that we perform imaginative acts that we do not (or cannot), or imagination is extended in ways that break down our working definition of it. By contrast, an artifactualist, it seems to me, can happily discuss scientists and their models as coupled, embedded systems in which acts of imagination occur.

A more plausible reason to prefer artifactualism, and much more importantly for the discussions in the final two chapters of this book, is the difficulty that make-believe comes to once it is applied to perspectival tools that are not models. Artificing is, at base, modelling with the intention of creating something with lost properties. But neither grafting nor anchoring involves modelling in the sense that fictionalists about models have in mind. When a scientist generates a phylogenetic analysis which, say, places *Dickinsonia* as a stem metazoan, they are not playing make-believe. They are making an inference. The easiest way of seeing this is just to say that quarantining fails: if *Dickinsonia* is a stem metazoan, this has further implications for how we reconstruct that taxon, as well as the order in which synapomorphies came online during the emergence of metazoans, and so on. Salis and Frigg might point out that this doesn't count as imagining at all by their account, which is right, but it certainly counts as a bona fide case of uncovering hitherto unseen or unconceived past worlds. So, that response won't work for my purposes, at least.

More difficult still for the fictionalist is imagining carried out with *specimens*. Not all perspectival tools are representations in the same way as models are. For instance, some perspectival tools are fossils. In chapter 4, we discussed a set of dinosaur trackways that were suggestive of a limp (recall this mattered because it would be indicative of pain-avoidant behaviour). There is no doubt that scientists considering the trackways would use mental imagining in considering how a critter might leave those tracks (as well as other perceptual tools), but it seems inappropriate to describe scientists as entering into a game of make-believe where they pretend that the fossils and trackways are, well, fossils and trackways. The fossil isn't a prop in a game of make-believe in these instances. Not only does quarantining fail as with the grafting case above, but I take it that it isn't at all make-believe that specimens are the specimens they are, with the aetiology they have: we're not *pretending* it is the case, but *inferring* it is the case. There is no doubt that some forms of

supposition⁹ and other acts of propositional imagining are involved in these cases—fossil interpretation involves interpretation and hypothesizing, of course—but to think that supposition is where things stay is to misunderstand the crucial role that specimens play in establishing the existence of lost denizens.

As I'll further explain in chapter 9, it is worth remembering the central role that specimens—traces of the past—play in the discovery of lost worlds: they are crucial for *re-contextualizing* evidence, information, and hypotheses provided by other perspectival tools. Insofar as traces provide a rich picture of an actual past, they ensure that the possibility we explore is relevant to that actual history. This point might lead us to question the relevance of “historical” studies that lean too heavily on either abstract modelling (Currie 2024a) or studies of contemporary phenomena (Meneganzin and Currie 2025). Without a rich record to be contextualized within, we might well agree that objective modal knowledge is being generated, but we might question whether that modal knowledge is in fact relevant to the historical targets we have in mind.

You might object here: doesn't the artifactualist do similar harm to specimens? Where the fictionalist gets things wrong by considering fossil interpretation as make-believe, perhaps the artifactualist mischaracterizes specimens by calling them *artifacts*. I think this is mistaken. It is certainly the case that applying strategic perspectivalism, as empirical reasoning generally does, requires *construction* in various senses. As Caitlin Wylie has documented and analysed, the use of fossils as data requires extensive *preparation*. But, as she argues, preparation sits somewhere between construction and “bare” empirical data (Wylie 2021). There might be some contexts where we want to distinguish between *constructed* artifacts like models and *prepared* artifacts like specimens, but I don't think epistemic damage is done either by the term “artifact” or the specificities of the view I've developed here.

Recall the distinction between physical and functional properties introduced above. A fossil has a bunch of physical properties—size, shape, composition, etc.—and the fossil preparator manipulates these properties to reveal and hone particular properties functional for palaeontological analysis (as well as storage and display). As such, the artifactualist has the conceptual machinery required to make sense of fossils as perspectival tools, and thus how they constrain and enable scientific imagining.

9 Salis and Frigg categorize *supposition* as a form of imagination that differs somewhat from make-believe.

Finally, the artifactualist is perfectly able to help themselves to the machinery of make-belief when it is appropriate (Currie 2017b). They are free to say that the mode in Cuthill and Conway Morris' models or in the experimental dinosaur burrows is to use those media as props in a game of make-believe. But the artifactualist can also accommodate the variety of other artifact-based interactions required to make sense of past worlds and uncover lost denizens.

Back in chapter 3, I appealed approvingly to philosophical accounts relating to "as if" representation, and this might seem to expunge the kinds of characterizations seen across uses of strategic perspectivalism and make-believe. However, as Salis and Frigg point out, propositional imagination is not restricted to make-believe; it also includes attitudes, such as supposition and counterfactual reasoning. If we isolate modelling cases, then I think make-belief gets us a long way, but it alone doesn't capture the scientific imagination. At its most minimal, to make scientific sense of data derived from observations, scientists must rely on a *frame*: decisions must be made about what to foreground and what not to foreground, what is salient, and what can be dismissed. We've seen palaeontologists artificing burrows frame their work by, say, backgrounding that the bones they use are from rabbits, but foregrounding their being from vertebrates. But this doesn't involve them engaging in make-believe, especially as it comes along with specific arguments suggesting that the particular features of rabbit bones compared to other vertebrates will not make a significant difference to their results.

To wrap up, then, let's consider how the artifactualist makes sense of the constraints on scientific imagination in targeting lost worlds. The various perspectival tools historical scientists construct can be understood as artifacts: they are various modes carried by various media, wherein the medium and use pick out some of the medium's properties as functional in particular contexts. Cuthill and Conway Morris' artificing are geometric modes in a synthetic, computational medium. Many of their model's properties have epistemic functions in virtue of their exemplifying traits that Cuthill and Conway Morris hope are also present in their target system. At the very least, they are functional in virtue of exemplifying traits and dynamics epistemically relevant to the task at hand. Fossils and data generated from fossils, such as Mitchell et al.'s scans and Varricchio and team's analysis of the burrow, are also artifacts. They are prepared in various ways to act as data and evidence; thus, some of their physical properties gain epistemic functions. The mineralogical medium of the fossil is treated as exemplifying an organismic

mode. As we saw in chapters 4 and 5, these various artifacts are brought into dialogue in virtue of overlaps in their representational or other functions, and these underwrite iterative, self-correcting investigations that can reveal lost worlds despite how much they diverge from the familiar present.

Thus, relevant scientific imagining is constrained and enacted through interaction with the multitude of perspectival tools at scientists' command. These enable us to imagine lost worlds.

