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Tool Use Beyond Humans

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Abstract

The definition of tool use has long been debated, especially in the context of tool use beyond humans. Despite repeated refinements of its definition, some recent work argues that the phenomena included within tool use are so broad and varied that there is little hope of using the category for scientific generalizations, explanations, and predictions about the evolution, ecology, and psychology of tool users. One response to this argument has been the development of *tooling* as a replacement for tool use. In this article, we analyze the tool use and tooling frameworks. Identifying advantages and limitations in each, we offer a synthetic approach that suggests promising avenues for future research.

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1. Introduction

Some dolphins use sponges to protect their nose while foraging on the seafloor (Krützen et al. 2005). Some orangutans use sticks to pry seeds from stinging fruit (Fox et al. 1999). Some Galapagos finches use cactus spines to dig grubs out of holes (Bowman 1961). Such discoveries are fascinating on their own, but they are also considered promising avenues of research on the distribution and evolution of sophisticated cognitive abilities. Despite this, there is considerable debate about how to conceptualize these behaviors. One school of thought considers these instances of "tool use" and attempts to define what tool use is as well as to link tool use with psychological and ecological factors. Tool use might, for instance, be an indicator of causal understanding, intelligence, or innovativeness (Bird and Emery 2009; Patterson and Mann 2011).

Throughout the history of the study of animal tool use, a series of tool use definitions have been proposed (Hall 1963; van Lawick-Goodall 1971; Beck 1980; Shumaker et al. 2011), but no consensus has emerged. A comparative analysis of the most well-regarded definitions of tool use (Crain et al. 2013) concluded that no single criterion is shared among all definitions, implying that each definition uses different indicators to determine which behaviors count as tool use. In light of this, contemporary empirical studies of nonhuman animal tool use often avoid explicit reference to any specific definition (Seed and Byrne 2010; Crain et al. 2013).

While some scholars continue to use the tool use category despite the lack of a consensus definition, others have begun to argue that tool use is not a useful scientific category, that it is not valuable for generalizing, explaining, or predicting the evolution, ecology, and psychology of tool users. The reason given is that because such a broad and heterogeneous class of behavior falls under the rubric of tool use, the fact that an individual is a tool user conveys little information about that individual's other traits (such as its psychology or ecology). One response to this seeming lack of scientific utility of tool use has been the development of a narrower, more precise concept tied to tool behavior: *tooling* (Fragaszy and Mangalam 2018). Tooling approaches animal tool behavior from an ecological theory of behavior based on a biomechanical analysis of movements and constraints, thereby aiming to place the study of tool behavior on a firm scientific footing.

As we will see, while the tooling approach has some advantages over that of tool use, it also has shortcomings. A key shortcoming is that because tooling is narrower in scope, it leaves much of what is traditionally considered tool use outside of tooling. In this paper, we articulate the nature, costs, and benefits of the tool use and tooling frameworks. We argue that while tooling has important benefits over the traditional tool use framework, it falls short of being a complete replacement for this framework. In light of this, we offer a synthetic account that combines key aspects of the tool use and tooling frameworks.

2. Classical definitions of tool use

Although ethologists had for decades documented instances of tool use—like extracting, pounding, and pulling, mostly among primates and birds—it wasn't until the late nineteen sixties and early seventies that explicit tool use definitions were offered. We will begin our survey of tool use definitions with the classical definitions of Hall (1963), van Lawick-Goodall (1971), and Alcock (1972), starting with Hall:

> The use by an animal of an object or of another living organism as a means of achieving an advantage. […] The mediating object is required by definition to be something extraneous to the bodily equipment of the animal and its use allows the animal to extend the range of its movements or to increase their efficiency. (479)

This served as a basis for the definitions of van Lawick-Goodall (1971) and Alcock (1972):

> Use of an external object as a functional extension of mouth or beak, hand or claw, in the attainment of an immediate goal. This goal may be related to the obtaining of food, care of the body, or repulsion of a predator, intruder, etc. If the object is used successfully, then the animal achieves a goal which, in a number of instances, would not have been possible without the aid of the tool. (van Lawick-Goodall, 1971, 195-196)

> Tool-using involves the manipulation of an inanimate object, not internally manufactured, with the effect of improving the animal's efficiency in altering the position or form of some separate object. (Alcock, 1972, 464)

These definitions share core similarities. Hall, Goodall, and Alcock all conceive of tool use as an action that establishes a relationship among three items:

a. A *subject*, which is the organism that acts (also called the *agent* or *actor*).

b. A *tool*, which is the mediating object (also called the *agent of change*).

c. A *target object*, which is the thing to which the tool is applied (also called the *object of change*).

Furthermore, these items exhibit a specific causal connection: *a* uses *b* to affect *c*. This causal structure allows us to distinguish proper tool use from other instances of object manipulation. If tool use is an object-mediated instrumental action, then it involves a triadic relational process, not a dyadic one. Thus, a capuchin monkey using its tail to hang from a pole, or a climber using the protrusions of a boulder to help it climb, are not instances of tool use because they do not involve a triadic relation. In both scenarios, the subject may be skillfully dealing with an object, but they are not using a mediating object to alter a target object.[1] Nest building also falls in this category.

To best understand the accounts of Hall, Goodall, and Alcock, we will focus on how they answer these two questions: How must an object be used for it to qualify as a tool? What counts as a target object? As we will see, despite some divergences among them, their conceptions overlap in most cases.

[1] Hall, Goodall, and Alcock do not reject these two behaviors as possible instances of tool use on this ground. Instead, they do so by denying that body parts can be tools.

How must an object be used for it to qualify as a tool? Each of these definitions holds that the mediating object—the tool—must be something external to the subject. Van Lawick-Goodall (1971) and Alcock (1972) go further, excluding other living beings from being regarded as tools. While Hall (1963) entertains the possibility of other creatures acting as tools, no instance of such tool use is reported in his article. Overall, the externality criterion serves the purpose of excluding body parts as tools. Hands, claws, and beaks are what a subject uses to manipulate a tool, not tools themselves. If we were to interpret body parts as tools, we would contravene the requirement that tool use is triadic, not dyadic.

A technique essential to skillfully climb a boulder is the full crimp grip, which involves grabbing a protrusion on the boulder with the fingers bent at the middle knuckles, while the thumb is bent over the top of the fingers. Despite the usefulness of this grip, it is not considered a tool. Nor is the rock protrusion, as we will see below. For this same reason, when a capuchin monkey uses its tail to sway poles, we are not witnessing an instance of tool use.[2]

While tool use thus requires external object manipulation—and not just using body parts in a tool-like way—what is it to manipulate an object? Hall, Alcock, and Goodall agree the object must be used with some degree of dexterity. Alcock (1972) discusses manipulation, but not to restrict tool use to actions in which a hand mediates the tool-subject relationship. Van Lawick-Goodall (1971) discusses the parts of animals' bodies that are involved in tool use but does not offer a detailed conceptualization of what kinds of use count as tool use.

Goodall, Hall, and Alcock, all hold that tool use improves behavioral efficiency. Hall conceives of it as a performance that aims at extending the motor range and reach of the animal when it expresses appetitive or aversive needs. Alcock subscribes entirely to this view, but Goodall adds a restriction, namely, that tool use applies only to needs that must be satisfied immediately. However, if not properly characterized, the immediacy criterion risks posing an overly restrictive timeframe for tool use. When chimpanzees "fish" for termites (van Lawick-Goodall 1971), they first collect or manufacture a bunch of leaves suitable to perform this behavior, then sometimes

[2] Van Lawick-Goodall (1971) uses a similar argument to reject interpretations of nest building as instances of tool use. In these cases, it is the beak or the claw of a bird that acts on a target, not an external intermediate object.

walk for half a mile before they use them. Is such a case "immediate" use? On the one hand, there is a significant delay between gathering the objects and using them as tools. On the other hand, when they are finally used, the needs are immediately satisfied.

What counts as a target object? Little is said about what kinds of objects qualify as tool use targets. Alcock (1972) denies that objects used on the user itself count as tool use. For him, target objects must be separate objects. Goodall and Hall refer only to instances in which the tool is used on a third object, but it is not clear whether they want to limit tool use to this type of action. Several animal species use environmental objects to scratch their back, but some animals, like horses and primates, are able to manipulate a stick to scratch their body to alleviate their itch. Such cases seem to involve tool use, but there is disagreement about whether the user itself can be a valid target object. Recall the triadic relation in tool use. For this to be maintained in the face of behavior like using a stick to scratch one's back, then the subject and target object must be able to be the same in some cases.

In sum, Hall, Goodall, and Alcock offer some relevant ground to demarcate tool use from other forms of organism-environment interaction. Their definitions have the merit of roughly aligning with our intuitions regarding tool use, which probably accounts for why some ethologists and comparative psychologists still use them. Nevertheless, these definitions are rather vague and have been criticized for inadequately answering the two questions considered above. More recent definitions have been offered to try to overcome some of the limitations of the classical approach, one of which we will focus on in the next section.

3. Contemporary tool use definitions

For an example of a contemporary definition of tool use, we will focus on Shumaker et al. (2011), which is an updated version of Beck's (1980) definition. We highlight their definition because it is widely considered the main point of reference in the contemporary tool use literature. Shumaker et al. (2011) criticize the classical approach to defining tool use along several fronts. For example, they point out that the classical account can be overly permissive and will include as tool use cases like a rat that learns through operant conditioning to press a lever to obtain a reward. Since only instances of manipulation that involve dexterity and control over an object are generally considered tool use, this is a problematic inclusion. Classical accounts can also be overly restrictive. If the sponge a dolphin is using is alive, then at least some classical definitions of tool use (such as Alcock's) will exclude this as a case of tool use. In response to these and other limitations, Shumaker et al. define tool use as:

> The external employment of an unattached or *manipulable attached* environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself, when the user holds *and directly manipulates* the tool during *or prior* to use and is responsible for the proper and effective orientation of the tool. (2011, 5)

This definition maintains the same kind of tripartite dynamic captured by Hall, Goodall, and Alcock, but offers a more precise characterization of the tool, its use, and the target object.

Under Shumaker et al.'s definition, any manipulable external object can be a tool, even living or deceased organisms. For instance, macaques sometimes grasp and hold infants when charged by aggressive conspecifics. This behavior, called agonistic buffering (Deag and Crook 1971), prevents or lessens the severity of the attack. In such a case, the baby is used as a tool (a shield). Additionally, tools can be unattached or partially detached from their location and can be externally or internally manufactured (allowing feces or exuviae to be used as tools).

The definition also takes a permissive approach to target object qualification. Any object whose condition, position, or form can be altered via an appropriate mediating object counts as a target object. Targets can include the organism itself, other animals, or environmental objects. The target could be a hermit crab that changes its condition by inhabiting a shell, a digger wasp burrow whose form has been altered after having been hammered with pebbles, or a fly that falls into the water after having been shot by an archerfish.

While Shumaker et al. are permissive about what can be a tool or target object, their definition excludes some cases that they identify as problematically included by classical definitions, such as lever pressing. Despite such advantages over classical accounts, Shumaker et al.'s definition is not immune to critique. Critics have mostly focused on the exclusion of some behaviors that they hold should be considered tool use, such as using objects to mediate information flow (Crain et al. 2013; Cenni and Leca 2020). However, Shumaker et al. do include social signal modification as a possible function of tool use, as well as tools more generally used for directing the flow of information.[3] Examples of information-focused tool use include gorillas checking stream depth with a stick and orangutans concealing themselves using a branch (Breuer et al. 2005; St Amant and Horton 2008). When a gorilla checks the depth, there is no external object they aim to alter (as is necessary for tool use under Schumaker et al.'s definition), but the tool is simply used to gain information about the water's depth.[4]

There is also the symbolic function of tool use. For example, consider the case of an orangutan who repeatedly handed a coconut to humans. When the humans kept giving it back, the orangutan held a stick and mimicked humans opening the coconut with a knife (Russon 2003). Although they do not present a compelling explanation as to why it should count as tool use, Shumaker et al. (2011) interpret this event as a case of a tool used to symbolize and communicate. The coconut is not (or need not be) altered for the signal to be effective. But perhaps it is the observing human and not the coconut that is the object. In this case, tool use would be effective if it altered the human, leading them to open the coconut.

Shumaker et al.'s definition classifies some actions in ways that seem hard to justify. While our focus here is non-human animal tool use, flaws in their framework can be highlighted through cases of human tool behavior. Consider the distinction between spear hunting, bow-hunting, and rifle hunting. The first two are tool use under their definition, while the latter is classified as

[3] As they state: "We considered adding a second sentence to the definition: 'The condition of another organism or the user itself may include its sensory input or its knowledge.' However, we decided that while this is a qualifying phrase, and a function of some tool use, it need not be part of the definition itself. Using an object to alter sensory input or knowledge of another organism would include modification of a social signal, which we would consider to be a function of some tool use" (Shumaker et al. 2011, 10).

[4] Breuer and colleagues (2005), followed by St Amant and Horton (2008), consider this an apt interpretation of the gorilla's behavior. However, given the anecdotal and isolated nature of the observation, further research is needed to strengthen the characterization of this behavior as informational tool use.

construction[5]. As such, using a gun is classified with nest building, not with bow or spear hunting. Shumaker and colleagues explain this distinction by noting that the shooter is not entirely responsible for all the connections between the rifle, bullet, and animal, and does not directly manipulate the object in its entirety (i.e., it does not manipulate the bullet). Certainly, there are evident mechanical differences between these performances, but we believe that hunting with a rifle is closer to spear hunting—hence tool use—than nest building.

One can quibble about other questionable classifications of Shumaker et al.'s definition and one can offer further refinements to their definition that allow for better classifications of tool use behavior. But instead of considering such refinements, we will now turn to an account of tool behavior that calls not just Shumaker et al.'s definition into question, but challenges the entire history of tool use definitions and the possibility of obtaining a scientifically useful definition.

4. Limitations of tool use as a scientific category

A rising tide of literature argues that tool use definitions are rather limited when it comes to generalizing, explaining, or predicting ecological, psychological, or evolutionary phenomena, especially in comparative studies (Mangalam and Fragaszy 2016; Cenni and Leca 2020; Colbourne et al. 2021, Heersmink 2022). In the face of these critiques, some have called for an approach to tool use that is more deeply connected to the ecology, psychology, and neurology of the behavior (Jacobs and Osvath 2016; Fragaszy and Mangalam 2018; Mangalam et al. 2022). Such critiques are not directed at Shumaker et al. (2011) or any other specific tool use definition, but to the overall framework through which animal tool use has been conceived and to its value as a scientific category.

Traditional approaches to defining tool use aim for a concept free from anthropocentric bias and broad enough to encompass all instances of what they consider to be tool use. In crafting such definitions, scholars have increasingly aimed to decouple the classification of behavior as tool use from the associated skills, ecology, and psychology of the tool users. As exemplified by

[5] A construction is defined as "two or more tools and/or objects physically linked to make a functional, semipermanent thing, that, once completed, is not held or directly manipulated in its entirety" (Shumaker et al. 2011, 19).

Shumaker et al., all that is required for tool use is a kind of object-mediated interaction. So long as this requirement is fulfilled, any object can be a tool or a target. While the traditional approach to tool use preserves inclusivity and allows for a rather efficient individuation of what qualifies as tool use, this inclusivity appears to have a downside. As Fragaszy and Mangalam (2018) argue, by divorcing tool use from specific mechanical, anatomical, neurological, or ecological parameters, the ability to use the category of tool use for explanatory and predictive power is undermined:

> We cannot claim that studies of tool use have made as significant an impact on our understanding of behavior as have, for example, studies of foraging or mate selection […] Nor can we claim that behavioral studies of tool use have had a strong impact on related fields, such as neuroscience or anthropology. Reports about tool use in nonhuman species by and large provoke curiosity, but rarely contribute to theoretical advances. (181-182)

What does this mean more concretely? Tool use in animals has been long considered to be a proxy for intelligence and cognitive abilities, such as problem solving, causal understanding, and goal directedness (Thorpe 1963; Parker and Gibson 1977; Peacocke 2011; Woodward 2011). However, its value for these tasks has been questioned, especially in light of empirical research indicating that sophisticated cognition is not needed for many forms of tool use (Shettleworth 2010; Emery 2013; Cenni and Baptiste 2020).

One example of evidence for this comes from an experiment by Teschke and colleagues (2011), in which the problem solving abilities of the woodpecker finch, *Cactospiza pallida*, were tested against non-tool-using conspecifics (tool use in this species varies across populations, habitat, and food abundance) as well as *Camarynchus parvulus*, a related tree finch species that does not engage in tool use. The groups were challenged to solve four problems designed to test different aspects of cognition, including problem solving and general learning abilities. The hypothesis was that the tool user group would learn to solve these novel problems more quickly than the other groups, given that the tasks resembled their natural tool use scenarios. Contrary to the experimenters' predictions, the group of tool users did not outperform the non-tool users in the physical cognition tasks and excelled in only one general learning task.

Their study suggests that tool users are not necessarily more intelligent than non-tool users, and that higher cognitive skills are not required for all forms of tool use. However, other studies highlight cases of tool use linked to higher cognitive abilities (Mendes et al. 2007). Thus, the relationship between tool use and cognition is less straightforward than it has been imagined in the past (Emery and Clayton 2009). Because of this, it may be difficult to make generalizations about the cognitive characters of tool users from the mere fact that they use tools.

Reports of the lack of explanatory and predictive value of tool use are not confined to the cognitive sciences. Colbourne et al. (2021) claim that the neutrality (with respect to the neurological and psychological underpinnings) of traditional approaches of tool use undermines its value for interspecific comparative analyses. They also claim that traditional approaches to tool use fail to offer insights into early human evolution based on the study of animal tool use. The neutrality of the traditional definitions—often considered an advantage and a way of avoiding anthropomorphism—thus appears to drain the category of tool use of scientific value.

In light of this apparent lack of scientific value, some scholars have begun to work on novel ways of conceptualizing animal tool behavior (Mangalam et al. 2022). In the following section, we will focus on *tooling* (Fragaszy and Mangalam 2018), an approach gaining currency in the empirical literature on nonhuman animals (Cenni and Leca 2020; Colbourne et al. 2021; Bastos et al. 2021; Jacobs and Osvath 2023).

5. Tooling

Tooling is not a mere iteration in the attempts to define tool use. Instead, it breaks with tradition and represents a rejection and replacement of tool use as a scientific category. In doing so, tooling offers a novel analytical approach to object-mediated instrumental action. Fragaszy and Mangalam (2018) define tooling as:

> *Deliberately producing a mechanical effect upon a target object / surface by first grasping an object, thus transforming the body into the body-plus-object system, and then using the body-plus-object system to manage (at least one) spatial*

> *relation(s) between a grasped object and a target object / surface, creating a mechanical interface between the two*. (194)

The domain of tooling so defined only partially overlaps with tool use as traditionally defined. Like tool use, tooling is an object-mediated instrumental behavior. In particular, it is an instance of problem solving that involves a relationship among a subject, a mediating object, and a target object. However, influenced by movement sciences and ecological psychology, tooling is centered on the analysis of specific kinematic, perceptomotor, and spatiotemporal features of a particular form of object-mediated instrumental action. Thanks to this focus, tooling offers a novel conceptualization and categorization of both the relationship between the subject and the mediating object, as well as between these and the target object. Proponents of tooling argue that because of its grounding in ecological psychology and the kinematic sciences, tooling has better explanatory and predictive power than the traditional tool use category.

According to Fragaszy and Mangalam (2018), when a user grasps an object to reach a target, the tool becomes a part of the subject's body, transforming the dyadic user-object relationship into one system: the *body-plus-object system*. This embodiment of the tool has a double effect on the user: First, it influences what the subject perceives as affordances. Second, it alters how it coordinates and interacts with its environment. These changes are most clearly observed if one focuses on the mechanical and psychological consequences of the embodiment (Mangalam and Fragaszy 2016).

While traditional approaches to tool use suggest that tools simply extend the reach, strength, or range of an animal's movement, Mangalam and Fragaszy (2016) propose that we conceive the relationship between the body and the tool in terms of *degrees of freedom* (DoF). In particular, they stress that during tooling, the animal's body acquires at least one novel DoF. The concept of *degree of freedom* is derived from a kinematic approach to locomotion (Bernstein 1967) and it is used to map out how a rigid object moves in a three-dimensional space. An object can change its position by moving along three axes: forward-backward (surge), up-down (sway), and left-right (heave). In addition, it can rotate on each of these axes. Thus, we have a total of six DoFs. As an example, if we assume that hand, elbow, arm, and forearm form one block, then raising an arm involves only one DoF, namely the rotation of the arm on the "left-right" axis, which is made possible by the shoulder.

In the interaction with a tool, a subject acquires at least one novel DoF (and thus the possibility of a novel movement) since there is one more rigid item that composes the body (now body-plus-object system). This acquisition triggers a redistribution of the overall DoFs, since using a tool changes the way the subject coordinates and manages their own body and, consequently, how it interacts with the environment (Fragaszy and Mangalam 2018). An example will help to elucidate this point. Grasping a screwdriver enriches one's movement repertoire by adding at least one novel DoF since one can now rotate a screw to drive it in or remove it. A series of conditions need to obtain for this action to be successful: the fingers need to be firmly wrapped around the handle of the screwdriver, which needs to be more or less parallel to the screw, and the arm has to be extended. These conditions correspond to constraints that the new action imposes on the body. It is in this sense that tooling involves the acquisition of novel movements and the reorganization of the extant DoFs.

In addition to these mechanical consequences, the transformation of the body into the body-plus-object system carries psychological significance. Fragaszy and Mangalam (2018) suggest that tooling entails a change in how tool users perceive the boundaries of their own bodies. In particular, the interaction with a tool extends the perceptual range of the subject, since the subject's "end effector" (the part of the system that interacts with the environment) is now the end of the tool, and not the end of the body. This phenomenon is called *distalization of the end effector* (Arbib et al. 2009) and has been assessed as a crucial factor for a correct representation of the user-tool relationship (Miller et al. 2018; Osiurak and Federico 2020; Mangalam et al. 2022). It consists of the transfer of the locus of perception from the boundaries of the body to the boundaries of the tools via the conduction of mechanical feedback from the tool to the body. In other words, since the user seems to sense with the tool itself, the user perceives the tool to be part of its body.

Finally, Fragaszy and Mangalam's approach introduces a new strategy for analyzing and categorizing the interaction between the body-plus-object system and the target object. This interaction is conceived as a spatial relationship: the body-plus-object system interacts with at least one target object, thus creating a spatial connection between the two. The assessment of this relationship is based on different spatial features including the egocentric or allocentric framework of reference, the number of spatial relations, the temporal dynamic (static or dynamic), and the specificity or precision in the action required to succeed in tooling.

The determination of these precise kinematic and perceptuomotor parameters, left unspecified in the literature on tool use, radically transforms the individuation and classification of object-mediated instrumental actions. By providing finer, measurable criteria across multiple dimensions, this approach yields more precise and interpretable data, leading to analyses that are more robust and replicable. Improved replicability is a critical advancement for cognitive and behavioral research, particularly in a field plagued by a replication crisis and historically reliant on anecdotal and sparse observations of potential tool use instances.

These parameters also enable more consistent grouping of behavioral instances, but also lead to the exclusion of many actions traditionally categorized as tool use, such as projectile throwing. Projectile throwing involves perceptuomotor features, spatial relationships, and organismal and environmental constraints that fall outside of tooling. For example, the distalization of the end effector—a hallmark of the body-plus-object system in tooling—is absent in projectile throwing, as is the specific perception of environmental constraints central to tooling behaviors.

In summary, the tooling framework introduces a methodology grounded in specific kinematic and psychological markers. This allows for more precise measurements of tool behavior, more coherent comparisons across species, and better interpretability of findings, ultimately offering promising advancements for the study of object-mediated instrumental actions and their associated cognitive and neurological dimensions. The apparent advantages of the tooling approach of Fragaszy and Mangalam (2018), and the limitations of the traditional tool use framework, lead us to ask whether we should simply replace tool use with tooling.

6. Should tooling replace tool use?

Although tooling is offered as an alternative to tool use, it has limitations that make it problematic as a complete replacement.

First, since tooling is restricted to direct mechanical interactions between a body-plus-object system and a target object, much of what has been traditionally understood as tool use is excluded. Behaviors like projectile throwing, dropping, and baiting require that the tool be released or detached from the subject during its use, which tooling forbids. Some of the excluded behaviors represent the very foundation of the interest in animal tool behavior. For Hall (1963), primates breaking off and throwing branches to scare off intruders was taken to be a standard of what tool use means. Along these lines, van Lawick-Goodall refers to instances of birds "picking up stones to drop or throw on hard shelled food" (1971, 198) as paradigmatic cases of tool use. Recent tool use discoveries include tool behavior that does not require the grasping of the tool, such as crocodilians positioning small sticks on top of their snout to lure birds (Dinets et al. 2015).

Being restrictive is especially problematic for cases of behaviors that are excluded from tooling yet are the same—under some descriptions—as ones included in tooling. For instance, consider applying one object to another. This can be manifested by different forms of interaction between the subject, median object, and target object. Some cases meet the requirements for tooling, while others do not. One that meets tooling criteria is hyacinth macaws' application of wood wedges or leaves around nuts placed in their beaks to facilitate nut cracking (Borsari and Ottoni 2005). By contrast, a squirrel applying a snakeskin to their fur to repel predators is not considered tooling (Clucas et al. 2008). Despite the latter not being tooling, both are examples of problem solving achieved by applying an object on a target (namely, the nut and the squirrel itself). The sameness of these behaviors is not reflected by tooling and it is therefore possible that tooling is masking useful similarities.

By excluding many instances of tool use, the tooling approach risks losing sight of the broader goal of the traditional approaches to tool use research. Tool use is not merely about the mechanical action of manipulating an object to act on a target. It is also about understanding the possibilities and consequences created by manipulating an object in a specific way and context (Baber, 2006; Baber et al., 2014). This ability is expressed in diverse forms across various contexts. While these expressions differ in their biomechanical and psychological details, they all share a connection to the overarching ability that tool use represents. Traditional approaches to tool use, despite their shortcomings in providing detailed parameters for biomechanical and psychological analysis, succeed in capturing this generality.

If we accept that tool use represents a general ability, it becomes essential to differentiate it from tooling. Tooling, while offering valuable insights, cannot be equated with the broader concept of tool use. Rather, it represents a specific instance—a particular pattern of interaction that exemplifies one way in which the general ability is expressed. This distinction highlights a key point: tool use and tooling target different explanatory domains. Tool use focuses on the overarching ability to manage objects to achieve goals, whereas tooling emphasizes the specific kinematic and perceptuomotor dynamics involved in one form of tool use.

Rather than viewing tool use and tooling as competing frameworks, they should be seen as complementary. Tool use captures the breadth of the ability to recognize and use objects to achieve goals, while tooling offers the analytical precision needed to investigate the dynamics and features of a specific kind of tool use behavior. Instead of choosing one or the other, we will argue below that we can retain both, allowing us to illuminate the diversity of tool use behaviors while at the same time articulating the specific cognitive and neurological mechanisms underlying its various forms, paving the way for more unified and insightful research.

In sum, while the tooling framework of Fragaszy and Mangalam (2018) carries many predictive and explanatory strengths, viewed as a replacement for the category of tool use, it has shortcomings. One of the biggest limitations is the fact that the domain of tooling is far smaller than the category of tool use. Faced with the benefits and drawbacks of both tooling and tool use, the question is whether we need to choose one or the other, or if there is a way of retaining the best of both. In the following section, we propose a way of building on the tooling framework in order to capture more of the domain of tool use, but in a way that retains the precision of tooling.

7. Synthesis

Animals use objects in a variety of manners and for a diversity of ends. Sometimes they maintain a grasp on the object and use it to physically manipulate a target object (in line with tooling), but other times the object is used for informational purposes or is released from grasp (St Amant and Horton 2008). These latter uses are excluded from tooling but fall within the broader category of tool use. We see the appeal of the tool use category but recognize the validity of the criticisms arising from the tooling camp. In light of this, we seek a synthesis.

To synthesize the accounts, we propose to distinguish two modes of interaction between the subject and the tool (retention and releasing) and two modes of interaction between the tool and the target (mechanical and informational). Retention refers to when the object is held throughout the duration of its use. Releasing, by contrast, occurs when an object is discharged from the direct physical control of the subject, though its movement in space and/or its orientation may be determined by the user. The mechanical-informational distinction is between object-mediated instrumental actions that generate their effect on the target object through direct contact and actions that generate their effect via changing the flow of information (between the subject and the target or between the target and its environment). These two distinctions can be ordered into a two-dimensional array, resulting in four categories of tool use (see Table 1).

	Mechanical	**Informational**
Retention	Maintaining a grasp on an object to mechanically affect a target object. Examples include every behavior that qualifies as tooling (Fragaszy and Mangalam 2018).	Maintaining a grasp on an object to change the flow of information (between the tool user, the target object, and/or other subjects). Examples include gorillas using sticks to check the depth of a pond (Breuer et al. 2005).

Releasing	Releasing an object to mechanically affect a target object. Examples include Egyptian vultures launching rocks on eggs (van Lawick-Goodall 1971) and archerfish spitting water at prey (Schuster et al. 2006).	Releasing an object to change the flow of information (between the tool user, the target object, and/or other subjects). Examples include primates violently throwing objects to gain social dominance (Goodall 1964, Lombardo and Deaner 2018) and California Ground squirrels throwing material to draw a predator's attention away from a burrow (Coss and Biardi 1997).

Table 1. Four categories of tool use, one of which represents tooling.

Let's consider each of these four forms of tool use, beginning with retention-mechanical. This category corresponds with tooling as spelled out by Fragaszy and Mangalam (2018). Thus, all the forms of tool use that fall into this category display the defining features of tooling. Examples include New Caledonian crows using twigs and other objects to extract prey from crevices (Hunt and Gray 2004) and capuchin monkeys using stones to dig up roots (Mannu and Ottoni 2009).

Next consider retention-informational tool use, which involves object-mediated instrumental actions performed with the aim of changing the flow of information (between the tool user, the target object, and/or other subjects). Gorillas using sticks to learn about the depth of water falls within this category (Breuer et al. 2005). Interestingly, this behavior involves the formation of a body-plus-object system, some degree of distalization of the end effector, and a direct interaction of the body-plus-object system with a target surface. However, this doesn't count as tooling since the action is not performed to modify the stream or pond bed, but to serve as an extension of the Gorilla's arm, thereby letting information about the water flow through the tool to the gorilla. Thus, it is a mechanical interaction that satisfies an informational goal.

Next, we have releasing-mechanical tool use. While this category falls outside of tooling, the same kind of kinematic, perceptomotor approach used in tooling can be applied to this form of tool use. We expect that commonalities among different instances of projectile throwing or dropping will be found by investigating this kind of tool use. This category includes many of the classic cases of projectile throwing such as Egyptian vultures launching rocks onto eggs (van Lawick-Goodall 1971), and archerfish spitting water at insects to make them fall into water (Schuster et al. 2006).

Finally, we have releasing-informational tool use. This is farthest from tooling, since it involves neither the continual grasp of the tool, nor the tool's use for mechanical interactions with the target. It is nevertheless an important category of tool use. Unaimed throwing frequently occurs during displays by male chimpanzees. They toss branches, sticks, stones, sand and grass without specific targets during agonistic displays. This behavior has been interpreted as communicating the individual's readiness to respond to intra- and interspecific threats (Goodall 1986, Lombardo and Deaner 2018). Another example is that of California ground squirrels (*Spermophilus beecheyi*) throwing material to keep snakes from discovering their burrows (Coss and Biardi 1997).

Our synthesis acknowledges the diversity of tool use, understood as the ability to identify objects as means for action and to manipulate the objects to act on a target. At the same time, we recognize the need to categorize different forms of tool behaviors based on specific biomechanical features. The approach of tooling has the advantage of tying tool behavior to specific mechanisms, but excludes most tool use behavior. Our synthesis extends the methodological advancements proposed by the approach of Fragaszy and Mangalam (2018) to encompass forms of object-mediated instrumental action not including within tooling.

This framework takes tooling to be a kind of tool use together with three additional categories. The sum of these four categories thus retains the advantages of tooling but no longer excludes most of what is traditionally considered tool use. Note that we say *most* of tool use. While we believe that the vast majority of documented tool use cases falls within our four categories, we do not claim that every instance of tool does so. It is possible that some tool behavior falls outside of our framework. If so, additional categories could be introduced without undermining the relevance of our framework.

We are optimistic that generalizations within each of the four tool use categories will be more robust than generalizations across tool use as a whole. Thus, this synthesis is a way of keeping the general category of tool use but dividing it into kinds to better serve scientific needs. In particular, tooling's focus on specific kinematic, perceptomor, and spatiotemporal features provides a solid foundation for generating reliable predictions, comparisons, and generalizations. Our synthesis broadens the scope of these features to include instances of tool use that the tooling framework overlooks, thereby expanding the epistemic benefits it offers. Furthermore, by grounding tool use on a firmer conceptual foundation, we not only enhance our understanding of tool behaviors but also pave the way for more effective studies of the cognitive abilities associated with tool use, such as future planning.

8. Conclusion

Observations of animals using tools to achieve goals have long captivated our curiosity and imagination. However, it is not clear to what extent tool use as a general category aids in understanding nonhuman animals' higher cognitive skills or in tracing the origins of human technical intelligence.

The historically dominant framework for studying tool use aims to encompass the entire realm of animal object-mediated instrumental actions. Thus, it favors broad definitions mostly based on a formal resemblance with how humans manipulate tools and is not anchored by specific mechanical or psychological mechanisms. Because of this, tool use is quite limited as a basis for comparative studies and doesn't ground many predictions and generalizations.

Fragaszy and Mangalam's tooling framework aims to overcome key scientific limitations with the tool use category by grounding tooling on specific kinematic and spatiotemporal parameters. This holds promise for making better generalizations and predictions. However, tooling can provide only a partial understanding of object-mediated instrumental action. Tooling focuses solely on the dynamic nature of one class of behaviors and leaves out much of what is traditionally understood as tool use.

Rather than viewing tool use and tooling as alternative frameworks, we propose that they can be complementary. Our model distinguishes two modes of subject-tool interaction (retention and releasing) and two modes of tool-target interaction (mechanical and informational). There are thus four forms of tool use, only one of which is tooling. The conjunction of these four forms borrows the precision and grounding of tooling without losing the breadth of tool use as traditionally understood.

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