A Unifying Account of Technological Knowledge: Animal Construction, Tool Use, and Technology

Ashley Shew Heflin

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Science and Technology Studies

Joseph C. Pitt, Chair
Davis Baird
Richard M. Burian
Richard Hirsh

March 15, 2011
Blacksburg, Virginia, USA

Keywords: technological knowledge, know how, animal tool use, epistemology of technology, animal architecture

A Unifying Account of Technological Knowledge:
Animal Construction, Tool Use, and Technology

Ashley Shew Heflin

ABSTRACT

Philosophers, historians of technology, and anthropologists often offer accounts of technology that include a "human clause," some phrase to the effect that only humans use or make technologies. When these academics do consider tool use, they refer to a few cases, usually from chimpanzee studies, as special and unusual in the animal kingdom and whose similarities to human tool use can be explained through some shared evolutionary heritage. However, new observational and laboratory animal studies demonstrate that tool use and the use of learned techniques are actually more widespread than many scholars have appreciated, encompassing the behaviors of dolphins, crows, gorillas, and octopuses. Some studies have shown that even species that are not known to produce tools in the wild can, in the right contexts, produce and use tools as capably as related species that do employ tools. Some of the non-human animals' tool use and manufacture indicates learned components, shared material cultures, innovation, an understanding of 'folk' physics and causal reasoning, the standardization of tools, and the use of metatools.

This dissertation involves a reflection on these new animal studies cases: what they might indicate, how they relate to concepts used in defining technology (and humanity), how they might disrupt human-centered models of technology. This dissertation also provides a framework for considering these animal cases within the context of technological knowledge, one important concept in philosophy of technology. To highlight the relationships between two different approaches to technological knowledge, this project introduces a graphical model for considering animal cases alongside human technologies; mapping individual technologies and techniques in terms of technological know-how and encapsulation of information allow for the additional consideration of animal constructions – webs, nests, dams, etc. – alongside animal tool use and human technologies. By categorizing non-human animal constructions, tool use, and technology along the same axes, we see that the individual material products of humans and non-humans are often a matter of degree, and not a matter of kind. Animal constructions and tool use can be productively incorporated into philosophy of technology.

ACKNOWLEDGEMENTS

This work has been shaped by my situation at Virginia Tech, the opportunities and generosity provided by the Departments of Science and Technology in Society (STS) and Philosophy, the support and enthusiasm of my graduate student colleagues, and the incredibly helpful advice of many faculty members. Thank you all!

I've been thoroughly lucky to have wonderful guidance while pursuing this topic. Though I did not fathom this project at the time, I was introduced to technological knowledge by Davis Baird at the University of South Carolina as an undergraduate researcher on the the ethical, social, and epistemological issues of nanotechnology. At Virginia Tech, Laura Perini, teaching a core STS class on philosophy of science and technology, served as my first sounding board for ideas that have led directly to this dissertation. Historian of anthropology Matthew Goodrum provided valuable feedback and encouraging enthusiasm on precursors to this project, serving on my two prior masters committees. Philosopher of biology Richard Burian has had the patience to correct my terminology and direct me to appropriate sources for ideas on biology and intention. Historian of technology Richard Hirsh has pushed me to write more carefully and crisply – so readers should be thankful to him! All errors of judgment and proofreading within this document remain my own.

I've been a "Joe student" for six years, and I am grateful for the freedom and conflict that this moniker confers. Though I spend a good deal of time arguing against aspects of Joe's work, I think his broader program of thought and his approach to science and technology studies are incredibly worthwhile, refreshing, and productive. Joe, thank you for egging me on.

I thank my committees and departments for their flexibility and support in the face of the work-life issues While pursuing my degree, I met my husband, married him, and we now have two children, Zora (2 years old) and Leah (2.5 months old). Thanks goes to my family for their support and naptimes, without which I would have never been able to complete this dissertation!

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

Chapter 1: Introduction and Literature Review

In Fall of 2010, National Public Radio (NPR) ran a series on the topic of "The Human Edge."[1] While it is certainly (and perhaps trivially) true that human beings have an evolutionary advantage to surviving as humans (in our particular niche), the way in which stories like this NPR series are couched – *with an assumption that humans have some sort of overall edge in the first place* – strikes me as very uncomfortable.[2] Most animals do, in fact, have an edge for survival *in their particular niche*. Evolving in a particular environment makes a species become better suited for that environment. Pieces in the NPR series dealt with such things as how the human hand is so incredibly useful for fashioning tools[3], on how the human voice can intone and produce wide variety of sounds so perfect for communication (even our closest chimp relatives cannot produce the sounds we can!), on how humans are adept at writing stories, and even on how the evolution of tear ducts serves a useful function (as a signaling function to others that wouldn't let predators know how scared a human was), etc. (2010). This series delves into the evolution of a host of features that make us distinct from other animals, though they give references to parrots and chimps as part of the discussion.

---

1 The audio recordings of this series can be found here: http://www.npr.org/templates/story/story.php?storyId=128245649

2 I consider the sin of species arrogance much more serious a threat to clear thinking than the threat of anthropomorphism. Mistaken anthropomorphism might make use elevate animals in our thinking, but the species arrogance of human beings allows for much greater injustices.

3 With the narrator of the piece actually saying, "I have the hand of the ultimate tool maker" at one point!

If someone were to do a piece that replaced 'human' with any subset of humans or with any professional group, public outcry condemning the piece would soon follow, or at least some heavy skepticism about the series would exist. Over the course of human history we have witnessed the violence that can follow when one racial or ethnic group promotes itself as superior in some way, at the expense of other groups. If it were merely a professional group promoting itself, an STS paper on “The Elitist Language of Physicists,” deriding the haughty language physicists use in describing themselves and their profession, would appear.[4] Most professional groups actually do this sort of thing – the pages of *Chemical and Engineering News* always tout chemistry as “the central science,” and I have witnessed administrative professionals comparing themselves to the central nervous system in the body, relaying information and keeping everything running. The self-promotionalism of these groups boosts morale and maintains a group identity, keeping people proud in their roles. NPR seems to be doing the same thing in this series: are we humans patting ourselves on the back (with our impressive hands!) for being human, admiring our own work and complexity in a self-congratulatory way?

This dissertation develops an epistemology of technologies that considers some of the actions and products of non-human animals as technological in character. Typically, we think of things as 'technological' in character when they are made, designed, employed, or implemented by human beings; in fact, the idea of technological knowledge – knowledge of how things work, of how to work things, and of how to create devices[5] – has typically been discussed in terms of

---

[4] I actually saw a paper by this title delivered by Stuart Mawler at the Brian Bertoti Graduate Student Conference at Virginia Tech (2006).

[5] Knowledge-bearing?

human agency by historians, anthropologists, and philosophers of technology and of engineering. Though occasionally employed in discussions of computer intelligence, technological knowledge is most often considered as the domain of engineers and craftsmen. However, these discussions overlook a large portion of the knowledge implemented in the world: namely, the technological knowledge employed by and associated with non-human animals.

This suggestion – that non-human animals have 'technological' anything – may initially strike some as absurd, for our definitions of technology often involve a human component. But, if we disregard the human portion of these definitions (which I argue we ought to do), the ability of some animals to shape and employ tools fits within the scope of technological knowledge as it is discussed by some philosophers of technology. To embark upon this project, I advance a more inclusive account of technology and tool use, give an argument for technological knowledge as inclusive of animal tool-making and -use, and provide a defense against possible objections by looking at actual cases of non-human animal tool-use. The content and nature of animal "minds"[6] becomes relevant in this discussion insofar as technological projects remain intentional, designed, and purposeful.

---

[6] Or, if preferred, animal awareness. The problem of whether or not animals have minds is equally vexing as the problem of whether human beings have minds. Strict materialists say there is no such thing as a mind and argue that all we have are brains. I do not wish to engage this discussion. We can talk about animal minds in terms of intentions, thoughts, cognition, awareness, in much the same way as human minds have been discussed. The terminology of "minds" may be controversial in some circles, but its use handily covers a wide range of "mental" content and representation. I use the term to refer broadly to the thought-content of animal brains – or whatever does the thinking in either human or animal brains.

The impetus for considering animal tool-use within philosophy of technology is the wealth of observational data concerning animal minds and new animal behaviors witnessed and recorded over the past decade or so. A growing literature on animal tool-use indicates much more sophistication than philosophers interested in technology have appreciated. New observations and observational practices have led to an impressive catalog of animal tools and their uses. From dolphins using sponges to help rustle up food to a chimp arming himself with rocks to throw at zoo-goers to crows shaping twigs in a number of distinct ways, the literature on animal tool-use has witnessed an explosion. New observational techniques, like camera traps, have contributed to some of these revelations, but even cameras in the hands of amateurs who post online videos of birds stealing bags of chips have contributed to a more general and popular recognition that the ability of non-human animals to manipulate their environments goes beyond what had been previously supposed. New techniques used by animals – to, say, open a bag of Doritos pilfered from a convenience store (CorellianScoundrel 2008) – are not simply the product of instinct in any pure sense.

These videos, pictures, and observational accounts – and even sometimes in the made objects examined by researchers – reveal the use of patterns, techniques, and strategies, the cultural transmission of know-how, the mimicking of others, the fashioning of implements. Similar processes can be seen on the part of human beings as we manipulate the environments in which we exist. Some objection may arise that what animals do and make, however sophisticated it may seem, is simply the product of some behaviorist stimulus-response or instinctual mechanism, not an example of planning or goal-directed problem solving. Certainly, in some contrast cases that I explore, there are some animal-made creations that we would *not* count as technologies at all – spider webs and beaver dams fall into this camp.[7] However, I claim that, *at least in the case of some animal artifact-use*, the sorts of things we associate with human technology – planning, problem solving, design – exist. *My guiding question is: do the activities of these creatures count as technological knowledge in the way human enterprise culminates in, encapsulates, or demonstrates technological knowledge?*[8] This question leads to an account of technological behavior that accounts for several approaches to technological knowledge and that remains sensitive to a wide range of animal cases.

My strategy for investigating this question consists of looking at the many ways in which technological knowledge has been described, to take each of these ways (or the important components) and, with use of animal case studies, argue that the type of technological knowledge in question applies equally well to non-human tool-users as it does to their human counterparts. My goal is twofold: (1) to establish that animal tool-use can and should be investigated by epistemologies of technology and (2) to initiate this work. The theoretical framework at which I arrive in this dissertation unites two different discourses on technological knowledge – one on the knowledge-content of objects and the other on learned skill or know-

---

7 But these things are related to technology, even if they aren't technologies. The account I offer can encompass a much wider variety of behaviors as they relate to to the use of artifacts.

8 In my second chapter, I draw some distinctions between knowledge, artifact, tool, and technology that will help clarify this project. Though there is more to consider about animal artifacts and how they fit into philosophy of technology, I have chosen to concentrate on technological knowledge as the lens through which I examine animal tool-making and -use. Technological knowledge has enjoyed some deliberation in the philosophical literature and provides a relatively straightforward point of entry that, for example, metaphysics or ethics of technology would not.

how by the tool user or maker. By mapping out animal constructions alongside human technologies on these two axes of interest, we can unite dialogues on biological and engineering design and provide a more coherent, unified account of made things.

The literature from which this dissertation draws comes primarily from three different bodies: (1) work on technological knowledge by philosophers, (2) work on animals from zookeepers, biologists, hobbyists, animal psychologists, and other specialists, and (3) reflections from philosophers of biology on animal studies. I spend the greatest portion of this dissertation on the first two bodies of work.[9]

Literature Review

Technological knowledge has been discussed in several ways by philosophers. At least two major types of accounts of technological knowledge exist. For the first type, these accounts of technological knowledge have been most often developed in contrast to scientific and theoretical knowledge; a negative reaction to the idea that technology serves as the handmaiden of science – that technology is merely or mostly 'applied science' – serve as an impetus to develop more clearly a domain of knowledge that remains special to technology. A. Rupert Hall (1978), Edwin T. Layton, Jr. (1974), Walter Vincenti (1994), Carl Mitcham (1994), and Joseph C. Pitt (2000) develop accounts that separate technological knowledge from scientific knowledge. In these accounts, much has been made of the distinction between 'knowing how' and 'knowing that'. This

[9] Focusing on the philosophy of technology, rather than the biology, is important for framing the topic into something manageable in a dissertation, but the biological literature is extremely important for continued work on this topic.

distinction remains fundamental to the first major way in which technological knowledge has been described. Technological knowledge, according to these historians and philosophers, consists of knowledge about *making* or *doing* something. Though they flesh out their concepts in different ways and with different sub-categorizations and types, and despite disagreement about the division between know-how and know-that,[10] these accounts are unified by the way in which they force us to identify the special character of knowledge produced and used by human beings in their technological endeavors. This *human-beings* component appears nearly universal in accounts of technological knowledge, and I seek to eliminate it.

A. Rupert Hall's account of technology involves human agency, going so far as to equate the history of technology with man's history as a maker of things (*homo faber*). He explains technological knowledge in terms of man's history, relating a young boy's knowledge of bicycle riding to prehistoric skills of blade-forging and clay-pot making. Using a notion of know-how that we find common in definitions of technological knowledge, Hall explains that

> Knowing how to ride a bicycle consists in acquiring a certain set of neuro-muscular co-ordinations as does mastery of many technical skills such as throwing a clay pot, making a good saw cut and ploughing a straight furrow. (1978, 94)

Knowing how involves coordination of the body, the learning of a skill. Hall makes a further distinction between "age-old" know-how and the mathematicized knowledge of steam-engines and airplanes; the character of technological knowledge changed though some application of

---

[10] For instance, Vincenti thinks both are involved in engineering knowledge; Hall thinks they are more closely connected than Layton does.

science and some imitation of science (ibid., 98). Hall gives us no reason why the neuro-muscular coordination and skill of which he speaks could not be performed (in its own way) by non-human actors. Though he describes technology in terms of what man has made, his discussion of know-how certainly leaves room for animal cases to be cast in his terms. However, any discussion of animal cases comes with the same warning Hall has concerning our reading of ancient human artifacts: we must be careful not to posit too much about the cognitive capabilities of those who produced such artifacts.[11]

In his 1978 article "On Knowing, and Knowing how to...," Hall argues against Edwin Layton's account of technological knowledge and its separation from science. Hall provides a historical model whereby science and its imitation plays into the way in which technologies and technological knowledge are now constructed. Layton envisions a much deeper division, picturing science and technology as wholly different bodies of knowledge that feed off of each other without the connectedness seen in other accounts. In both "Mirror-Image Twins: The Communities of Science and Technology in 19th-Century America" (1971) and "Through the Looking Glass, or News from Lake Mirror Image" (1987), Layton depicts the relationship

[11] Of course, we assume the cognition of other humans all the time. A huge issue with animal studies is the problem of induction on the ability of animals to think, feel, and reason. Even if we witness a smart or emotional action on the part of some animal, we are often more skeptical about these inferences than we are about the inferences made for other humans. We understand what it is like to be human, have goals from a human frame of reference, etc., so reading the emotions of other humans and inferring their intelligence often rests on assumptions – ones that we are much more comfortable with for humans than for non-humans. (Discussions on AI and intelligence also bear on this topic.) When is it justified to make the inference that something feels/thinks/reasons?

between science and technology as a mirror-image: their images are very much alike, but different in important ways and firmly separate from one another. Rather than an image of science passing knowledge for practical use down to technology (technology as applied science), the flow of knowledge from technology to science exists in symmetry with the flow from science to technology. Technological knowledge, for Layton, can be divided into technological science (or theory), design, and technique (1987, 604). Design involves all three components, and is "knowing how," a phrase synonymous with technological knowledge for Layton, "at the highest level" (ibid.). Layton takes engineering design as his historical examples in all cases.

Walter Vincenti, in his 1990 *What Engineers Know and How they Know It*, makes a significant contribution to the study of technological knowledge by using in-depth aeronautical engineering case studies to explain the design process. He recognizes the limits of his approach, and even explains that his discussion is limited to engineering design knowledge, rather than the entire domain of technological knowledge (1990, 7). The incorporation of engineering design case studies in discussions of technological knowledge remains standard. This approach makes sense because, though others may design and use technologies, engineers indisputably do. While this approach may help us clarify the process of design and recognize knowledge transformations across many steps in the creation of technologies, this type of analysis tells us little about what constitutes technological knowledge *in general*, and not just *for engineers*.

Engineering case studies, commonplace in discussions of technological knowledge (as seen in Layton, Vincenti, Mitcham, Pitt, etc.), handily illustrate the process of building and employing technological knowledge and build a clear contrast between scientific knowledge and technological knowledge (something which was once very important to philosophers of technology). However, a larger body of technological knowledge exists outside the realm of formal engineering. If a Venn diagram illustration were made on the subject, engineering knowledge would be a small circle completely located inside the larger circle of technological knowledge. While all engineering knowledge is technological knowledge, *not all technological knowledge comes from engineering*. By looking at technological knowledge only in terms of what engineers do, the limits of the discussion are severely restricted, and the prospect of approaching the use of tools by animals in our discussions of technological knowledge remains remote.

Joseph C. Pitt (2000) attempts to extend what has been learned from studies of engineering knowledge to technological knowledge more generally, but his very definition of technology - "humanity at work" - includes a *huge* assumption about the types of creatures who can possibly engage in technological activities. However, Pitt thinks that the definition could change to include "the activity of beavers or aliens," but that first we need to have in mind " a good idea of purposeful activity for non-humans" before considering others (11). He suggests that we develop an account of what purposeful activity consists of for humans before we venture into the animal kingdom. Giving us a model for his human-centered account, Pitt explains an input-output transformation process of humanity at work where decisions and deliberations about knowledge are fed back into the system, allowing for an evaluation of progress; these "feedback loops" of evaluation are important to the notion of progress. While I cannot yet investigate aliens at work, the activity of beavers warrants at least some consideration, in the very least as a contrast class for the sorts of things that interest Pitt. We may be able to make better sense of purposeful activities for humans by investigating what purposeful activities look like across a variety of species.

A second sort of technological knowledge relies on objects themselves. Springing from work in philosophy of science and still standing in contrast to 'applied science' accounts of technology, technological knowledge can be viewed in light of Davis Baird's so-called 'thing knowledge' – or knowledge that is materially instantiated in our devices and implements (2004). For Baird, knowledge can be embodied or encapsulated in oscientific instrumentation. This account of technological knowledge brings into focus actual physical objects and their configurations, rather than the smart humans who have skill in their creation and use. Though the people who build scientific apparatuses play a large role in making this knowledge visible and tangible, the knowledge itself can be built into the device or model. Materials themselves can sometimes exist as an explanation. Baird talks about three different types of thing knowledge: model knowledge, working knowledge, and instrumentally-encapsulated knowledge. Though situated in the context of science, working knowledge holds promise for some of our animal cases. Working knowledge is know-how that is demonstrated or instantiated by the construction of a device. Baird's justification for thing knowledge and five ideals for knowledge (detachment, efficacy, longevity, connection, and objectivity) (2002) can give us some framework for evaluating the material creations of non-human animals. In some animal cases, we find that some knowledge embodied in an animal artifact comes by way of evolutionary processes. The beaver dam may demonstrate more knowledge about the world than a beaver himself, who fells trees in response to the stimulating sounds of rushing water.

New studies of animal behavior have opened up some philosophical discussions about animal minds. Many compelling case studies complicate our human-centered approach to technology. For the purpose of this dissertation, I choose only a handful, both from laboratories and from field studies. Though laboratory studies tell us much about the capabilities certain animals have, they do not tell us much about the actualities of how animals behave absent human direction. Laboratory studies serve to complement field studies of animal behavior; the laboratory studies help build a case for inferences of purpose or intelligence in animal construction behaviors. In epistemology of technology, many possible criteria for determining which tasks require technological knowledge exist – design is taken as most important by Vincenti and Layton, social factors and feedback loops are heavily emphasized by Pitt, the information evidenced in the material products (or tools) themselves is rallied by Baird, and some sort of intentionality plays a role in every account of technology I have encountered. Though serendipity and exploration can lead to invention, an intention of using a thing for some purpose is fundamental to the success and continued use of a tool or system. In my investigation of animal cases and how they might map on to our epistemic accounts of technology, I have chosen five main case studies of wild animals, though I use other contrasting cases and laboratory studies along the way.[12]

The first set of animal studies pertains to chimpanzee tool-use, in the wild, in laboratory situations, and in zoos. Chimps have been found to use a set of tools to avoid getting stung by army ants as they raid ant nests (Sanz et al. 2007, Sanz et al. 2009). Crickette Sanz and her team

---

[12] In "What Dolphins Want: Animal Intentionality and Tool-Use" (Shew 2007), I analyze one possible way to make sense of the material products of animals.

of researchers recovered over 1,060 chimp tools and recorded 25 videos of this behavior. The researchers even call the tool kits of these chimps technology, just as we will see in the cases of New Caledonian crows. Though calling something a technology does not simply make it so, the videos of chimpanzee tool-use are especially compelling. The social factors of this tool use and the sophistication and purposeful employment of these tools pose a quandary for those who would like to bar non-humans from the realm of creatures who use technology. Further research, presented in Nicholas Toth and Kathy Schick's 1993 *Making Silent Stones Speak*, suggests that chimps in captivity can, when presented with the opportunity, create new ways of doing a task without being shown how by researchers. Philosophers sometimes point to ingenuity as an important part of what it means to create a technology, and, by this criterion, we might be forced to conclude that chimps and dolphins have technology.

Bottlenose dolphins provide the second set of case studies important to this dissertation. Krützen et al. (2005) discovered a peculiar hunting technique on the part of a family group of bottle-nosed dolphins. The team found eight dolphins breaking off the tops of sea sponges to use over their noses to scrounge up small fish to eat off the ocean floor. This seemed to be a shared hunting technique, with know-how passed among females in a family group. Other dolphin studies corroborate the capacity dolphins have for this type of learned, shared behavior (Janik 2000, Pryor and Norris 1998, Tyack 2000). Starting with the sponge study, I look at other dolphin foraging techniques and linguistic learning in dolphins and whales that give evidence for dolphin possession of know-how.

Reports on New Caledonian crows and other birds serve as my third detailed case. Drawing from the work of Gavin Hunt and his team, which shows the many types of tools and their specific uses by these crows, I suggest that many of the hallmarks of technology that we associate with being human cannot be maintained. New Caledonian crows manufacture and use an array of tools that meet three criteria for tool use cited by Hunt and his colleagues, features that were once only identified as appearing in hominids: standardization, the clear making of a form, and hook-use (Hunt et al. 1996). These crows will also keep track of and use these tools, repeatedly going back to get a tool to use again, and they use certain tools for specific purposes. Other bird cases reveal interesting things about the importance of environment in the development of tool use.

While the chimp cases are striking, we often think of apes as 'our younger brothers in knowledge', and so these cases are less controversial because we tend to casually think of apes as being more 'like us' than other creatures. Even in the case of dolphins, we are accustomed to their smarts being lauded, witnessing their fantastic water shows and TV programs. The research on New Caledonian crows making sophisticated tools to catch prey requires more work to reconcile with our current cultural assumptions about animals and technology.

In addition to addressing New Caledonian crows and the ways in which their tool use negates our ability to maintain human-centered definitions of technology, I discuss spider webs and beaver dams – both often-referenced constructions that provide a contrast class to compare to other animal and human technology. By drawing from these cases, I hope to show that a complete epistemology of technology requires a more nuanced approach the material products of non-humans.[13] We can talk about spider webs and beaver dams and crow tools and human implements as bearers of information, something akin to Baird's thing knowledge.

Philosopher of language and biology, Ruth Garrett Millikan (1984) wrote most suggestively about intentionality and the behavior of animals, exploring bee dances in her model of intentionality. Her work defends the idea that intentional mental states only make sense within the context of an organism's evolutionary history. If a random collection of molecules were by accident to form my exact duplicate, I would not be able to refer to this creature's eye or brain or intentions – because these parts of me come from a particular evolutionary history from which this random copy of me has not come (Millikan 1984, 93). This analysis contrasts with certain analyses in the philosophy of technology dealing with functions. We typically call something an eye when it does the sorts of things an eye does, and we refer to technologies with regard to their functions: an antique iron being used as a doorstop *is* a doorstop. We often recognize technologies by their functions: something is what it does. Millikan's openness to animal cases – especially given that her focus is on language – provides some grounding from which to look at intentionality in the cases I present. However, her focus on language poses a problem because we cannot know the minds of the creatures we hope to study and cannot ask them what they are thinking. For this reason, tool-use becomes an important way around the language barrier and helps motivate my inquiry.

---

[13] I start describing this project in "Spider Webs, Beaver Dams, and the Sticky Wicket" (Shew 2007) : it might be better to imagine tool-use and technology as existing on some sort of continuum rather than as either-or categories. I will return to this idea in the concluding chapters of this dissertation.

In the environmental literature, Mark Rowlands (2005) develops an environmental epistemology that, like Millikan's, recognizes the importance of evolution and environment to an organism's navigation of the world. Rowlands cites several examples, from both human and animal cases, where the world itself is used like an informational memory store (2005, section 7). Environmental cues direct thinking in important ways. He explains:

> ...the environment contains structures that carry information. This information is relevant to the accomplishing of a cognitive task, and it can be appropriated by organisms that are capable of acting upon the structures in the right sort of way. (ibid.)

Our environments – and those of non-humans too – structure our thinking. Though for some animals, there may be a simple stimulus/response reaction on the part of some animals in dealing with the informational structures of the world (as imagined by Rowlands), some cases are more complex, especially cases that deal with the creation of material artifacts by non-humans. When creatures use tools, the relationship between the environment and the animal changes. Rowlands brings our brains and behavior back to nature, much like Millikan.

Given Baird's encapsulation of knowledge in scientific instruments (that have been designed for a particular purpose), one could argue that evolution and environments have produced organisms and structures that bear information in parallel ways. Both biological and engineering literature use 'function' and 'design'. I address the parallel dialogues of engineering function with biological function in relation to my case studies and develop a way to unite these dialogues through the concept of technological knowledge.

Historian of technology Rachel Laudan (1984) highlights the cognitive change prompted by technology. To Laudan, the major cognitive activity of someone engaged in a technological practice is problem-solving (1984, 84). She creates a taxonomy to help sort out the problems technologists pursue, most of which apply only to human technological activity. However, seeing technology as problem-solving presents significant challenges for some animal cases. Spiders cannot be said to be actively engaged in a problem-solving activity (or can they?), while chimpanzees can be seen to be problem solving in a way we recognize (if not in the field studies, then certainly in the laboratory studies). Additionally, research with crows quite strongly indicates problem solving at work (Bluff et al. 2007). Problem-solving might be some sort of cognitive divide, helping us to sort out these animal cases, but such inferences can be difficult to judge, and there are even human cases where problems are solved by luck rather than intelligence.

Anthropologists Schick and Toth (1993), aforementioned with regard to ape studies, survey tool-use among animals, looking at innovation as a possible dividing line. They think that sea otters using tools to open mollusks demonstrate innovative behavior, while birds (the ones they reference) rely on instinct without the sort of flexible, innovative tool-use witnessed among great apes (humans included in this category). Seeing culture as more developed among mammals, they dismiss the prospect that birds and insects could demonstrate innovative tool-use altogether (1993, 55). When Schick and Toth collaborated, the case studies of animal tool-use were much slimmer, and they even claim that tool-use among non-primates is rare (ibid., 54), though we now have many more examples that have since been observed. Their considerations concerning the difference among the types of tool-use by different species need to be updated to reflect the greater numbers and sophistication of tool-use that has been discovered, particularly in the complexity of crow cases.

What I produce here integrates new studies of animal tool-use with technological knowledge. This project requires me to address concerns about animals minds – intentionality and its evolution, ability to innovate, problem-solving possibilities, ability to learn – as well as concerns about what constitutes technology and what constitutes knowledge. My greatest assumption is that technological knowledge is actually a type of knowledge, something that has been under-recognized in the history of philosophy (which has valued propositional knowledge above all others for some time). The literature on my chosen topic of inquiry is truly literature *around* my topic. Mark Rowlands gets perhaps closest to my project by integrating studies of animal cognition in his work on how we use the environment as an informational bucket, but his work concerns memory and thinking in the world, while I locate this work centrally in the philosophy of technology.

In my second chapter, I sort out the language I employ (tool, technology, artifact, knowledge) and argue that there is no *a priori* reason to exclude all non-humans from our definitions of technology. And, if there is no *a priori* reason to exclude non-humans, we should take a look at these animal cases, which is what I do in chapters four through seven. In Chapter Three, I take a closer look at technological knowledge to help situate the animal cases I proceed to examine, providing a theoretical frame for the animal cases. Chapter Four considers the social learning of apes and their tool-related behaviors. Chapter Five considers dolphin sponging, culture and learned know-how. Chapter Six deals with the variety of material products of New Caledonian crows and other birds are capable of making. Chapter Seven handles thing knowledge, beaver dams, spiderwebs and other animal constructions, looking at the role of environmental niche, design, and evolutionary processes on the tool-use of non-humans. In chapter 8, I provide further justification of my theoretical framework and situate instances of construction and technique in a graphical representation. This theoretical framework relies on know-how (or learning requirements) and encapsulated knowledge as axes on which construction or technological behaviors can be mapped. From this map, animal artifacts and technological behavior can be seen as fitting within the same realms of discussion as that of human technological activities. We do not consider all human technology and tool-use as equal in terms of sophistication (levels of built-up-ness) or in terms of learning processes or in terms of the way in which knowledge is constructed, nor should consider all the tool-related phenomena of animals as equal along these same lines of concern. Allowing for a range of possibilities (rather than a binary division) helps in considering animal- and human-made objects and behaviors in the same terms, even if we agree that they are not the same things.

Chapter 2: Technologies, Tools, Artifacts, Anthropomorphism, and the Human Clause

This chapter seeks to disambiguate the relevant terminology – artifacts, tools, technology, and knowledge – in order to argue that some non-human animal tool-related behaviors can be grouped alongside tools and technologies of human manufacture. Animal tool use seems to be separated by degree, and not by kind, from human technological endeavors. Many accounts of technology have included what I term "the human clause": the idea that human beings are the only creatures capable of using or making technology. The concept of *homo faber*, man the maker, remains central to many definitions with human clauses. For at least some time and to at least a relatively large group of people (as evidenced by the number of people who today still hold this view), technology belonged as the domain of human beings only, a uniquely human phenomena. Other animals might be clever, but none other than humans had harnessed the power of physical manipulation, creativity, and design that human beings could, as embodied in our technologies. This power and its adaptability (to environments, to problems, even to entertainment) sets us apart from and above all other animals. In this vein, we see the following things said of technology and its relation to human beings:

> In its simplest terms, technology is man's efforts to cope with his physical environment – both that provided by nature and that created by man's own technological deeds, such as cities – and his attempts to subdue or control that environment by means of his imagination and ingenuity in the use of available resources. (Kranzberg and Pursell 1967, 5)

> Technology, then, is much more than tools and artifacts, machines and processes. It deals with *human work*, with man's attempts to satisfy his wants by human action on physical objects. (Kranzberg and Pursell 1967, 6)

> Modern physiology, psychology, evolutionary biology, and anthropology all combine to demonstrate that *Homo sapiens* cannot be distinguished from *Homo faber*, Man the Maker. We now realize that man could not have become a thinker had he not at the same time been a maker. Man made tools; but tools made man as well. (Kranzberg and Pursell 1967, 8)

Technology is as old as man himself. Man was evidently a "tool making primate" from the day when the first human-like creatures roamed the earth.... (Forbes 1967, 11)

I propose to treat technology as a form of human activity, others of which include science, art, religion, and sport.[14] (McGinn 1978, 180)

Thus technology, like human creature itself, can be understood as natural in both these [aforementioned] senses, i.e., rising naturally out of the character of *Homo sapiens*, as evolved within nature. (Ferré 1995, 29)

Technology has driven our brains. Our expanded physical capabilities made technology – extended toolmaking – inevitable. Technology has, in turn, expanded our minds and fed itself. (Leinhard 2000, 4)

… I propose the following definition: *technology is humanity at work*. (Pitt 2000, 11, his emphasis)

---

[14] This quote is followed by the parenthetical remark: "It should be added that recent work of Jane Goodall and associates has shown that humans are not the sole practitioners of technology. Not only do chimpanzees use tools – e.g., compress leaves, inserting them in water-filled tree trunks as sponges – but they also engage in rudimentary tool manufacture: stripping leaves, inserting them into tree trunks to extract termites." (page 180)

> I also see technology as a creative process involving human ingenuity.... I see technology as craftsmen, mechanics, inventors, engineers, designers, and scientists using tools, machines, and knowledge to create and control a human-built world consisting of artifacts and systems associated mostly with the traditional fields of civil, mechanical, electrical, mining, materials, and chemical engineering. (Hughes 2004, s 3-4)

> … technology – in the general sense of the manipulation of nature to suit human purposes – is not peculiar to modernity. Technology has always existed since the first adze made by our Stone Age ancestors. (Lee 2009, 19)

Historians and philosophers of technology have included human beings (and excluded other species) in their definitions of technology for seemingly the entire history of the history and philosophy of technology as academic disciplines. Most of these accounts of technology provide that chimpanzees use rudimentary tools. However, scholars almost always proceed to discuss technologies as human projects, even if they acknowledge the chimp cases.

And one might reply: why shouldn't they? We humans make the definitions, we defined technology, and we should be able to insert the human clause anywhere we like. I see no problem with this sort of response. This project does not replace other accounts, but better sense of human work can be made from looking at just what other animals are making and doing. Philosophy of engineering can continue to grow as a specialized discipline, but this human clause inhibits us from creating a broader account of the sorts of things constructed and manufactured in the world. Accepting the human clause without first looking at the sorts of things some animals make, do, plan, organize, and implement does a disservice to a large segment of living things on Earth. Our accounts of technology remain impoverished if we neglect to look around at what other species do.

We ought to at least consider what it is animals do and make and use *before* limiting technology as a humans-only activity, especially given new animals research. Without the human clause, many definitions and accounts of technology actually map quite well onto what some animals do. To disrupt our inherited accounts of technology and their ties to humanity may be problematic for those who think that technology is what makes us human; however, I ask for suspension of the human clause for a moment to take stock of what happens outside of human endeavor.

In chapters four through seven, I offer cases where animals manipulate their environments, make and use tools. As I proceed into this consideration, it is important to make sense of the terminology with which I hope to approach the topic. Most philosophers of technology, in their books on the subject, have a definitions section where they either come up with a definition or reject the idea of coming up with a definition, preferring instead to offer some account of technology.[15] Rather than formulate a new definition, I provide a map at the end of this project. Many current definitions or accounts overlap in important ways, and my graphical

[15] I am a fan of many of these latter approaches. I do not mean for this map to undermine prior approaches. We can draw on what has been accomplished to help form this continuum of possibilities.

account not only helps in reconciling the definitions of others[16], but places the sorts of toolish things humans do in relation to the sorts of things some non-humans do. Viewing humans as completely separate from nature is surely folly, and my use of technological knowledge unites seemingly disparate things. Creating a continuum of tool use and technology helps naturalize technology. No one really denies that at least *some* animals use tools – the chimp cases are often referenced by philosophers of technology and anthropologists. However, people most often consider technology as something human-specific. The use of tools to make or get tools (metatools use), standardization of tools, or creativity in creation are often cited as potential dividing lines between tool and technology – but in more recent animal studies literature, researchers have established the use of metatools, creativity, and standardization.

Mapping

To establish a map that puts into concert tools of animal and human manufacture, I want to borrow some quick terminology from Nicholas Toth and Kathy D. Schick, authors of the book *Making Silent Stones Speak* (1993). In a discussion of the differences between tools and technology, they say that tools, in their simplest form, are external objects used to achieve some goal (48). Tools may be modified or unmodified by their users (which for anthropologists Toth and Schick will almost always be humans or protohumans). Artifacts, for these anthropologists, are a type of tool that has been modified in some way by human beings. However, they see even

[16] Though that is not my project here.

this definition as problematic and point to cases of chimps modifying tools such that the might count as artifacts. Technology is more than mere tool use:

> [Technology] refers to the system of rules and procedures prescribing how tools are made and used. In a broader sense, this term can be used for the systems of tool-related behavior of non-human species as well. (Toth and Schick 1993, 49)

Toth and Schick note that "technological behaviors" are often more instinctual for non-mammals (ibid.. 51). I lift the phrase "technological behaviors" from Toth and Schick to appropriately label my map. I see tool use and manufacture (the production of artifacts) as resting in concert with the more built-up technologies, and so the map accomodates a range of technological behaviors, from simple constructions to the wielding of tools to complex systems. As we'll see in subsequent chapters, the grand hallmarks associated with technology – intellect, intention, design, use of form, metatools, and so on – can be attributed to at least some non-humans.

By examining these hallmarks, found in definitions from the history and philosophy of technology, a larger account of technological behaviors can be fleshed out.[17] In *Philosophy and Technology* (1972), Carl Mitcham and Robert Mackey give three ways that we might choose to define 'technology' – epistemologically, anthropologically, and sociologically. Epistemological definitions identify knowledge of how to do or make things as central to technology. I have already mentioned some anthropological approaches in this chapter: historians Melvin

[17] Later I use this term almost interchangeably with construction behaviors, as things like webs and nests are not considered tools, but as animal *constructions,* since they are *not* easily detachable from their environments. When we consider that cave paintings and power plants are equally impossible to detach from their context, at least without significant damage, then this detachability requirement seems unimportant.

Kranzberg and Carroll Pursell, as quoted early on, obviously use an anthropological definition, saying that technology exists as fundamental to the sort of being man is. Toth and Schick, quoted just above, are anthropologists talking about technology and accept an anthropological account. Sociological approaches are "characteristic of thought and action in modern society" (Mitcham and Mackey 1972, 2). A prominent sociological account of technology can be found in the work of Joseph C. Pitt, most clearly articulated in his *Thinking About Technology* (2000). Defining technology as "humanity at work," Pitt develops a sociological account of technology that involves the use of feedback loops bringing about improvements over time. He ties this clearly to philosophical accounts of engineering. Andrew Feenberg is another philosopher who examines the importance of sociological factors in modern technologies (Feenberg 1999).

Philosophers have been known to mix these approaches in the formulation of their definitions. Don Ihde, in *Philosophy of Technology* (1993), purports to define technology "anthropologically and philosophically" (51). Technology, for Ihde, involves humans "relating to their environment" (ibid.). The non-neutral power of humans to transform their environments is the focus of this anthropological-sociological definition. Frederick Ferré, in a different book also entitled *Philosophy of Technology* (1995), provides an anthropological-epistemological account. Though Ferré does not restrict his definition to humans from the outset, his definition - "the practical implementation of intelligence" (26) – can sometimes only be implemented by looking at anthropological or biological studies to see whether an artifact was created by the use of intelligence or 'mere' instinct.

None of these approaches is without merit, but each identifies something slightly different as an important. Several factors exist that we might put together to map out the gradations between simple tool use, to tool making, to manufacture, and to the use of technology. These candidates for how to map out technological behaviors come from sociological, anthropological, and epistemological considerations. Sociological factors include social learning and culture that go into the transmission of technological behavior. Epistemological factors include the use of know-how in the using and designing of tools. Anthropological factors include the evolutionary processes and intentionality that go into technological projects. Using instinct, intellect and reason to gradate technological behavior is an epistemological-anthropological approach. I discuss these possible factors in the following chapters on animal behavior, paying special attention to the ideas of embodied knowledge and know-how. Most of Chapter 3 sets up technological knowledge as a way to start piecing together this two dimensional graph, or map of technological knowledge. My proposal in this dissertation is fairly simple: let's see what the animal cases look like to put together a map of technological knowledge that will enable cross-talk among philosophies of technology and will help situate human tool use and technology together.

I situate constructions, tool use, and technology on a single graph in order to place things that appear, perhaps, obviously related in a more obvious way, making it easier to talk about technology as something we came naturally to do and use, not wholly divorced from our human status as animals. Rather than position humans as superior to other animals because of our use of tools and technology, I show that the technological skills we have are related to technological behaviors that we find elsewhere in nature. Some animal behaviors prove much better suited for their context than some human constructions; in this way, human constructions are not always better or superior to what some animals do, especially given certain environmental constraints at play or environmental niches inhabited.

Anthropomorphism

In animal studies, one receives instruction to be constantly vigilant against anthropomorphizing animal behaviors. However, we can move too far in the other direction – viewing human beings as removed from the larger animal kingdom. By putting technology on a map alongside other tool-related behaviors – the use of objects in one's environment to get to some end, the making of a form, the repeated manufacture or use of an object, the cultural transmission of toolish behaviors, etc. – we can avoid anthropomorphizing or swinging too far in the other direction, as has often been done in discussions of technology which start out with the assumption that technology is man's domain alone. A hierarchical view about man's relation to the rest of the world (animal and environment) remains an assumption underlying much of the discourse surrounding the ethics and epistemology of technology. By offering a continuum of possibilities (one that I do not intend to be hierarchical), a space is provided for talking about tools and technologies in a way that is more equitable.

One objection that I need to address before continuing stems from the specter of anthropomorphism, the ascription of human categories to non-humans. Because we have so long associated human beings and technology, talking about animals using tools and technology seems absurd to some from the outset. Our categories of 'human' and 'technology' have very often been associated, even in popular news and commercials and cartoons, not just in more scholarly work. We have been inundated with imagery that links man with technology. However, serious anthropological work with chimps and new studies on crows and dolphins demonstrate that other animals use tools, make tools, convey techniques, and create ways of doing things that involve the use and construction of artifacts. Are these animals creating technology? The answer to this question depends on where one parcels off technology on this map of technological behavior I propose, but these animals are certainly doing some complex work that ought to be recognized by scholars as they embark on their discussions of the nature of technology. To neglect constructive behaviors simply because humans are not doing the constructing is to neglect a rather large segment of made things and processes of making. If we want a more generalized account of technological knowledge, we should be looking at the embodiment and employment of technology in a more general way. At the very least, technology must not be merely tied to the nature of humanity, but of humanity in our animality. The fashioning of tools and use of technology rises from an evolutionary history, one of humans in nature and as a part of nature. The inherited view, where human beings exist outside of nature thanks to tool use, cannot be maintained in the face of the evidence coming from recent animal studies.

Other animals are unlikely to think about themselves as users of technology or tools (in any way that we might be able to understand, even though students of dolphin behavior have produced evidence that dolphins seem to understand abstract concepts (see Pryor 1998)). These animals may employ a hunting strategy or shape a stick with the idea of getting prey, though even that sort of thought may or may not be part of what the animal thinks. We cannot know what it is like to be another animal, so positing the thoughts of another may not be possible. By the same token, we can never truly know the mind of another human being. Nonetheless I posit the intentions and feelings of other human beings all the time. I do this by looking at *what other* *people do*. While we cannot posit mental content without very careful study, we can look at what other species make, do, and share. By following the objects themselves in their uses and production, we can formulate an account of made-things to place on a map of technological behaviors.[18]

The past ten years have produced an explosion of research in animal studies related to cognition and emotion. With this research has come skepticism that researchers have been inappropriately ascribing human categories to non-human animals. (Who is to say what another creature thinks anyway?) But we can easily swing too far in the other direction – putting ourselves in a position of never positing the sorts of intellectual, sensory, and emotional hallmarks that matter to things like how we treat others (even animals). Much of the excitement over new animal studies has been about the emotional (and, relatedly?, moral) standing of animals. This is not my project. However, the concerns about anthropomorphism loom just as largely for this project, though my project actually has little bearing on how we should treat other beings.

In a non-technical, personal account of his life with his dog, nature writer Ted Kerasote explains that inaccuracies exist both in ascribing human characteristics to animals and in *not* ascribing human characteristics to animals:

> Anthropomorphism is often maligned for ascribing human characteristics to animals who can't possibly know what we know. And there is some truth to this. I doubt Merle [a dog] thought of the Big Bang when he gazed at the starry heaven. But the reverse – not ascribing volition to creatures who repeatedly display it – is

[18] New research may cause us to move where a behavior sits on the graph.

> also inaccurate. It leads to what poor translation always does: misunderstanding between cultures. (2007, 112)

Skeptics would counter, perhaps, that even the use of 'culture' here is an improper ascription of human characteristics to animals. However, we also assign human characteristics – the categories with which we think about our own personal experience of the world, our own mental traits, and our own behaviors – to the sorts of things other human people do. David Hume, in *A Treatise of Human Nature* (1888), makes the case that the difference between non-human animals and humans is a matter of degree, and not of kind:

> … no truth appears to me more evident than that beasts are endow'd with thought and reason as well as men.... We are conscious, that we ourselves, in adapting means to ends, are guided by reason and design, and that 'tis not ignorantly nor casually we perform those actions, which tend to self-preservation, to the obtaining of pleasure, and avoiding pain. When therefore we see other creatures, in millions of instances, perform like actions, and direct them to like ends, all our principles of reason and probability carry us with an invincible force to believe the existence of a like cause. (176-177)

Hume explains that a great resemblance exists between the external actions of animals and our own actions, and this resemblance should cause us to to see mental operations as common in humans and animals (ibid., 177). In this way, Hume argues that reason, custom, and instinct operate in men as well as animals (ibid., 179). Striking resemblances exist between animal constructions and tools and human technologies.

Though writing on morality and animals, Mark Beckoff and Jessica Pierce (2009) make the claim that it is narrow-minded to discount the possibility that animals think and feel:

> New information that's accumulating daily is blasting away perceived boundaries between human and animals and is forcing a revision of outdated and narrowminded stereotypes about what animals can and cannot think, do, and feel. We've been too stingy, too focused on ourselves, but now scientific research is forcing us to broaden our horizons concerning the cognitive and emotional capacities of animals. (Beckoff and Pierce 2009, x)

I present some of this new information from animal studies that brings into question whether categories like culture, intelligence, and planning are exclusive to human beings. Ted Kerasote talks about other animals as speakers of foreign languages – *translation is difficult and takes a concerted effort, deciphering meaning is no easy process, but meaning is there* (2007, 10-12). Anthropomorphism may sometimes be too hasty or misguided or in error, but, properly carried out, anthropomorphism, the ascription of human categories to non-humans, can prove appropriate and important to making sense of the things we do.

A great example of the threat of anthropomorphism can be found in a news story from December of 2005. *The San Francisco Gate* first reported on the rescue of a humpback whale (Fimrite 2005), and the tale was sent around as an email forward and re-reported in publications across the country. A female humpback whale had gotten herself tangled in crab lines near the Farallon Islands (about 18 miles from San Francisco) and was discovered early in the morning by a crab fisherman, who called the Marine Mammal Center. The center sent out a group of divers to evaluate the situation and try to rescue the whale. The divers were unsure they would be able to rescue the whale, which was seriously tangled in the lines and heavy crab traps, and the rescue posed dangers “because the mere flip of a humpback's massive tail can kill a man” (ibid.). Around the whale hung 12 crab traps of 90 pounds a piece, and the whale was struggling to keep is blow-hole out of the water (ibid.). The divers spent hours cutting the ropes – *all while the whale held still for the divers*. *SF Gate* reports that:

> When the whale realized it was free, it began swimming in circles.... it swam to each diver, nuzzled him and then swam to the next one... Whale experts say it's nice to think the whale was thanking its rescuers, but nobody really knows what was on its mind. (ibid.)

One of the diving team's organizers explained that, “You hate to anthropomorphize too much, but the whale was doing little dives and the guys were rubbing shoulders with it... I don't know for sure what it's thinking, but it's something I will always remember” (ibid.). The worry of anthropomorphism keeps us from making large generalizations from one incident, and, while we may not wish to conclude that this whale was showing gratitude, our descriptions of the whale's patience or carefulness (in holding still) and excitement (as witnessed in his little dives and nuzzles against the divers) might still be applicable to the situation.

Mike Hansell, in *Built by Animals* (2007), explains why anthropomorphism became a concern among animal studies researchers and why questions of whether animals and humans shared moods or behaviors went unaddressed for some time:

> I was warned as a student that anthropomorphism was a sin against science. In 1872 that brilliant and versatile scientist Charles Darwin published his book *The Expression of Emotions in Man and Animals*. This includes, among many skillful

> etchings by a certain T.W. Wood, the face of a chimpanzee bearing the caption 'Chimpanzee disappointed and sulky'. Soon after this it became impossible for a scientist in the field of animal behavior to say such a thing and still retain their scientific credibility, and remained so for the best part of a hundred years. The reason was that by the start of the twentieth century, scientists were frustrated by fruitless debates on the relationship between mind and body generated by the approach of so-called psychological introspection (what you might call 'thinking about thinking'). Scientist in the then young discipline of animal behavior, keen to stress their experimental approach and objectivity, rejected this method... (2007, 8-9)

Hansell goes on to explain that only in 1976, with the publication of *The Question of Animal Awareness* by Donald Griffin, did the field of animal behavior research seem mature enough to start to tackle questions of the nature of animal minds. Researchers can tackle questions of animal thoughts and feelings now without derision from their colleagues. And so we have witnessed the flood of such publications. Questions of whether animals think and feel are within the bounds of scientific inquiry (Hansell 2007, 10). We now witness this explosion in publication and knowledge about animal minds because the taboo has been lifted. I draw from some of this animal studies material with the acknowledgment that it's possible to go overboard and posit too much. However, with careful study, some anthropomorphism is not just justified, but also desirable if we hope to make sense of the world and its inhabitants. I apply concepts once only used in philosophy of technology to the material creations of non-human animals. If we discount these material products only because technology is something we associate so closely with humanity, our accounts of material production, knowledge, and artifacts remain impoverished and isolated from a much larger discourse, one that could be inclusive of the information and production of non-humans.

The Terminology

The terminology I deploy – artifacts, tools, technology, and knowledge – is not static and need not be for the development of a map meant to encompass all these related categories. I work with a number of definitions of technology without problem – and refer to different people's accounts of technology along the way. Because I offer an array of possibilities, some areas might be carved out differently by different accounts of technology and not by others. As for tools, I look to animal studies and anthropology for help; I use these terms as the researchers use them. The most famous account of what constitutes tool use, formulated by Benjamin Beck (1980) is constantly referenced in the literature, though the definition has its detractors (which I discuss in chapters 7 and 8). Artifacts cover a wider range of things than do tools or technologies: artifacts are simply objects which have been modified in some way. This would include things like nests and dams and webs, which would be discounted in many definitions of tool use that hold detachability and manipulability as fundamental (like Beck's).

Chapter 3: Technological Knowledge(s)

Marc J. de Vries, in "The Nature of Technological Knowledge" (2003), laments that there are not yet very many philosophical studies of the nature of technological knowledge, and his statement remains largely true. Most of what is now published and presented on technological knowledge is in the sub-domain of engineering knowledge. According to one acquaintance at the most recent Society for Philosophy and Technology meeting (2009), technological knowledge used to be a hot topic, but has now fallen out of favor.[19] My purpose in this chapter – and in this dissertation – is not to map out a grand account of the nature of technological knowledge.[20,21] My interest here in technological knowledge is instrumental in setting up a way in which we can talk about the types of things humans make and do alongside the types of things non-human animals make and do.

In Chapter 1, I described two broad types of accounts of technological knowledge: technological knowledge that resides within the maker, designer, or user of an artifact (know-how is the most common description of this type) and technological knowledge that resides within an artifact ('thing knowledge' in the terminology of Davis

[19] I do not know why that is, except that most people have focused down on engineering knowledge, rather than work on more generalized accounts.

[20] I set aside this larger project to focus on a unification of approaches to technological knowledge and an expansion of the domain of technological knowledge.

[21] Walter Vincenti does do this sort of work for a pocket of engineering knowledge (itself a type of technological knowledge) in his *What Engineers Know and How They Know It* (1990).

Baird).[22] These two types, though quite obviously connected, relate to each other in a non-linear way. Things tend to "bite back," in the words of Edward Tenner (1997), and the configuration of know how to thing knowledge is messy and changes on a case-by-case basis. However, the literature on technological knowledge (of both types) can serve as a guide for one way to approach the topic of non-human animal tool-use. Subsequent chapters consider the animal cases more closely. But, in this chapter, I describe several ways to consider technological knowledge and how they might be fit to match the animal cases. All of the current accounts of technological knowledge found in history and philosophy of technology center on humans, human technology, engineering and science,[23] so I provide a less particularized reading of technological knowledge in this chapter. I discuss both technological and thing knowledge broadly and as ways to think about the cases I address in upcoming chapters.

Though Joseph C. Pitt argues that is impossible to talk about *technology simplicter* and argues that we have to talk about individual technologies (2000), discussions of bodies of knowledge are often detached from the objects of knowledge. No one contests talking about knowledge in the singular. Given this convention, even if we are unable to talk about technology as some unitary thing, we should still be able to talk about technological knowledge. Sociologists and philosophers of science dispute whether we can ever talk about science in the singular – because science is made up of some

[22] For the most part, I will call this first type 'technological knowledge,' while the second type is 'thing knowledge,' though I hope to recognize that thing knowledge is also a type of technological knowledge.

[23] Engineering studies is currently popular.

vastly different disciplines. In the same breath, they talk about scientific knowledge, its construction, and use. By looking at the nature of technological knowledge, we can view the sorts of things animals do within the same framework of investigation as human beings, despite vast differences in construction.[24]

Technological Knowledge

The most in-depth study of technological knowledge to date remains Walter Vincenti's *What Engineers Know and How They Know It* (1990). Though now twenty years old, Vincenti's analysis of the use and construction of knowledge by aeronautical engineers involved with design remains the most thorough study of technological knowledge. However, his concentration on a specific set of case studies in one branch of engineering fosters the depth of his study. Though the knowledge he describes is local to one segment of engineering, the discussion he provides about categories of technological knowledge and design may prove relevant to discussions of tool-use more generally. Three goals of engineering exist for Vincenti: design, construction/production, and operation, though design is taken as central by Vincenti, Layton, Petroski, and others. Design, according to Vincenti, is "multilevel and hierarchical" - with different levels of design interacting with one another (1990, 7). He distinguishes between normal and radical design: normal design exists when engineers know how a device works and what should be done; radical

[24] Here I ask that you suspend the human-claused use of 'technological'. The animal cases will speak for themselves in subsequent chapters, but, for now, I just set up technological knowledge as a frame through which we can look at a variety of different cases – be those human or not.

design exists in situations where there is not established practical knowledge about how to work or design a device (7-8).

Vincenti describes normal design as “evolutionary rather than revolutionary” (8), a sentiment that many historical studies of technology echo, like Henry Petroski's *The Evolution of Useful Things* (1992) and George Basalla's *The Evolution of Technology* (1988). The evolutionary metaphor used to describe technological change is not trivial: Petroski's accounts of the role of failure in design maps nicely onto descriptions of the role of mutations without a survival value and accounts of extinction (Petroski 1985, 2003, 2006). In a way that parallels biological descriptions of design failure (where mutations did not provide a survival value), engineering failures may tell us more about a project – and the specifications and external pressures for that engineering project – than a successful design can (Petroski 1992). Engineering knowledge “reflects the fact that design does not take place for its own sake and in isolation” (Vincenti 1990, 11), much like the functioning of evolutionary biology. What we think of as the biological design of, say, a spider's silk is actually the product of an evolutionary history that happened in the context of environmental pressures on some pre-spider creatures. The pressures that drove the use of silk (and subsequent web-making, in some spider species) may have been climatological, geographical, a matter of prey and availability, etc. External pressures drive both engineering and biological design. Vincenti, by the end of his book, actually champions a model for the growth of engineering knowledge that comes from studies of biological adaptation. He argues that the variation-selection model that he lifts from Donald Campbell “is fundamental to all genuine increases in knowledge [including the knowledge generated in his aeronautical engineering case studies], from that embodied in genetic codes arrived at by biological adaptation to the theoretical structures of modern science" (1990, 241). Within the scope of Vincenti's work, the model works like this:

> …. [D]esign itself constitutes a variation-selection process of knowledge generation.... In [a] more normal situation, the desired knowledge is how to arrange and proportion the particular device so as to accomplish its task given the constrains of the normal configuration. The design of most airplanes after the early 1910s was more or less of this kind. In this situation, the designer usually lays out a number of plausible variations on some basis and selects the final design by some sort of analysis or experimental test or combination of both. More often than not, the process takes place iteratively.... (ibid., 244-245)[25]

This iterative process is described elsewhere as a system of "feedback loops" with assessment feedback that allow for the improvement of technology (by some assessed standard) over time (Pitt 2000, 13-15).

The possibility of using Vincenti's account of technological knowledge in the realm of animal behavior seems like a stretch at first because he discusses only the high technology realm of aeronautical engineering. However, his strong dependence on a variation-selection model to help explain the growth of knowledge over time provides a

---

[25] Richard Burian has pointed out to me that this is an American conception of engineering and that engineers from other countries may describe their work differently.

point of easy entry into biological cases. A strong, though rarely highlighted, connection in the literature on engineering design to that of biological design exists. While intentionality may not play as large role in biological design as it does in engineering design, that linguistic links of 'design' and 'function' provide an interesting way to approach the prospect of technological knowledge, especially given that historians and philosophers use evolution as a central metaphor in their accounts of technological change.

Biological literature discussess about how spider webs are designed to catch bugs for prey – without problems of intentionality creeping in. Biological function is how something does what it does, while we think of engineering function in almost the same terms: a function is what something does. The function of a web is to catch prey; the function of a net can be to catch butterflies. These are similar ideas, functionally speaking, though their designs take radically different paths, one evolutionary and the other through some sort of technological evolution. A worry that may creep in here is that, if intentionality is ignored, everything may be reduced to technological knowledge. Certainly, someone catching butterflies with a net has something very different in mind than a spider – and the process of learning and technique for these two activities will be radically different (the spider requires no training). A second way to bring Vincenti's technological knowledge to bear on the non-human cases exists: in those cases where we see evidence of *intentional* design on the part of some animals, we can talk about the design process and the transformations of knowledge that take place in relation to

Vincenti's descriptions. Such intentional design is impossible for a spider, but other animal cases better align with intentional accounts of design.

Knowing-How and Embodying Knowledge

Vincenti interprets knowledge in a broad manner, to include both knowing-that and knowing-how (1990, 13), picking up on Gilbert Ryle's classic distinction (Ryle 1946). Both knowing-how and knowing-that remain critical to engineering knowledge, in Vincenti's view. Edwin Layton describes several key characteristics of know-how (1971, 1974, 1987). Though his focus, like many in the early discussions of technological knowledge, rested in disambiguating scientific knowledge from technological, he manages to describe technological knowledge in the process. Like Vincenti and others, Layton identifies design, or the ability to design, as the important component of technological knowledge. Design is, for Layton, “an adaptation of means to some preconceived end” which results in made artifacts (1974, 37). The process of design involves first a conception in one's mind, followed by a more detailed plan, then in the drafting of plans (or blueprints or a model), and then into the making of some object or thing (1974, 37). Knowledge of design – its systems and products – is synonymous with know-how for Layton (1987, 604). The process of forming an idea and making it into some concrete reality exists as the essence of design and the “highest level” of knowing-how (ibid.).

If we are to treat non-human cases appropriately within Layton's framework, we would have to see whether non-human animals are designing anything. Though figuring out whether an idea of some end or object exists in the mind of a tool-making animal can be tricky, we can watch for behavior that would indicate prior consideration or planning. Planning behaviors can be identified through repeated making of the same object, through the sharing and learning of some technique, and through cases where an animal has been found to anticipate future states.[26]

Layton talks about how technological knowledge "can exist on all levels" (1987), from abstract thinking about technology to specific objects. He recognizes that technological knowledge is used by the most difficult and the least intellectual of tasks. Even a typing clerk possesses the appropriate know-how for his or her job, though this knowledge is not theoretical in nature (1987, 604). Technology does not involve *only* mental components for Layton, as *know-how involves physical memory and training that cannot be adequately described by theory*. However, Layton warns against comparison between a low-wage worker and computer geniuses, as well as other bizarre contrasts:

> I do not think comparing Einstein's knowledge of science with a child's knowledge of how to ride a bicycle advances our understanding of anything. (1987, 605)

Technological knowledge is "tailored to serve the needs of design," and so comparing two incomparable things makes little sense to Layton.

---

[26] There exist non-human examples of all of these.

Contra Layton, I do think it makes sense to compare technological knowledge that exist far from each other, especially if one hopes to make general remarks on the topic. Recognizing the cultural and biological niches in which tools and technologies are employed is important to approaching such a comparison appropriately. We should expect know-how to appear widely different and consist in different contexts and techniques. A beaver's dam looks and is designed for different purposes than a human's dam. The knowledge or skills employed in these dam projects are vastly different and come from a different ecological and environmental histories altogether! In the case of the beaver, the skill employed may come from some inclination or instinct in response to running water to which human beings are simply not inclined. We may never flesh out a nativized account of know-how in beaver dam building simply because we cannot properly understand what it is like to be a beaver or think like a beaver does. However, we can compare the processes and procedures and knowledge transformations of the beaver's *construction* to other construction projects. Distinguishing the differences in the *processes* makes for a more fair comparison. The comparisons I make in this dissertation provide some sort of way between the engineering design and biological design literature: one way in which we can talk about engineering and biological design is to talk about the *know-how* that is involved in both instances.

Thing Knowledge

In contrasting science and technology, Layton tells us that design is “manifested” in made artifacts (1974, 37). Know-how, possessed by lowly typists up and great engineering minds, rests in their creation of devices – *and in the devices themselves*. Looking at the instantiation of knowledge within technological products approaches the topic of technological knowledge from a very different angle. Davis Baird (2004) provides an account of thing knowledge that elaborates the ways in which the material products of science embody or bear knowledge that rivals the way in which scientific theories bear knowledge. Baird specifically discusses the way in which scientific instruments bear knowledge, but he would also include “recombinant DNA enzymes, 'wonder' drugs and robots, among other things, as other material products of science and technology” as knowledge-bearing things (2004, 1). Baird does not have in mind beaver dams or spider webs or the tools crows make and use (and he speaks specifically against spider webs), but he does provide three ways in which scientific instruments bear knowledge that might be worth exploring: model knowledge, working knowledge, and encapsulated knowledge. The overall idea of thing knowledge – that objects can bear knowledge – may not be exhausted in the three ways Baird illustrates, but he uses these three ways to explain three modes by which scientific knowledge can be encapsulated (and illustrated and created).

By looking at the made-artifacts themselves, rather than examining the mindof a maker or user, we can view thing knowledge as a prospect for animal creations. Understanding the mind of another can be a greater obstacle than understanding the workings of a thing, and a verbal explanation can sometimes be more difficult than providing even a simple physical model. Material models, for Baird, point to a theory – explaining or demonstrating the theory, in many cases, better than a theoretical model might. Baird refers specifically to John Smeaton's model water wheel used to determine efficiencies for waterwheels, Watson and Crick's "ball and stick" DNA models to help figure out the structure of DNA, and 18th Century physical models of the solar system called orreries (2004, Chapter 2). Material models of science help denote some part of the world to help demonstrate or understand some phenomena. These models help people figure out something about the world. This type of thing knowledge does not hold great prospects in the animal kingdom because one does not expect to understand something in the same way another species might. We might not be able to recognize a model even if one were created. It seems that one has to be in search of scientific knowledge of some type in order to create a model in the first place, and science is a practice particular to certain groups of human beings.[27,28]

Baird's second type of thing knowledge provides better prospects outside of human practice. Both people and things use working knowledge: a person has working knowledge when he knows how to do something, and a device can be said to have working knowledge when it works regularly (2004, 45). Baird appeals to pragmatism and the idea of *knowledge as effective action* to justify his claim that reliably working devices encapsulate knowledge. Baird explains that making material knowledge involves "contriving, arranging, and refining materials" (ibid.). Effective action through the use of a tool has been documented outside of the human species. Baird describes effective action in terms of reliably presenting a phenomenon (in the case of the cyclotron), and

---

[27] Not that animals don't explore their world or understand the workings of nature.

[28] Less problematically, we can talk about the 'folk physics' of different species. When crows of the same type repeatedly drop nuts off a ledge to crack them open, it seems like something of an understanding of gravity and forces is being used – and laboratory animal researchers work on this, too.

such reliability requires many tests and trials of materials and techniques for building. The creation of a working knowledge requires tinkering. Encapsulating knowledge exists as the third type of thing knowledge. This type involves both model knowledge and working knowledge, resulting in the creation of measuring instruments. Measuring instruments effectively "de-skill" a process. A phenomenon and a model from which to make a measure are necessary components of this type of instrument.

Though Baird's categories of thing knowledge are compelling, they are specific to scientific instrumentation and the goals of scientific work. His general discussion of thing knowledge is more relevant than his specific types to the project at hand. In a paper on the topic of thing knowledge (2002), he claims that "an artifact bears knowledge when it successfully accomplishes a function" (15). In order to get around the classic definition of "justified true belief" for knowledge (a definition that simply cannot adequately handle technological knowledge of any sort), Baird suggests that we replace truth with function in the material realm. When something functions properly, it is 'true' – much like expressions like 'a true wheel' and saying something 'runs true' seem to indicate (16). Using a "thin" notion of function (by which he means one that is not intentionally-loaded), Baird gives us five ideals for knowledge that he thinks can describe scientific as well as thing knowledge (from page 19):

(1) Detachment

(2) Efficacy

(3) Longevity

(4) Connection

(5) Objectivity

For Baird, function can serve for truth. Although a much greater context-dependence exists for function than there is for truth, the ideals he provides allow for arguments over whether made objects should count as true (whether they 'run true'), just like the way in which we can refer back to these ideals to see what should count as a scientific truth. The ideals provide a way to talk about both material and non-material creations in terms of knowledge and truth. Baird explains that "as ideals, they tell us why truth is important" and why we pursue scientific knowledge (19).

Though Baird makes no such distinction, the way in which he talks about the detachability of knowledge suggests a link to information and not just knowledge. Knowledge requires some knower, some skilled worker or someone who understands a theory or its components (in the case of some large scientific theories, knowledge may reside in a more distributed manner). The way in which I use the word 'information' here is closest to the dictionary definition of "a collection of facts or data," rather than the definition of "knowledge derived from experience..." ("information" 2003).[29] Facts or data can be stored without any such active, current practitioner of said information, though, in the case of thing knowledge, that data is still context-laden whether it is stored as information or as "noise". The knowledge that Baird speaks of as making it possible to "de-skill" large, complex machinery really becomes information, often to be processed

[29] Although this second definition might also be adequate, since information is knowledge derived from experience – which can then be decontextualized or generalized. Without context, information is just noise. Context matters.

by some technological thing, most often a computer program. This move from knowledge to information relates to the ways in which something-like-knowledge about the world is evolutionarily encapsulated into the instinctual material productions of some non-human animals.

Baird specifically speaks against spider webs as encapsulating knowledge of any sort. He first argues that we can linguistically and materially distinguish objects made by humans "from other natural products of life" (2004, 142) – as if human creation were somehow divorced from other creation, a prospect I wish to deny vehemently. While much of human construction can be recognized as being constructed by humans, cases that are less obvious exist: rocks that look like arrowheads, man-made ponds, etc. Some cases of human construction are ambiguous, and natural phenomena can sometimes be mistaken for a product of human intervention.

Baird advances a second argument against the prospect of spider webs as thing knowledge by appealing to his ideals:

> Thing knowledge, existing in a more refined, constructed space, exhibits greater simplicity... than do the adaptive living creations of natural history… [O]ur material creations, through our various acts of calibration, connection them with one another and with what we say, have a greater depth of justification than do animal phenomena. Spiderwebs are well adapted to catch flies. But there is no connection established between this approach to catching spider food and other possible and actual approaches.

> We can and do connect direct-reading spectrometers with other spectrographs... (2004, 143)

The ideal of connection, of establishing a relationship between the world and us, simply cannot be met by a spiderweb because spiderwebs are not related to other things. Baird is choosing a somewhat easy case to dismiss, yet the five ideals of thing knowledge, detachment, efficacy, longevity, connection, and objectivity, speak against this simple dismissal. Detachment might be the hardest criteria to meet: some spiderwebs are fragile, yet they can be detached or made elsewhere. They accomplish their ends – meeting efficacy criteria. They can be depended on in the future – meeting longevity standards as well as at least some technologies. In the case of some bird nests, the nests can be taken over, revised and reconstructed, and last for years. Connection: spider webs and bird nests do establish a relationship to the world, a physical relationship that puts the spider at home in its place in the world. As for objectivity, the world's voice certainly has priority in the relationship, given the fragile nature of the web and the possible threats in the world to it.

While I do not intend to argue that a spider has technological knowledge, the way in which Baird divorces function from intention becomes highly problematic in the face of animal artifacts. The web can encapsulated information without the spider actively participating in the creation and use of that knowledge. In *The Extended Phenotype* (1982), Richard Dawkins explains that a spider's web is "a temporary functional extension of her body, a huge extension of the effective catchment area of her predatory organs" (198). If we can distinguish between those things that are made by an animal from phenotypic action and those things that are made with a greater awareness, perhaps evidenced by the sharing of some learned activity within a species (that is not done by all within that species, given the same environment), then we may have evidence of something beyond mere instinct. Dawkins considerssome animal artifactsas effective extensions of that animal's body – as in the case of ant hills and spider webs.

The x-axis: Know-how

We can integrate know-how and thing knowledge by setting them up as axes on a graph and mapping technological behaviors along them – this can work for objects of human manufacture, as well as those of animal production. Some objects present a "de-skilling," where a user does not have to have know-how to construct it, but can still use the object without knowing how it works. Know-how requires skill and can be inferred through observations of learning (as in dolphins) and in problem-solving and the related understanding of folk physics (as in many of the laboratory bird studies). Ingenuity, creativity and innovation seem to be the ultimate expression of know-how: they indicate a greater understanding of causal factors and of material working than simple operation. Although innovation can be fostered by happy accidents, the realization that a new way of doing something proves useful demonstrates know-how – you really know how to do something when you can find a new way of doing it! I think here of Kanzi's new stone-flaking technique that I detail in the next chapter. While throwing a rock at the ground hardly seems innovative, *recognizing* the usefulness of this action (as compared with other approaches) and *practicing* this technique (and improving) reveals know-how about the process and about the material. The ways that human instrument makers tinker in creating their instruments, trying different materials and methods to get at intended results, and recognizing problems along the way, seems to show this sort of understanding, this knowledge, too.

Causal reasoning plays an important part in know-how because what a person or animal has know-how about is often causal. Recognizing the differences in materials and usefulness for a given and intended task is important for the successful completion of a task. Discussed in Chapter 6, the ways that New Caledonian crows in both the wild and in captivity pick out materials appropriate for given tasks points to a recognition of what produces the desired results. The studies of rooks and crows bear out an understanding of causal relations (the use of meta-tools indicates this) as well as judgment about proper lengths of tools (the right tool for the job). Material culture also indicates know-how that can be taught or learned and passed. The selection of certain materials by different groups of the same species of chimps in different regions, even with availability of alternatives and similar environmental contexts, demonstrates the importance of material culture to what the chimps learn to do, in the skills they develop. I also think here of the foraging techniques of dolphins (described in Chapter 5): though not necessarily a *material* culture, hunting and foraging strategies are often passed down in the matriline, without any clear evidence of genetic basis for these behaviors. What a dolphin learns to do is often what its mother does. I use know-how as my x-axis in mapping technological behaviors.

The y-axis: Encapsulated Information

Encapsulated information provides the other axis of interest – we might call this encapsulated information or thing knowledge (*a la* Davis Baird). Baird explains 'thing knowledge' as knowledge encapsulated in a technology or device – things *bear* knowledge, knowledge that may or may not have a theoretical counterpart (2002, 2004). Artifacts can be said to bear this knowledge when they "successfully accomplish" some function (2002). For Baird, functioning – whether or not it can be explained propositionally or not – demonstrates whether an object bears knowledge. Baird spends some time in his book on the topic *insisting* on the difference between the sorts of things that he wishes to call thing knowledge (the products of science) and natural artifacts (like spiderwebs and beaver dams) (2004, 142-144). I consider his objections here.

He first objects to the possibility that spiderwebs and beaver dams are instances of thing knowledge on the grounds that we can distinguish animal and natural artifacts from human-made ones. Baird explains: "Whatever the analysis of them, we can distinguish objects of human manufacture – both linguistic and material – from other natural products of life" (2004, 142). I'd like to reply on two grounds. First, we come to distinguish the category of human-made things through experience; I have known preschoolers who look at a really nice bird's nest and sweetly ask about who helped the bird to make it.[30] I've also seen a kid pick up sticks with the aim of adding them to a beaver lodge – which looks, on the surface, just like a big pile of sticks. We have an easier time (even as children) picking out what is human-made, of course, because these things interest us; they are the things we spend most of our time handling. We can also pick out things that are outside of their of context: when we see a candy wrapper alongside a stream, we know that the candy wrapper does not "belong". While we can separate out what humans have manufactured and what other animals have, that alone does not speak against the possibility that both sorts of made-objects encapsulate knowledge. This sort of objection about thing knowledge – that it is only applicable to human-made objects – has vestiges of the human clause. But, until we actually investigate those objects made by animals, we should not rule out the possibility that they could bear thing knowledge.

Second, the cases Baird gives of beaver dams and spider webs are cases of construction that *don't* involve the sort of fashioning and learned technique that we witness in the work of dolphins, chimp, and crows. It looks as though Baird is generalizing hastily when he takes the easy cases to dismiss the entire class of animal-made things. While there may be categorical differences that one might apply – based on complexity or the employment of intelligence or ability to improve over time – we cannot simply rule out animal artifacts on the grounds that they are made by animals.

Baird raises a second objection to the notion of animal artifacts as examples of thing knowledge, arguing that bearers of thing knowledge exhibit more simplicity and

[30] Baskets and nests do share some resemblance, in the defense of preschoolers.

better justification than animal artifacts can. The difference here becomes a matter of degree[31], rather than a rigid categorical distinction. He explains:

> [O]ur material creations, through our various acts of calibration, connecting them with one another and with what we say, have a greater depth of justification than do animal phenomena. Spiderwebs are well adapted to catch flies. But there is no connection established between this approach to catching spider food and other possible and actual approaches. (2004, 143)

But animal artifacts that receive greater 'depth of justification' than webs do exist. That New Caledonian crows make several distinct, standardized forms of tools indicates a connection and calibration that provides more justification – more evidence of know-how or learned skill – than the behaviors of a spider. That these crows return to retrieve a particularly good tool to use again also speaks to a *connection* between a task and approaches to it. The way some chimp groups repeatedly test their tools as they construct them can be understood in terms of the calibration and connection that Baird insists upon. While these processes may not be as complicated or built-up as the direct-read spectrometers Baird gives as an example to contrast against spider webs, the crow's hook-tools do involve various acts of calibration and a real connection with the world, as do the implements of chimps. Certainly, a gorilla's use of a walking stick to repeatedly test the depth of water suggests something more akin to the measuring instruments Baird

[31] And, mapping things out in terms of differences in degree is part of my project.

describes than either of the examples of animal constructions he dismisses do (see Chapter 7).

There are at least four types of tool use – only one of which seems to describe the material creations Baird describes in *Thing Knowledge* (2004). In a completely unrelated context, a group of computer scientists has described four general categories of tools:

(1) Effective tools "produce a persistent effect on materials or the environment" and include hammers and other pounding devices, screwdrivers, and other things we generally call 'tools'.

(2) Instruments are tools that "provide information about materials or the environment" and include things like the instruments Baird considers in his book, and I would include Leah's measuring stick.

(3) Constraining tools are those that "constrain or stabilize materials or the environment for further application of effective tools." This category includes many examples of metatools that help in the creation of some other tool. The authors give the example of clamps, rulers, and wedges that help in the creation of effective tools.

(4) Demarcating tools are ones that "demarcate the environment or materials" such that those materials or part of the environment can be treated differently, with examples of pencils and working surfaces. (Categories taken from Horton et al. 2010)

Most of the animal examples I discuss are of effective tools, with a few examples of instruments and constraining tools along the way. While these authors neglect a larger picture that includes constructions alongside tools, their division makes sense in light of Baird's claims. Not many animal cases are instances of instrumentation, even though tool use is well-established in other species. What Baird considers in terms of his theoretical schema centers on the material products of human beings in the context of science. However, despite instrumentation's special role in science for human beings, the material products of non-human animals can be considered in terms of technological knowledge – or at least in terms of encapsulated information, a term that I think works better in the absence of a greater depth of description in terms of intentionality in Baird's account. Though I wish to borrow Baird's idea that some tools (instruments only, in his case) encapsulate or bear knowledge about the world, the tool use of animals is hard to describe within his categories, which are so deeply attached to scientific instrumentation in particular. What Baird does offer, however, is a way to talk about tools and technologies (and constructions) and what they represent without reference to some deep-seated intentionality on the part of the maker or user. Instead, we can rely on *function* to make sense of the epistemological content of an object.

Integrating the Axes

Baird's 'thing knowledge' divorces function from intentionality, but this account is unsatisfying because one would not be able to judge whether something was functioning properly without reference to a user's or maker's intent.[32] Because objects can detach

[32] While one might object that you can talk about function without reference to intent, to understand the purpose of a broken or new object, one has to either have some account of the user or maker's intent

from their context of discovery or development (like scientific theories), Baird thinks we can take a "thin" notion of function in place of a "thicker" account. He explains of functions that:

> A function is a purposeful phenomenon. But adding purposes adds problems. There are problems ascertaining purpose or intentions. Without access to a designer's mind or a design team's interactions, determining the intention behind some part of an instrument can be a difficult matter of reconstruction and interpretation. (2002)

For this reason, while Baird recognizes that functions involve intention, he chooses to champion a "thinner" notion, one that acknowledges "human intentions and purposes, but that attends to the reliability and predictability of our crafted artifact" (ibid.).

What I offer here is an account that differs from Baird's. Baird can champion a lesser-intentioned account of artifactual knowledge, but this move comes with the price of accepting the very animal artifacts he would like to exclude from consideration as 'thing knowledge'. If we remove (or reduce) the effect of intention in our consideration of objects and instead consider their function, spider webs and beaver dams *should* count as bearing thing knowledge of some sort. The spider doesn't *intend* to design the web as it does, but it functions beautifully! The same can be said of other animal constructions. Some actions, like a beaver's tree-felling activities that lead to dam construction, lead to a

(what is this object supposed to do?) or the context in which the object is supposedly used (where does this object belong?). There's a Smithsonian annex of objects whose function/purpose is unknown – Joseph C. Pitt likes to give this as an example to his Philosophy of Technology classes for debate over whether something is a technology if its function is unknown.

well-designed product (they are always at the smallest point in a stream) and are quite functional (useful for the beaver in a variety of ways). Intention may differ for humans and beavers building dams (and the dams differ widely too), but both make functional constructions that alter their environments.

By placing encapsulated information (or thing knowledge, if you prefer) on one axis and know-how on the other, we can describe constructed artifacts of all sorts in terms of both functional and intentional terms and map very different objects out alongside one another. We might think of encapsulated information as the sort of knowledge contained in devices or tools or constructions and think of know-how as the knowledge that it takes to work or use or create a device or tool or construction. A spider may not have very much know-how – most of the skill necessary would be part of its phenotype – but the web itself may encapsulate information about the world, information that is not 'known' by the spider but nonetheless employed. We would map a spider web low on the x-axis (know-how) but relatively high on the y-axis (encapsulated information).

By setting up an account of two types of technological knowledge represented on the axes, we can actually unite discussions of biological and engineering design and function. A biological design is available to reference when discussing a spider's web and an engineering design to consult when looking at the scientific devices Baird discusses. Both designs work to encapsulate knowledge and produce a material artifact that works in a given environment. A scientific device involves a great deal of know-how on the part of its makers to produce and use; this know-how requires skill and understanding about causal or scientific phenomena. The spider has no such know-how. Some objects require something between biological and engineering design – a combination. Young male weavers watch other males construct their nests, learning how to weave materials to make a better nest. Some of the behavior may be instinctual, a function of the bird's genetic predispositions, but they also learn technique and then employ this know-how of nest-building. Dolphins do the same with foraging techniques, though these often do not result in a material product that could encapsulate knowledge.[33] For the most part, most dolphin foraging techniques will rank low in terms of encapsulated information, though they still present know-how.

Conclusions

In the following chapters, I present case studies of animal behaviors that stand as candidates for technological knowledge, followed by a discussion of how we can fit these constructions into discussions of technological knowledge. From these studies, I construct an account of technological knowledge that integrates know-how with encapsulated information, providing one graph on which to plot a wide variety of technological behaviors. By integrating these two dimensions of technological knowledge, I show how the technological behaviors of animals can be mapped alongside

[33] We could even talk about linguistic encapsulation of knowledge, something more akin to information shared by written words or spoken statements.

human engineering feats. Many of the animal cases come from recent research. Jessica Pierce and Marc Bekoff (2009), in a recent *Chronicle for Higher Education Review*, explain that "[r]esearch on animal behavior has never been more vibrant and more revealing of the amazing cognitive, emotional, and moral capacities of a broad range of animals" and herald the past decade as "the decade of the animal." Much of the reaction from the humanities with regard to animals has been about morality and the under-recognized emotional nature of animals. What I provide in the following chapters is an integration of this new animal research with research in the philosophy of technology.

Chapter 4: Great Apes

Tool use among chimpanzees is the least controversial and best documented of all animal instances of tool use. Some definitions of technology already extend the human clause to make it into a hominid clause (or at least footnote something about this possibility), citing evidence of tool making by the hominid ancestors of humans and cases of tool use by orangutans and chimpanzees. In this chapter, I describe research about Great Apes – the tool use of gorillas, chimpanzees, and orangutans – to argue that a human clause on a definition of technology is inappropriate. Though many philosophers of technology and anthropologists mention the tool-use of chimps, the literature in the past few years on the use of tools by chimps and other apes has shown this tool-use to be both more complex and targeted than previously assumed. This new data makes maintaining a human clause much more difficult. I rely mostly on chimpanzee studies due to their abundance in the literature.

As early as 1960 (and after a long time where it was assumed that humans were the only tool-using species), Jane Goodall and her research group documented tool use by chimpanzees. But, even then, and as late as 1990, the data were still limited: it was held that "in the wild only chimpanzees have been observed to make tools" (Boesch and Boesch 1990). Part of the problem with documenting tool use in the wild by apes is that habituating a group of apes to the presence of humans takes time. Note that "in 45 months of initial observation, Goodall saw ant dipping only once, although it is common in Gombe" (Boesch and Boesch 1990). Human presence makes observing tool use in the wild difficult, and only more recently have researchers been able to better capture the wide array of tool use by primates. Gorillas have been found to use simple tools to perform tasks in the wild – using a stick to test water depths, using stick and shrubs to support their posture, using a trunk on swampy ground as a bridge (Breuer et al. 2005). Orangutans have been found to use branches for foraging and to use leaves to modify calls to mislead potential predators (Scheldeman 2009; Breuer et al. 2005). Chimpanzees, of course, have a wide array of well-documented tool use: using stone tools to process food and crack nuts, hunting with the use of wooden spears, and more. The Gombe chimps studied by Jane Goodall use an array of objects – stems, twigs, sticks, leaves, rocks – in nine different ways that have been observed, and chimpanzees in other areas use *other* objects for other purposes or have a slightly different material culture, *making different tools for the same purposes*. These tool-related behaviors are learned through watching others and are passed within a community (Jane Goodall Institute 2007).

Chimpanzee studies by Crickette Sans and her team in the Congo reveal the use of "tool kits" by some groups of chimps that forage for army ants, tool kits that allow for more sustainable ant harvesting methods (Sans et al. 2009). In this chapter, I describe some of the pertinent research on the tool-use of apes, concluding with a look at the way this research might be better incorporated into discussions of technology. This research gives us grounds to consider at least replacing the human clause with a primate one and works to expand the domain of discussion for considering technological artifacts. In subsequent chapters, I maintain that even a primate clause cannot be maintained in the face of other non-primate animal artifact production.

Kanzi and Bonobo Chimps

Along with Koko the Gorilla of sign-language fame, Kanzi is one of the great apes on whom studies to figure out ape abilities have yielded terrific results. There are two types of chimpanzees: bonobos (also called pygmy chimpanzees, *pan paniscus*) and the common chimpanzee (*pan troglodytes*). Kanzi is a bonobo. Though less famous than Koko, Kanzi's learned tool-use and innovative technique point to a greater capacity and flexibility in tool-use than many had assumed. Though this bonobo chimp was used mostly in language studies, Kanzi was also enrolled in an important study on tool-use.[34] Researchers set out to see if bonobos could learn to make stone tools, like those made and used by hominid ancestors to humans (Schick and Toth 1993, 135). Using Oldowan stone tools as a guide, and the work of Richard Wright (an archeologist who demonstrated that an orangutan could be taught to make stone flakes to use as a tool to cut a string on a box containing food in the 1970s), researchers first showed Kanzi how useful stone tools could be – cutting cords to open boxes with Kanzi's favorite treats in them. Kanzi could use stone flakes made by researchers to cut into boxes by the first day. On the second day, Kanzi could judge well the best tool for the job – choosing the sharpest knife most of the time; Kanzi was also hitting stones together to make his own tools (ibid.,136).

---

[34] Actually, Kanzi is better known for his participation in language studies with the Language Research Center at Georgia State University. Raised in captivity and exposed to language experiments on his adoptive mother, his ability to use and manipulate language has demonstrated the ability of bonobos to pick up language through social interaction. The best reading on this topic may be: Savage-Rumbaugh, S., and R. Lewin. 1994. *Kanzi: The Ape at the Brink of the Human Mind.* Wiley.

Within a month of the start of the study, Kanzi struck rocks to make flakes with hard-hammer percussion. He was given some demonstrations by researchers of how modern humans would make their tools (ibid., 136). Within several months, Kanzi came up with his own technique – throwing a stone on his hard floor to splinter them into edges for cutting. The researchers note parenthetically:

> Curiously, he had never been very interested in throwing until this technological advance of his, although some of his siblings have shown a penchant for throwing things. But now he seemed to find a purpose to it. (ibid., 138)

The researchers go on to refer to this new process of Kanzi's (repeated floor throwing) as an innovation where Kanzi "seemed to have made his own connections between the force of the throw and successful flaking" (ibid.).[35] With this new association, Kanzi's hard-hammer percussion work "became much more forceful," and Kanzi started producing better flakes with this method, "producing objects that we can begin to compare with those in the early archaeological record" (ibid., 139).

---

[35] Describing chimpanzee behavior as innovative is not new. H. Kummer and Jane Goodall have described the "Conditions of innovative behavior in primates" in *the Philosophical Transactions of the Royal Society of London B* in 1985 (volume 308, pages 203-214). To Kummer and Goodall, an innovation may be "a solution to a novel problem, or a novel solution to an old one; a communication signal not observed in other individuals in the group (at least at that time) or an existing signal used for a new purpose; a new ecological discovery such as a food item not previously part of the diet group" (page 205).

Researchers note that Kanzi's work after nine months was not of a quality comparable to the found Oldowan tools to which the researchers were comparing, but his innovative technique and new understanding as he worked with the tools impressed researchers (ibid., 139). Though this study was conducted in a controlled environment, it demonstrates the capacity for tool-use of bonobos and speaks against assumptions by some philosophers of technology and anthropologists who insist that humans are the only species capable of producing innovation in their technologies and techniques. With the case of Kanzi, researchers produced evidence for innovative capacities in tool-use by a non-human. And Kanzi's new finding in his throwing technique led to better hard-hammer percussion of stones, producing better stone tools.[36]

In a study following Kanzi's feats, capuchin monkeys in captivity have produced stone flakes to use as cutting tools and exhibit patterns of right-handedness that some associate with tool-making hominids, like the Oldowans. Hominids produced the first stone tools 2.5 million years ago in what is called the "Oldowan technological stage" (Schick and Toth 1993, Westergaard 1995). These tools consisted of flakes and battered stones. The known tool use of wild chimpanzees comes largely from vegetation – bent twigs, leafs, sticks – with the exception of chimps who use stones to crack open nuts (Westergaard 1995). Capuchin monkeys, also produce tools in a series of contexts, clubbing snakes with sticks, using shells to crack open oysters, etc. Taught to flake stones in captivity like Kanzi, capuchins demonstrate "impressive artifact production skills"

[36] Incremental improvements like this may even point to the sort of feedback loops that Joseph C. Pitt promotes as an important component of technology (2000).

(Westergaard 1995, 3). Capuchins also demonstrate right-handedness at a population level, something that some researchers associate with the complex object manipulation that can be related to the evolution of language (Westergaard 1995). This particular discussion is startling in that Great Apes (humans, chimps, orangutans, and gorillas) are often thought to be more closely akin than other primates. This *capacity* for the use and production of tools certainly extends beyond the closest of human relations, as demonstrated by the capuchin monkey studies in tool-use.

The Tool Kits of Common Chimps in the Congo

More recent research in the wild on the common chimpanzee has yielded a new wealth of data on the type and use of tools by chimps. Led by Crickette Sanz, an anthropologist from Washington University at Saint Louis, researchers have found that common chimpanzees can employ a set of tools (not just the simple use of one tool) to prey upon ants. Though chimps were discovered to use dipping tools to extract ants to eat, this new finding suggests that tools can be employed in concert to extract food better – with "better" in this case meaning in a sustainable way (Sanz et al. 2009). Collecting over 1,060 tools used for ant-dipping and making 25 videos of tool-use on ant nests, Sanz's research team has concluded that the particular chimp groups which they were examining have "developed a specialized method for preying on army ants, which involves the use of an additional tool for opening nests" (ibid., 1).

Dipping for ants has been well-documented as a use of tools by chimpanzees. Chimps take some sort of probe (typically a stick) to poke into a large army ant nest. Ants will climb up the stick, and a chimp can enjoy an antsicle.[37] Dipping probes vary in length based on ant or termite species, as well as group of chimpanzees.38 In the Goualougo Triangle of the Republic of Congo, where Sanz and her team perform their research, several groups of chimps preying on several *Dorylus* species army ants employ two different types of tools: one is a "woody sapling to perforate the ant nest" and the other is "a herb stem as a dipping tool to harvest ants" (Sanz et al. 2009, 1). The use of a tool set is even more rare to witness than the use of a tool. With this discovery, Sanz and her team found these chimps to "exhibit more flexibility in order of tool types" than had been found in honey gathering of chimps, another documented use of a tool set by chimps (ibid., 2).

From the artifacts gathered, video clips, and observation, these two different tool types are used in concert. The nest perforating tools have an average length of 92.3cm and average diameter of 7.3mm and are typically made from saplings with leafy branches still intact on the far end (ibid., 4). Composed of a more flexible material and having an average length of 64.4cm and diameters of 5.4mm, the ant dipping tools are made from "herbaceous materials" gathered by uprooting plants; many recovered dipping tools still had roots on the unused ends (ibid., 4). Different in material composition, length and diameter, and in method of procurement, these tools were observed being used in different manners. Researchers observed ant nest perforation with the perforating tools

---

[37] Yes, an antsicle: a popsicle of ants. I'm coining the term.

[38] This cultural difference in ant-dipping will be described in more detail below in the section on Cultural Differences.

eleven times, consisting of the sapling tool insertion into the nest, partially withdrawn and several reinsertions, and then withdrawn; the herbaceous-material dipping tool was then inserted to gather ants onto that tool to make an antsicle (ibid., 4). Researchers recorded 48 bouts with the dipping tool, sometimes being used along with bouncing, twisting and tapping, possibly to "stimulate movement of the ants onto or up the tool" (ibid., 4).

The nest perforating tools observed by Sanz and her team are similar to nest digging tools seen in Guinea, and the researchers suggest that "it is possible that this tool set once had a wider distribution or has been independently innovated in different chimpanzee populations across western equatorial Africa" (ibid., 5). Nest digging and ant-dipping tools have been observed in Guinea on a few occasions, with tools being different in size and composition (ibid.). Researchers speculate that the different reactions of different army ant species may contribute to differences in the material cultures of different populations of chimpanzees. In the case of the Goualougo chimps:

> The use of perforating tools instead of hands for opening nests might confer two advantages to the chimpanzees of Goualougo (a) it elicits a less aggressive attack from the ants which may in turn allow overall longer dipping times and higher yields and/or (b) it causes less disturbance and reduces the likelihood of an early migration of the army ant colony so that chimpanzees can continue to exploit the same nest repeatedly over the course of days or weeks... (ibid., 5-6)

which can lead to a greater nutritional gain. Additionally, the use of nest perforating tools may be better for the structural integrity of army ant nests, “which means that the ants may stay longer in their nest and not quickly migrate to another location in response to the attack” (ibid., 6). Chimps could exploit the same army ant nest for longer, repeatedly using the same nest and reducing search times and “could also be a form of 'sustainably harvesting' this food resource” (ibid., 6).

These chimps in Goualougo do not simply use these two tools, though. Sanz and her team have also witnessed several different tool sets used to “open a substrate and then gather the embedded food resource”: puncture and fishing tools to use on subterranean termites and epigaeic termites, and several types of tools in honey gathering, including thick tools from dead branches are used in bee hive pounding (ibid., 6). The variety of tool use among these chimps is notable, as is their use of tools in concert with one another.

At another research site in Bossou, New Guinea, wild chimpanzees regularly use stones to crack nuts to get to the kernels. This nut-cracking tool use is supposedly the most complicated known tool use by chimps in the wild (though more impressive feats have been taught in laboratory settings39). According to Inoue-Nakamura and Matsuzawa (1997),

> It basically consists of the following actions: (a) picking up a nut, (b) putting it on an anvil stone, (c) holding a hammer stone, (d) hitting the nut

[39] Kanzi's activities, for instance.

> on the anvil stone with the hammer stone, and (e) picking up the kernel in the cracked hard shell and eating it. (ibid., 159)

Nut cracking has only been observed in limited areas of West Africa and not at all in East Africa, although nuts and stones are available in both locations. Inoue-Nakamura and Matsuzawa explain nut cracking to be "a strong example of the diversity of material culture among chimpanzees" (ibid., 160). Bossou chimps have tool use behaviors that include: "nut cracking, ant catching, leaf folding for drinking water, and pestle pound for sap extraction from oil-palm trees (ibid.).

Inoue-Nakamura and Matsuzawa performed an experiment with infant chimpanzees on nut-cracking to help figure out the development of stone tool use by wild chimps, discovering that neither human infants younger than 2 and chimp infants in the age group of 2.5 years old possess an understanding of basic touch-together actions, and both are unable to combine actions together to either crack a nut or some human equivalent (the proper use of a spoon, for example). "The lack of adequate composition of each action is a common characteristic" in these two groups (ibid., 170). Their comparison of young chimpanzees tool use acquisition to human young helps illustrate the idea that the learning processes are not dissimilar. The researchers summarize the learning process of these chimpanzees in the following way:

> True imitation cannot explain the results of the present study. The infants showed various combinations of stones and nuts. They also showed a variety of fundamental actions. Not all of them were adequate actions for nut cracking. They gradually increased the relative frequency of adequate

> sequence of the basic actions through each stage of development. They did not copy the motor patterns or the way to relate nuts with stones, which were shown in the tool use by mothers and other members of the community. As the present results suggest, they learned the general functional relations of stones and nuts and also learned the goals obtained by the demonstrator. This learning process might be called emulation. (ibid., 172)

But the process of learning does not mirror the human case:

> Active teaching seems to be a clear distinction in the process between humans and chimpanzees. Active teaching is rare in chimpanzees in the wild although it is popular in humans. So far, there have been no instances of active teaching or guidance except two reported episodes in which mothers influenced their infants' attempts to crack nuts... (ibid., 172)

The chimp studies in the wild on tool use are perhaps even more compelling than the Kanzi case, which demonstrated that some chimps were capable of making stone tools. The actual variety and cultural difference and learning process witnessed in the wild speaks to a great misunderstanding and a lack of respect for the sorts of work done outside the human domain.

Chimp Planning

My favorite chimp case, and the last one I will discuss, comes neither from a laboratory nor the field, but from a zoo. The popular press reported that a chimpanzee at Furuvik

Zoo in Sweden stockpiled rocks to pelt at zoo-goers – and then threw them at the visitors! Named Santino, this chimp furtively stashed away stones, demonstrating "the first unambiguous evidence of spontaneous forward planning in a non-human animal" (Henderson 2009). According to Mathias Osvath, who published the study of Santino, explains that

> Planning for a future, rather than a current, mental state is a cognitive process generally viewed as uniquely human.... The planning actions [of Santino], which took place in a calm state, included stone caching and the manufacture of discs from concrete, objects later used as missles against zoo visitors during agitated chimpanzee dominance displays. Such planning implies advanced consciousness and cognition traditionally not associated with nonhuman animals. (Osvath 2009, R190)

Santino's stone-caching behavior was not simply a one-time occurrence. In June of 1997, Santino was throwing stones several times for each of his aggressive displays; zookeepers did a sweep of his enclosure, finding five cashes with three to eight stones each, as well as individual stones between caches, all along the shore facing the public (ibid., R190). On five consecutive mornings, a hidden zookeeper watched the chimp gather stones from the water and cache them. A year later, in June of 1998, Santino added concrete pieces to his caches, breaking off concrete rocks from large concrete rocks in the center of the island enclosure (ibid., R191).

Santino even had a technique for making these concrete rocks to hurl at visitors: he "was observed to gently knock on the concrete rocks from time to time delivering harder blows to break of the detached surface section in discoidal pieces, and sometimes breaking these into further smaller fragments" (ibid.). Since 1997, zookeepers have removed hundreds of Santino's caches, though Santino never found, stored, or made these missiles while zookeepers or visitors were obviously present. In the off-season and on off-hours, Santino does not throw stones, and his stone caches are located only along the shoreline that faces the visitors' area, making the purpose of his stone caching fairly apparent (ibid.). Additionally, the use and making of the concrete discs with which Santino has tossed at visitors were never shown to Santino (ibid.), so it seems he came up with their production and use on his own.

No zoo-goers have been hurt, as Santino only throws underhanded (Henderson 2009).

Comparison of Chimps, Bonobos, Orangutans, and Capuchins

In 1995, Sue Savage-Rumbaugh, a team member in the Kanzi studies and an important figure at the Language Research Center associated with Georgia State University, along with Elisabetta Visalberghi and Dorothy M. Fragaszy published a comparative study on the tool-use of bonobos, common chimps, orangutans, and capuchin monkeys. They noted differences between the great apes in the study (bonobos, chimps, orangutans) and the monkeys. The experiment participants were 6 capuchin monkeys, 5 common chimps, 4 bonobos, and 1 orangutan, of which all were born in captivity except for a single bonobo (Visalberghi et al. 1995, 53). None of the participants had encountered this particular experimental set-up, though a number had participated in other tool-related experiments.[40] The age range of the participants was 2.5 to 20 years of age (ibid., 54). The apes in the study – chimps and orangutan – participated from the Language Research Center, while the monkeys encountered similar experimental conditions from Washington State University (ibid., 53-4). The relevant experimental apparatus consisted of a clear tube with a treat inside and different tools for extraction. In the first trials of the experiment, the tool available to the test subject was a wooden dowel – with which the participant could push the treat out of the tube to receive the "highly preferred food" (ibid., 54). After mastery of this set up was achieved (for the monkeys, this meant 10 consecutive successful trials; for the apes, this meant successful performance for three consecutive trials), the participants were given more complex conditions: two tools, a bundle of dowels, and an H-shaped stick constructed from dowels, placed much further away from the tube (ibid., 54). For the bundle of dowels, the participants had to take apart the bundle to use one dowel in the tube for successful completion of the task. For the H-shaped sticks, the H had to be deconstructed so that one component of the H could be used in the tube for success.

Four of six capuchins solved the simple set-up on the first trial, and the other two succeeded by the fourth time, but all capuchins made errors in the complex trial (ibid., 55). Eight of ten apes solved the simple-set up on the first trial; the two youngest participants did not work as quickly, with one ape solving on the 7th trial and the other

[40] In fact, Kanzi is one of the participants in this study, as well as his adoptive mother Matata! Small world.

removed from testing after 13 unsuccessful trials (ibid.).[41] For the complex trials, all but one of the monkeys made errors on with the bundles of dowels before success, attempting to insert the bundle before taking the bundle apart, while the apes were extremely successful, with none of them trying to insert the whole bundle and solving the problem easily (ibid.). For the H-shaped complex trials, monkeys made two types of errors: inserting the unbroken H and inserting the short H dowel that held together the two long dowels that were useful for getting treats. All of the monkeys made errors on the H-shaped complex trial (ibid., 55). The apes made three types of errors on the H-shaped complex trials, but performed much better, with researchers concluding that "[o]verall it appears that apes have or easily acquire an appreciation of the length of the stick needed for solution" (ibid., 56). One ape named Sherman, a common chimp, had a particular problem during the trials with the H-shaped sticks:

> It appeared that he was acting even more carefully than the other apes, so as not to damage the object give to him. For example, one time the sticks fell out as he rotated the dowel, and Sherman replaced them in their original positions. (ibid.)

Sherman's trials had to be discontinued because he was becoming "increasingly distressed" during the H-stick trials.

In the discussion of the study, the authors explain that these trials demonstrate that tool use is not simply "a yes-or-no capacity," and that equal success at a task may not

[41] This youngest ape, Tamuli, age 3, would be subjected to this experiment 2 years later and perform successfully. The youngest monkey in the study was 2.5.

"imply equivalent understanding" (ibid., 56). Capuchin monkeys were found to succeed just as often as apes, but with more inefficiency in subsequent attempts and new situations.

> The number of errors did not decline significantly from the first block of trials to the second block of trials in either complex condition.... The persistence of errors across blocks of trials suggest that the subjects did not achieve full comprehension of the requirements of the task within the testing period.... their behavior toward the task was not random, and it improved (although not significantly) with experience. (ibid., 58)

All three ape species tested performed similarly well, and, in comparison with the capuchins, apes did much better on subsequent trials, with none of the apes trying to insert the bundle of dowels (ibid.). Apes seemed to have a better understanding of the situation such that they could perform better in subsequent trials. While capuchins continued to make mistakes, the ape participants in this study improved with practice. The researchers conclude that:

> These findings suggest, at the least, that apes can acquire more readily those associations relevant to solution of the task. An equally plausible interpretation is that apes acquire a fuller comprehension of the task than capuchins do.... [A]pes and capuchins can achieve success in a tool-using tasks and still have an apparently limited understanding of the causal relations involved... It appears that the experience of using tools does not, by itself, lead to or require the emergence of additional conceptual

> complexity. Nevertheless, apes appear to make greater progress to this end than do capuchins. (ibid., 58-9)

In this way, the researchers tested understanding of the causal relation between a tool-using act and its outcome, with startling results about the success and methodology of monkeys versus apes. Of course, further research on gorillas (a great ape not in the study) and other types of monkeys would be necessary for a more definitive category distinction.

Interestingly, this study produced another outcome: a noticeable difference in performance for apes based on young age where there was no difference for capuchins. The youngest capuchin was 2.5 years old and performed as well as the other monkeys; the two youngest apes were the least successful at the outset (ibid., 58). This finding suggests different learning trajectories or abilities between apes and monkeys, though more research would be needed to draw any conclusions.

Cultural Differences

Comparative studies of different primate groups and their tool-use tell us something about the capacities of different groups, but intra-species studies have also yielded intriguing results about differences not arising from capacity or environment, but from culture. My younger sister, an anthropology major, reported to me that her anthropology textbook told her that culture was something uniquely human. Despite this textbook claim, evidence of material cultures among wild chimpanzees, as well as other species, exists.[42] Without written record on the part of these animals, or any sort of communicative tradition of which we are aware, looking at traditions in *tool use instead of language* may be our best avenue into discussions of differences in culture. Tools may be the only physical manifestation of cultural tradition that we can trace in some groups.

Although more studies on these matters have accumulated in the literature, the study of Chrisophe Boesch and Hedwige Boesch (1990) comparing three wild chimp populations and their tool use demonstrates differences between these populations in terms of tool-making, too-use, and diversity of tools. For the purposes of their study, Boesch and Boesch limit tools to only objects that "must be held in the hand, foot or mouth and used as to enable the operator to attain an immediate goal" (Boesch and Boesch 1990). Taking data from three long-term studies of wild chimp populations in East and West Africa, the researchers discuss the impact of environment on tool-related behaviors. The three populations examined hail from Tai National Park (a rainforest environment on the Ivory Coast, West Africa), Mahale Mountains National Park and Gombe Stream National Park (both in a savannah/woodland environment in Tanzania, East Africa).

During a nine-year period, researchers in the Tai National Park observed five different tool-use activities (insertion, probing, cleaning, displaying, and pounding) for eighteen aims (including ant-dipping, honey fishing, boring bee nests, sponging off, throwing, dragging, etc.). Boesch and Boesch provide a table of their data on tool use in Tai chimps over a nine-year period:

---

[42] Dolphins and whales, for instance, to be discussed next chapter.

Table 1. List of types of tool use in Taï chimpanzees observed during a 9-year period

Tool-use activity	Tool-use aim	Number of observations	Tool material	Tool size in cm: length (range) thickness (range)	Number of tools used (number of tools made)
(1) Insert	ant dipping	20	twigs; (n = 28)	23.9 cm (58–11) 5.7 mm (3–10)	35 (34)
	wood-boring bee killing	6	twigs; (n = 3)	29.0 cm (29) 7.3 mm (7–8)	11 (11)
	honey fishing	15	twigs; (n = 42)	28.1 cm (60–14) 7.8 mm (3–18)	45 (45)
	bone marrow extraction	33	leaf stem, twigs; (n = 24)	14.4 cm (5–35) 4.0 mm (2–7)	51 (50)
	brain eating	1	twigs		1 (1)
	eye eating	1	twigs		3 (3)
	nut emptying	93	twigs; (n = 91)	15.4 cm (4–80) 4.1 mm (2–9)	196 (172)
(2) Probe	wood boring bee nests	6	leaf stem, twigs; (n = 7)	14.8 cm (10–22) 4.8 mm (4–6)	11 (10)
	corpses	4	twigs		4 (0)
	wounds	1	twigs		1 (1)
	bark interstice	1	twigs		2 (2)
	other objects	3	twigs		3 (1)
(3) Clean	sponging	12	leaves		12 (12)
(4) Display	aimed throwing	6	branches		16 (2)
	throwing	3	branches		13 (1)
	dragging	7	branches		12 (0)
	hitting	4	branches		4 (0)
(5) Pound	nuts	932	clubs, stones; (n = 719)	clubs = 81% stones = 19%	1,037 (85)[1]

[1] Data on tool use and making by identified individuals only for the sample of 1983–1988.

Figure 1: Table 1 from Boesch and Boesch 1990, page 88

Chimps in the Mahale Mountains and Gombe Parks seem to have only four different tool-use activities, and their tool-related aims differ widely, with Gombe and Mahale chimps doing more tool-aided cleaning and using insertion and probe tools in fewer context. Table 2 from Boesch and Boesch shows types of tool use divided by chimp group:

Table 2. Tool use activities of table 1 observed at three long-term study sites of wild chimpanzees, classified following the

Tool use activity (type	Tool use goal		
	Gombe	Mahale	Tai
(I) Insert (grass, stick, club)	(1) termites (lsp) (2) ants (lsp) (3) bees (lsp)	(1) termites (2 sp) (2) ants (4 sp) (3) honey	(1) ants (2 sp) (2) bees (1 sp) (3) honey (4 sp) (4) bone marrow (5) brain (6) eyes (7) nuts (4 sp)
(II) Probe (grass, stick, club)	(1) termite nests (2) tree holes (3) feared objects (4) other items	(1) ant nests (2) tree holes (3) feared objects	(1) bee nests (2) feared objects (3) wounds (4) under bark (5) other items
(III) Clean (stick, leaf)	(1) sponging (2) wounds (3) dirt (4) brushing (5) catching	(1) ants (2) dirt	(1) sponging
(IV) Display (club, stone)	(1) aimed throwing (2) throwing (3) dragging (4) hitting	(1) aimed throwing (2) throwing (3) dragging (4) hitting	(1) aimed throwing (2) throwing (3) dragging (4) hitting
(V) Pound (club, stone, fruit, termite mound)			(1) nuts (5 sp)
(VI) Combined (club, stone + stick)			(1) pound + insert

(Gombe data are from Goodall [2, 7, 9], McGrew [10] and Teleki [13]; Mahale data are from Nishida and Hiraiwa [3] and from Nishida and Uehara [5].)

Figure 2: Table 2 from Boesch and Boesch 1990, page 92

On tasks which both rainforest and savannah chimps perform, like ant dipping, different strategies are employed. Tai chimps have been seen to eat with their hands, taking out eggs, larvae, and pupae out of an ant nest, excavating the nest with their hands and inserting arms to the shoulder; they also use short sticks, averaging 23.9cm in length for ant-dipping, letting ants crawl 10cm up the antsicle before eating and dipping again (ibid., 89). They dip around 12 times per minute with an average of 15 ants per dip (ibid., 89). Gombe chimps use ant-dipping sticks of around 66cm and dip 2.6 times per minute with 292 ants per dip (ibid., 91). Gombe chimps are less likely to directly remove grubs from nests with their hands and more likely to rely exclusively on tools to intake ants (ibid., 91). Mahale chimps sometimes fish for tree ants with tools, but have not been seen to ant-dip like Gombe and Tai chimps, despite that the Mahale chimps are geographically much more closely located to the Gombe (ibid., 92). Tai chimps are also known to use tools for hammering open nuts, eating bone marrow (and other parts) of colobus monkeys, as well as some other activities (ibid., s 89-91).

In terms of body care, Gombe and Mahale chimps "seem rather fastidious" and researchers have observed that "males regularly wipe semen from their penis after copulation, a behavior never observed at Tai" (ibid., 93). Chimps at Mahale have been observed performing 12 kinds of tool use, at Gombe with 16 types of tool use, and at Tai with 19 (ibid., 93). At this point, only the Tai chimps have been discovered "to pound objects with tools and to combine different tool uses to get access to a single food item" (ibid., 93).[43]

Striking differences in the tool-making procedures of these chimp groups exist. The very methodology of tool making differs. For example:

> Qualitative descriptions from Mahale indicate that, when making a tool, the chimpanzees tend to modify it progressively, i.e. testing the tool after each modification until it becomes adequate. Thus, the standardization of the tools in Mahale chimpanzees seems to be only the result of the successive improvements made on the tool during use. In contrast,... Tai

[43] Although we also know now that tool sets are used by Crickett Sanz's Congo chimps.

> chimpanzees proceed to all modifications before using the tool. Hence, tool making in Tai chimpanzees seems to require a precise idea of the form of an object must have to be considered a tool, as well as all of the technical steps necessary to perform on it to conform to this predefined idea. (ibid., 95)

This difference not only in use and aim of a tool, but in the very making of a form, points to a sharp contrast in the material cultures and practices of these communities.

Early learning seems to play a large role in the sorts of tasks a group of chimps will pass on to others in their group. While the Tai chimps are the only chimps observed to use hammers to crack nuts, there are hard shelled fruits and hard objects in Gombe that would allow for this behavior. However, "such demanding tool use can develop only in a situation of rich nutritional rewards," and young chimps learn what to eat based on "food sharing in the family" (ibid., 96). Researchers have observed "[t]he more prominent role of food sharing during meat-eating episodes" in Tai chimps, thus playing into the acquisition of nut-cracking skill (ibid.).

Environmental factors, like materials available, also influence the sort of tool use of a group:

> Tai chimps have apparently developed high faculties in representation of space for finding the rare stones at previous nut-cracking sites rather than developing sophisticated techniques to make tools of hard material: raw material being rare, it is more economic to search for tools rather than to

> search for raw material... Tool making in chimpanzees seems to be inversely proportional to the availability of material. (ibid., 97)

Selectivity, the making of tools, and the availability of raw materials seem to be related. According to Boesch and Boesch, “an increase in the sophistication of tool making may permit less selectivity for the raw material and individuals become less dependent on the environment” (ibid., 97). From this chimp research, we might discover some data that can be productively imported to philosophy of technology.

Conclusions

The tool use of chimps, orangutans, and monkeys covers a range of behaviors, though most of it can be characterized as techniques for procuring food. The available data on the tool use of apes indicates:

- At least some ape groups have material cultures, ones that differ by population, place, prey, availability of raw materials, learned traditions of tool use, etc.
- Chimps, if not other types of apes, are capable of standardization in the making of tools.
- Chimps use a variety of tools, sometimes in concert, that varies by population.
- Chimps, at least in captivity (and with strong examples from the wild[44]), have the *capacity* for innovation. Kanzi's new idea and the understanding shown by apes in the comparative study point to this conclusion.

[44] Although I have not covered these here.

- Chimps (and perhaps other primates) can unambiguously plan for the future. The example of Santino and his rocks at the zoo is only the beginning of this research.[45] Surely, especially given a more complex environment, wild chimps do plan in advance. A little more research might lead us to discussing life-worlds of chimpanzees in a richer way. As Osvath explains, "They most probably have an 'inner world' like we have when reviewing past episodes of our lives or thinking of days to come" (2009).
- The young life of chimps is extremely important to their future tool use and comprehension. This is further confirmed by the language studies on Kanzi, Koko, and other primates.

The ape research is highly provocative. The tool-use of chimpanzees (and of great apes, if not other primates also) cannot be meaningfully separated from what humans do with tools and technology. In many of these studies, researchers make reference to human toddlers and their capacities to complete technological tasks successfully (Visalberghi et al. 1995; Inoue-Nakamura and Matsuzawa 1997). Anyone who has ever watched a toddler struggling to insert a block into a shape sorter might easily understand this contrast. Even when an understanding is present, the physical capacity to perform some tool-related tasks must be learned through practice.[46]

---

[45] While we may not be able to generalize about what wild chimps *do* from the study of a single captive animal, we can definitively say something about the *capacities* of the species for certain tasks – even mental tasks, like planning for the future.

[46] There has been work done on the "specialness" of the human hand in allowing for the ability to make and manipulate tools – it might be that humans are better suited to a wider variety of environments and

These ape studies should be of great interest to those wishing to draw generalizations in the philosophy of technology. These studies serve to show a way of making distinctions between species that might be useful in setting up a map of tool-related behaviors. The tool-related processes and comprehension of capuchins differs from the great apes, which may also differ from human beings. These processes or comprehension should not be seen as hierarchical – the capuchins studied in comparison to apes succeed just as often as apes, though it takes them more time, due to the way they approach at a problem. Their methodology may simplywork out better in the environments in which they operate.

My goal in this dissertation, however, is not simply about expanding the human clause to chimpanzees, which is something some people have already done anyway. Given what we now know about chimps, that much seems obvious at this point. My project is more ambitious. I hope not just to expand the human clause, but to blow it up. My next chapter is on dolphin tool-use, and the one after that is about birds. It is easy to accept primate understanding and tool use, as they are our "younger brothers in knowledge" and members of our wider family in popular literature. We feel kinship toward and empathy for these animals more easily than other species – better understanding their facial expressions and body movements than species further removed from our experience and lineage. Accepting the tool use of dolphins and crows does much more to speak against the human clause and sets up a way for us to discuss

tasks because of our hands, and this might also explain the extreme variety and endemic nature of human tool-making and -use.

construction and technical skill in a *much* wider context. Distinctions can and should be made concerning things like ability to anticipate/plan for the future, the participation in a material culture and social learning, the complexity and standardization of tools, ability to innovate and improve tools, and the use of causal reasoning in their construction. Chimps meet all these criteria, at least to some degree, and I can show that other species perform well along these criteria too.

Chapter 5: Dolphins and Whales

Planning for the future, a material culture, social transmission of knowledge, ability to innovate, etc.: we can take all of these things as important characteristics that lead to the rise of technology for humans. However, animal cases that follow these same characteristics exist – certainly the chimpanzee cases are startling, but perhaps not controversial because we humans already think of chimps as being somewhat like us. We think of opposable thumbs and dexterity as important in tool-work[47], but some animal cases should make us think that a hominid-revision to the human clause does not go far enough in widening the scope of tool-related and technological behaviors. I propose that cetaceans be included in any account of tool-use and technological behaviors, for their cognitive and linguistic abilities of manipulation, and also for a few cases of tool use witnessed in observational studies. Cetaceans have many techniques, and a few tools, though we may question whether they have the ability to manipulate and form material objects like humans and chimps (and crows, as we'll see in the next chapter).

'Cetaceans' is a category that covers whales, porpoises, and dolphins. In this chapter, I will first focus on the dolphin literature, followed by some interesting findings from whale research.[48] The literature on dolphin tool use is much less extensive than the chimp research, in part due to increased barriers to observation and collection. Observation of chimp tool use goes back to only 1960, so, though relatively recent,

[47] And they are.

[48] I'm neglecting porpoises . They are not well represented in the literature.

dolphin tool-use research lags far behind this. Only in 2005 was the first case of dolphin tool use in the wild reported. Therefore, my research on cetacean tool-use is somewhat slimmer in this section, though I provide additional research on dolphin and whale linguistic abilities (since I take language as a tool, this makes sense[49]) and cognition. These things can easily be considered parallel abilities or groundwork for technological capabilities and are worth a discussion as I set up a map with regard to technological behaviors. In asking what it takes to make something a technology, many sources would include the cognitive abilities that go along with understanding and making and socializing within an environment as requirements for the proper understanding and context in which technology can exist.[50] In the case of bottlenose dolphins, their ability to manipulate and use sounds (language?) is something one might count as a technological endeavor (as I do).[51] The complexity of interaction, socialization, and communication in dolphin groups stands as a counter-example to both linguistic and technological ways of arguing for the specialness of humans in contrast to all other animals. While dolphin behavior does not always involve technological objects or a *material* culture, the variety

---

[49] Language requires form and manipulation and sometimes planning and technique and culture, though certainly of a less material kind than tool-making would indicate.

[50] Isn't this what the human clause is really trying to get at? The human clause tells us that humans are special because of their use of technology, which gets conflated with and related to more intelligence and linguistic ability such that we can transfer things *and* ideas between one another.

[51] My claim here – that language abilities are technological – might seem somewhat controversial, but there are defenders of this position. I will address concerns about this aspect in my concluding chapters.

and cultural dependence of their techniques, as well as their transmission of technique, suggests that dolphins have the capacity for technological behavior.

Cultural Transmission of an Invention

Examples of dolphin tool use, outside of their linguistic feats, are few, but researchers were not looking for evidence of dolphin tool use until fairly recently.[52] In Western Australia's Shark Bay, a population of wild bottlenose dolphins has been under observation since 1984.[53] From 1984 to 2005, eleven foraging tactics were observed, "exhibiting a diversity comparable with that of chimpanzees and orangutans" (Krützen et al. 2005, 8939). Only one of these tactics involves the use of a tool, and this tool use has been witnessed in only fifteen of 141 known dolphin mothers and in 7 of their young (ibid.). This use of a tool by dolphins has been termed "sponging". Sponging consists of breaking off a piece of marine sponge from the seafloor, placing it over one's nose (rostrum), and using it to probe the seafloor for hidden fish. Sponging is almost exclusively used by females as a foraging technique, with only one observed male "sponger" (ibid.).

Researchers rule out ecological factors alone as motivating this sponging technique because other female and male dolphins in the same areas were seen foraging

[52] One wouldn't really expect a species without hands or any manipulable extensions to be able to use tools, so no one looked out for this sort of behavior.

[53] Shark Bay is the home of an extensive research effort on dolphins; researchers from North America, Europe, and Australia have observed this population since 1984. For more on the Shark Bay Dolphin Project: http://www.monkeymiadolphins.org/

without use of the technique (ibid., 8939). The researchers think it seems "highly likely that sponging is culturally transmitted mainly within a matriline, i.e., daughters learn this behavior from their mothers" (ibid., 8939). To rule out genetic influence on this technique and promote the theory that this trait is culturally transmitted, researchers did genetic and statistical analysis on spongers and nonspongers. They report:

> Previous genetic analyses showed that random mating can be assumed for the Shark Bay population. Hence, if the relatedness levels among all spongers were significantly above the population average, then it would be likely that sponging was a fairly recent invention. (ibid., 8940)

Their genetic study concluded that the spongers were indeed "closely related to each other and share a recent common ancestor" (ibid., 8942), significantly above the population average, inferring that cultural transmission was likely (ibid., 8943) and that sponging was indeed a recent invention (ibid., 8940). This study drew interesting headlines in the popular press about dolphin moms teaching their daughters a new technique.

While that is the limit of documented dolphin tool use (insofar as tool use necessarily indicates a manipulable external object), researchers have observed other techniques for foraging that vary by population, even given similar environments (Sargeant et al. 2005), just as witnessed in the comparative studies of chimp tool use and making. This points to shared cultural practices or techniques, rather than genetically determined behaviors. Citing a variety of studies on bottlenose dolphins, B.L. Sargeant et al. report of the variety of foraging behaviors that:

> …. [bottlenose dolphins] forage both in groups and individually and have also adapted to human activity by following fishing boats to obtain discarded fish, visiting provisioning locations, and catching fish cooperatively with net fishers. Additional tactics include using their rostra [noses] to dig into the substrate, smacking their tails on the water surface over shallow seagrass beds to disturb prey, whacking fish with their tails, foraging with the aid of marine sponges worn over their rostra, and stirring up sediment to trap fish, among other behaviors. (ibid., 1401, in-text citations removed)

In another study from Shark Bay, researchers conducted a longitudinal study of mother and calves, documenting 13 foraging tactics. Some dolphins may specialize in a narrow range of tactics as compared with others in the group (ibid.). Researchers observed one particular tactic used by only "a handful of known individuals" that made for a nice case study of a foraging technique on which they could see the development of the technique and possible teaching and/or learning methods. This tactic, called beach hunting, is where one dolphin "surg[es] partially or fully out of the water and onto the beach to catch a single fish" (ibid.) This tactic was easy to observe by researchers and has similarities to other tactics: killer whales beaching themselves to catch pinnipeds in Argentina, humpack dolphins at low tide pushing fish up onto exposed sand near Bazaruto Archipelago, bottlenose dolphins use of mudflats off the southeastern coast of the United States, etc. (ibid.). There is a risk with beaching tactics like the beach hunting of Shark Bay bottlenose dolphins of becoming stranded on the beach (ibid.).

The detailed observation in this study involved identifying individual dolphins (by fin shape and markings) and observing the East Peron Beach, a beach often used by beach hunters (ibid.). Though beach hunting is performed elsewhere on the coastline, the ease of observation on this beach made it a good choice for researchers. Researchers observed from the water (in a boat) and from the shore. In over 96 hours of observation of already-known and identified dolphins, researchers documented 98 beach hunting bouts, of which 28 involved a full beaching onto shore, by four beach hunters and their juveniles and calves (ibid., 1404). The identified prey included mullets and longtoms, and, in every case observed, a dolphin went after only one fish at a time (ibid.). Calves and juveniles were seen engaging in the method, but none of them used full beaching as a technique (ibid.) No coordinated or cooperative foraging effort by the beach hunting method was recorded, though some dolphins pursued different individual fish within meters of each other (ibid.).

The researchers in Cape Peron wanted to figure out the role that teaching plays in learning this technique. Younger calves waited apart from their mothers, observing beach hunting from further away than older calves and juveniles (Sargeant et al., 1405). However,

> … mothers were never observed attending to their calves or altering their foraging behavior in response to calf presence during beach hunting, presenting no evidence for teaching. (ibid., 1405)

The researchers define teaching as an active instruction, rather than a chance for observational learning. With the evidence on hand, it seems as if the dolphin calf case is much like that of the young chimps who learn different techniques based on observation of their own mothers' behavior. Interestingly, the beach hunting technique does seem to be passed mother to daughter. Researchers observed the association of the two most frequent beach hunters, and, excluding their own young and other known beach hunters, they frequently associated with at least 25 other individual dolphins (ibid.). There were even two frequent associates that have been regularly observed with these two beach hunters over the past 10 years, but these two frequent associates have not been observed to use the beach hunting technique at all. And, so the researchers explain that: "… despite consistent association with many other dolphins, regular use of beach hunting in the Cape Peron area currently appears restricted to just four adult females and their offspring" (ibid.). Researchers also note that the mitochondrial haplotypes among the beach hunting dolphins differ. While three of them examined beach hunters had one haplotype (the most common among this particular group of dolphins), the most frequent beach hunter had a different one (ibid., 1407).

This study demonstrates the specialization that individual dolphins can have in foraging techniques, despite a population with a wide array of techniques. Researchers quantified individual dolphin's time spend on different foraging techniques in their small sample group of beach hunters. They also came up with evidence that "foraging complexity and learning correspond to longer periods of dependency" of juveniles and calves on their mothers, given that juveniles under the age of 5 were not observed trying full beaching at all (ibid., 1407-8). However, despite examples of possible teaching in chimps and killer whales, the researchers found that mothers did not change their techniques in the presence of their calves in any way that would demonstrate the use of teaching on the part of these dolphins, though it seems that observational (as opposed to instructional) social learning in the matriline plays a significant role in the acquisition of the beach hunting technique.

Specialization in Bottlenose Dolphins

In the above study by Sargeant et al., the researchers focused on the role of specialization by individual dolphins in an individual foraging technique (2005). However, bottlenose dolphins do not always hunt individually, and many participate in cooperative or group hunting. Killer whales and humpback whales are also known to hunt in groups (Gazda et al. 2005). In an observational study conducted in Cedar Key, Florida, among two groups of bottlenose dolphins, one at Seahorse Key and the other at Corrigan Reef, researchers found a division of labor with specialized roles in a group hunting method (ibid.). Group-hunting dolphins in Cedar Key use two behaviors to herd fish for prey:

> One individual in a group of three to six dolphins, the 'driver', herds the fishes in circles, as well as towards the tightly grouped 'barrier', or 'non-driving' dolphins that are less than one body-length apart and often touching. The driver may perform fluke slaps (when a dolphin lifts its fluke, or tail, out of the water and slaps it against the water surface forcefully) during the drive. Fishes being herded in this fashion leap into the air, where some are captured by driver and barrier dolphins. (ibid., 135)

In the two groups observed, herding behavior as described above was witnessed and analyzed in 126 cases, with 60 from the Seahorse Key group and 66 from the Corrigan Reef group (no group members overlapped) (ibid., 137). In all of the Seahorse Key group hunting bouts, the same dolphin served as the driver; the same was true for the Corrigan Reef group, which had the same (but different from the Seahorse Key driver) dolphin that group serving as driver every time – a surprising finding (ibid.). Researchers observed one dolphin in the Corrigan Reef group who would practice driving, but without other group members present at the time of the drive, and who was a non-driving member of the group in the group-hunt (ibid.). On average, with this technique, driver success in terms of fish eaten did not differ from that of non-driver success: everyone in the group in this technique was, on average, equally successful (ibid.). Though cooperative fishing has been witnessed elsewhere, the level of *specialization* in this one activity was surprising: "the consistent role-playing in cooperative herding that was seen in Cedar Key" had not been found among other cooperative groups at that point (ibid, 138).

The researchers argued against an interpretation of the results whereby the non-drivers were actually scroungers benefiting from the driving dolphin's work – a "noncooperative" explanation (ibid.). They argue that the barrier dolphins perform a role in this technique, a role that involves trapping fish, and the driver wouldn't move toward the barrier dolphins if they were only scrounging (ibid.). Additionally, these groups were observed to move "slowly in a cohesive manner along the channels during the search for fish schools" and group members were seen repeatedly together even 4-5 years before this particular study was conducted (ibid.). Evidence of this role specialization in group-hunting points toward a sophisticated group dynamic, one that is further evidenced in the vocal learning of dolphins.

Vocal Learning in Bottlenose Dolphins

Bottlenose dolphins are highly social, with pairs of dolphin males and mother-young pairs being observed together "continuously for 5 to 10 years or more" (Tyack 2000). Studies have shown that wild bottlenose dolphins can imitate and learn the signature vocal whistles of their group members (Tyack 2000, Janik 2000, Janik et al. 2006). Researchers who study dolphin whistle matching initiated a study whereby matching interactions – where one dolphin copied the vocal whistle of another, perhaps indicating one dolphin addressing another – by recording whistle matching off the shore of Kessock Channel in Moray Firth, Scotland (Janik 2000). In this study, two whistles were considered matched when they came within 3 seconds of each other from locations more than 26 meters apart and were judged to be matched by "five naïve human observers," who rated the similarity of the whistles (Janik 2000, 1355).

Recording equipment was set up such that there were no humans or boats present in the channel during the study (ibid.). Because individual dolphins could not be identified any closer than within 26 meters, researchers note that it is possible that there were more matching whistle interactions than observed in this study. Matching whistles were found on all seven days of observation typically taking place between two dolphins, but also twice between three dolphins and three instances where one gave a whistle, followed up by the same whistle from another dolphin, and then repeated again by the first dolphin (ibid, 1356). The researchers concluded about their study that:

> These results show that bottlenose dolphins use their learned whistles in matching interactions, most likely to address each other... Although vocal matching is common in birds, bottlenose dolphins are the only nonhuman mammals in which matching interactions with learned signal types have been found. (ibid., 1357)54

The whistle matching of dolphins is "thought to function in group cohesion and individual recognition" and captive dolphins are known to imitate the sounds of humans in a way not even apes can ape (Janik 2000, 1355; Tyack 2000).

In a follow-up study on the matter, this time conducted in Sarasota Bay, Florida, researchers tested dolphins to see whether they could identify an individual without hearing that individual's voice make its own whistle, which would indicate that signature whistles are "independent of voice features, as it is in human naming" (Janik et al. 2006, 8293). In the experimental set up, the researchers

> … produced synthetic whistles that had the same frequency modulation but none of the voice features of known signature whistles. We conducted playback experiments to known individuals, testing their responses to synthetic signature whistles that resembled those of familiar related and unrelated individuals. We hypothesized that... animals would turn more

[54] There is actually now research on this topic that suggests that male chimps have pant-hoots that identify different groups, using a type of learned vocal matching.

> often toward the speaker if they heard a whistle resembling that of a related individual. (ibid.)

The hypothesized effect – that individual dolphins would turn toward the synthetic signature whistles of relatives more often – proved correct, with the effect demonstrated in nine out of 14 of the test subjects (ibid., 8293). Additionally, the researchers found that "individual rather than kin discrimination" was taking place, by looking at how the dolphins responded to whistles similar to (but not the same as) the signature whistles of related individuals (ibid., 8295). In this way, signature whistles seem to serve as names, names that are recognized by others in the group.

Signature whistles are developed by infants copying the whistles they hear and modifying the sounds slightly to produce their own signature whistles (ibid., 8295). This means that the vocal learning of dolphins "allows increasing interindividual variability of signature whistles while maintaining potential group, population, or species features in the signal" (ibid.), leading to whistles that vary greatly over longer distances and different populations of the same species of dolphin – something that seems similar to human dialects (ibid.).

In an earlier study (1984) on bottlenose dolphin comprehension in captivity, two dolphins were taught to understand imperative sentences, one in an acoustic language and one in a visually-based language (Herman et al. 1984). Comprehension was found from both forms of communication, and included following the instructions of novel sentences, sentences that expressed a new relationship between objects, and more (ibid.). Even in new contexts and locations, directions could be followed "at levels far above chance" (ibid., 129).55 Noted dolphin researcher Karen Pryor, in a book she co-edited, *Dolphin Societies: Discoveries and Puzzles* (1991), recalls one dolphin that was trained in a free-swimming environment to look for objects in the water that were "anything man-made and bigger than a breadbox" (346). This dolphin "soon found engine blocks, a movie camera, quite a lot of fishing equipment, and a World War II airplane" (ibid.) This anecdote perhaps shows that dolphins can come up with abstract categories of objects – and work quite well with the category!56

Whales and Cultural Revolution

Though I have spent most of this chapter looking at dolphins, some fascinating research on whales, especially as it relates to vocal abilities, exists. A paper on "Cultural Revolution in Whale Songs" details observations made on humpback whales off of the eastern Australian Coast in the Pacific Ocean (Noad et al., 2000). Male humpback whales sing tunes, and population groups of these males all produce the same song, though the songs change through time, with all singers keeping up with the changing, "implying a cultural transmission and evolution" similar to some bird songs (ibid., 537). Different humpback populations, especially those separated by great distances, produce different,

[55] This sort of understanding is useful in training dolphins for rescue and in more abstract tasks.

[56] Pryor also speculates about dolphins becoming the next animal to be domesticated by humans because of their usefulness in tasks like these, as well as their enjoyment of the sorts of tasks that trainers teach them to do. They may gain a role similar to other working animals, given tasks that "require an animal to give up the extensive social contact of a large wild group", but "gain the benefit of interesting things to do" (Pryor and Norris, eds., 1991, page 346).

"apparently unrelated" songs (ibid.). In this observational study, researchers were lucky to catch the changing of a tune with the introduction of two new members to the group – two whales from the Indian Ocean, off the west coast of Australia (ibid.).[57]

During a north-south migration in 1995-1998, researchers recorded 1,057 hours of songs using hydrophones attached to buoys and boats (ibid.). In 1995 and 1996, researchers observed the song pattern change slightly, as would be normally expected. But, with the introduction of two new male singers to the group of 82 whales, 1996-1997 was a time of radical change. The researchers report that:

> In 1997, the new song became more common. Most of the 112 singers produced either the old or the new song, but three used an intermediate song containing themes from both types. By the end of the 1997 southward migration, almost all males had switched songs, and in 1998 only the new song was heard. (ibid.)

The interchange between the two populations – from the east and west coasts of Australia – is typically very low, and this radical change of tune with the introduction of only two new group members is stunning. The songs of the two populations have continued to evolve independently, but this one quick change is notable because "there are no examples of radical song replacement initiated by a small number of immigrant

[57] I like this study because it came about without researchers inserting themselves into the study. Researchers were merely recording the whale tunes to track their change – the introduction of two new group members and the radical (and completely unexpected!) change of tune was complete luck, not some manipulation of the context or experimental variable.

individuals in these or any other species of song-bird," so this finding is unique and startling (ibid.).

Memory and Cognition in Cetaceans (Compared with Primates)

In an overview study entitled "Cetaceans Have Complex Brains for Complex Cognition," a team of researchers sums up the neurological findings on cetaceans (dolphins and whales, specifically), arguing against those who might suggest that cetacean brain size is merely a byproduct of ocean temperatures during cetacean evolution. Rather, these researchers suggest that an "integrated" view, combining research from cetacean neurology, behavioral studies, and evolutionary based science, leads to the accepted view of cetaceans: that their large brains "evolved to support complex cognitive abilities" (Marino et al. 2007). Cetacean brains are larger than most other animals, and are eclipsed only by human beings when their brains are judged against body size. While this finding alone does not tell us that cetaceans are smart or anything about their cognition, along with behavioral, anatomy, and evolutionary studies, the researchers suggest that cetacean brains are capable of many of the qualities normally associated with the higher complexity and cognition of human beings and primates.

One must look back 95 million years to find the common ancestor of cetaceans and primates, and cetacean brains have been on an evolutionary trajectory separate from other mammals (like hippopotamuses) for 55 million years (ibid., 0966). For this reason,

> there is no reason to expect that cetacean and primate prefrontal cortical analogs would be, in fact, located in the same region of the brain. (ibid.)

But, these areas, for both primates and cetaceans, are “consistent with high-level cognitive functions – such as attention, judgment, intuition, and social awareness” (ibid.). And, in both types of species, brains have “a large number of large V spindle neurons.... similar to those reported to be unique to humans and great apes” (ibid.). In the researchers' estimation of cetacean neurology, cetaceans possess “structural complexity that could support complex information processing, allowing for intelligent, rational behavior” and point to the wealth of behavioral data that supports this conclusion (ibid., 0968). Laboratory studies have demonstrated that cetaceans can:

- understand symbolic representations of things and events
- understand how things work and how to manipulate them
- understand the activities, identities, and behaviors of others
- understand their own bodies and behaviors
- have accurate and robust memories (ibid.)

The researchers label these declarative knowledge, procedural knowledge, social knowledge, self knowledge, and memory, respectively (ibid.) Additionally, the ability of dolphins to abstract rules and understand instructions, as well as their complex acoustic abilities, points to a robust intelligence. Indeed, “dolphins are the only mammal, other than humans, shown capable of extensive and rich vocal and behavioral mimicry” (ibid., 0969).

These researchers consider the imitative abilities of dolphins “one of the highest forms of social learning,” one that goes beyond even the abilities of apes (ibid.). Dolphins also have a capacity of self-knowledge, something once considered a hallmark of humankind. Self-aware and able to recognize themselves in mirrors, dolphins demonstrate “a rare ability previously demonstrated in the great apes and humans, and, recently, in elephants” (ibid.). Studies of wild dolphins have revealed much about the complexities and diversity of dolphin social groups and culture, including “impressive cultural learning of dialects, foraging sites, and foraging and feeding strategies” (ibid, 0970). Cetaceans exhibit culture, which the study's authors define as the transmission of learned behavior, and multiculturalism, or 'groups with different cultures using the same habitat' (ibid.). The authors cite a study in which killer whales in the North Pacific have several social tiers that have their own vocalizations, feeding techniques, and play-time activities (ibid.). Advanced social learning skills and cultural characteristics have been observationally documented in bottlenose dolphins, killer whales, sperm whales, and humpback whales – the cetaceans on which the most research has been conducted (ibid.).

The evidence, at least to these researchers, points to the conclusion that dolphins clearly exhibit “some of the most sophisticated cognitive convergences with primates, including humans” (ibid., 0971). This cognitive sophistication and convergence agrees with other integrative studies, like one by Lori Marino on the complexities of cetacean and primate cognition (2002). In contrast to the differences of cognitive architecture of primates and cetaceans, Marino argues that the two groups share important similarities of mind: “social behavior, artificial 'language' comprehension, and self-recognition ability” (ibid., 21). Despite difference in environment and evolutionary history, it seems that cetaceans share a number of cognitive traits that are often considered important in founding ideas like rights, community, and intelligence.

Conclusions

Though we have run far off-course of tool use at this point, the research about cetacean intelligence, along with the upcoming crow research, tells us what might and might not matter when we put together a map with regard to technological behavior. It seems that, given all the techniques, linguistic ability, and abstraction which at least some cetaceans are capable of, cetaceans may be capable of technical change, innovation, and behavior without having many physically manifested tools or trinkets to show for their changes in technique and tune. The available research on cetaceans indicates:

- The foraging tactics used by dolphins are comparable in variety and complexity to those of chimpanzees.
- Dolphins can pass a shared material culture (as shown by sponging).
- Dolphins specialize in hunting and foraging techniques, both in individual tasks and in coordinated hunting groups.
- Dolphins have the capacity for abstraction, self-awareness, learning, and other characteristics considered important by human beings.
- Dolphins have some ability to name with their "signature vocal tunes" and vocal matching.
- Whale studies have demonstrated that cultural revolution – one that involves patterns and learning – is possible.

If we consider that signature whistles and whale songs encapsulate information[58], and that they require know-how, they can be mapped alongside manufactured artifacts in terms of technological behaviors. While not tools or technologies by some definitions, the vocal stylings and foraging techniques of cetaceans demonstrate a skilled, informational component, something important to know-how. In the context of cetacean environments (with poor visibility) and anatomy (with little in terms of manipulable appendages), the techniques of cetaceans may make a nice contrast study for philosophers of technology and biology with interests in the development of techniques within niches or competitive environments. Cetacean research can be integrated into discussions of technological know-how because of the wide variety and complexity of techniques shared among these animals.

[58] Whether this information is representational in the case of whale songs is unknown, but signature whistles seem to pick out one individual by the vocal handle.

Chapter 6: Crows, Rooks, and Jays

Corvids, a group of bird species that encompasses crows, rooks, and jays, warrants investigation in a project concerning technological behaviors and tool use. Much of the recent research on birds reveals sophistication in tool use unmatched by even chimpanzees. The tool-making abilities of birds certainly go beyond those of dolphins – due to environmental and bodily differences, this much is obvious. Birds certainly have the ability to manipulate and build objects – one only needs to look at a nest to realize that. But, some bird species do more surprising and complicated things than the manipulation required in nest-building. A wealth of new research on the tool handling capabilities of birds exists that demonstrates that at least some birds are capable of manufacturing, standardizing, and crafting tools, employing them handily in different contexts with an understanding of causality.

In this chapter, I look at New Caledonian crows, rooks, and scrub-jays. New Caledonian crows manufacture distinct tool types, rooks can perform smartly in tests of calculation, and scrub-jays have shown an ability to plan (and to lie).[59] I have already argued that the human clause cannot hold in the face of chimpanzee work, and even a modified "hominid clause" does not accommodate the complex techniques of dolphins. Some might accept that dolphins be included in the mix of those species who are adept at manipulation (at least of the linguistic sort), given the cognitive and behavioral

[59] Alex the African Gray Parrot has also shown surprising linguistic abilities that will go neglected in this dissertation.

comparisons made so easily to primates. If one hopes to retain some sort of hominid-cetacean clause on a definition of technology, new research on birds shows that even these modifications to the definition prove inadequate. Technological capabilities alone cannot separate humans from other animals; the things humans do and behaviors that humans have with their tools are not unique to this species.[60] Even species whose brains cannot be well-analogized to those of human beings have a capacity for complex tool use, planning, social learning, and language.

New Caledonian Crows: Fashioning Tools

Crows on the island of New Caledonia in the Loyalty Islands in the Pacific Ocean are well noted for their impressive tool use, and research from the past fifteen years demonstrates the complexity, flexibility, and diversity of their tool-related, or even technological, behaviors. Gavin R. Hunt first highlights the features of New Caledonian crow tool use that makes these birds so notable (1996). In his 1996 article in *Nature*, he reports the manufacture of two types of hook tools used to capture prey – a hooked-twig and a stepped-cut barbed pandanus leaf. The manufacture of these two types of tools includes: “a high degree of standardization, distinctly discrete tool types with definite imposition of a form in tool shaping, and the use of hooks” (Hunt 1996, 249). These

[60] Difference turn out to be a matter of degree, and not a matter of kind. And, I would add, most of the qualities that have been proposed as the moral difference between humans and non-humans cannot hold either. Whether associated with tool use or not, planning, rational thought, calculation, manufacturing, empathy: none of these things can be said to separate humanity from other animals. No simple dividing line exists.

features of tool manufacture “only first appeared in the stone and bone tool-using cultures of early humans after the Lower Palaeolithic” (ibid.). These crows also manipulate twigs, drop nuts onto rocks to get seeds, and carry their tools around for use (ibid.).

Hunt describes hooked-twigs that are made from living twigs, stripped of leaves and bark, and hooked on the end; stepped-cut tools are cut from pandanus leave edges, which are shaped by the crows into a taper, remaining sturdy and sharp with “their uncut edges... always faced upwards from the narrow ends” (ibid., 250). With these tools, the crows use “[s]low and careful movements... to obtain prey from bases of leaves and holes where it was possible that crows could see their prey” (ibid.). Hunt was able to collect tools from three forest sites, demonstrating standardization of tools, and he suggests that these birds appreciate the functionality of the tools, as indicated by the hook-use, and the diversity of tools found suggests the use of tool kits (ibid., 250-251), something Hunt and his team revisit in later publications. Research performed after this study points to an even greater complexity, with a much more recent study showing three tools used in succession (a tool set), solving a problem to get food and crafting tools out of materials which they had not previously encountered (Morelle 2010). In fact, tool manufacture by New Caledonian crows in laboratory settings has been startling.

Four naïve juveniles in captivity “developed the ability to use twig tools” without ever coming into contact with adult crows (Kenward et al. 2005, 121). These crows, upon being exposed to pandanus leaves, were able to tear and cut them into shapes, some of which would have made decent tools, according to researchers (ibid.). However, though they seemed able to cut and shape twigs and leaves, with one even using a made tool to get to food, it seems that "[s]ocial input... may be important in transmitting specific techniques and toolshapes," an idea bolstered by "the close attention... juveniles paid to demonstrations of tool use by their human foster parents" (ibid.). Regional variation exists in the tool shapes of New Caledonian crows, crows that live in social groups, which researchers speculate may be "the result of cumulative *cultural* evolution" (ibid., with my emphasis). While some capacity for the development of tools could be innate in New Caledonian crows, the forms of tools and materials used can vary significantly, and research suspect social-cultural components. In other words, these crows may be inclined toward tool-use, but their choice of materials and form may be greatly influenced by social factors, something given more support in further studies.

Researchers Gavin R. Hunt and Russell D. Gray, who have published a wealth of studies on the New Caledonian crow, observed an adult crow and its dependent offspring manufacture 10 tools and watched the crows use the tools (Hunt and Gray 2004, S88). They caught some of the juvenile's manufacturing on video tape and observed the use of the newly made tools (ibid.). The manufacturing process followed four basic steps for all of the 10 tool manufacturing observations:

> They (i) selected a fork formed by, usually, two twigs; (ii) broke off one twig just about the junction (side twig), then discarded it; (iii) broke off the remaining twig just below the junction (tool twig); and (iv) carried out fine sculpting of the hook on the tool twig with the bill, in between removing the compound leaves... The sculpting removed small pieces of wood form the hook, which refined and sharpened it.... (ibid.)

Researchers timed the fourth step, which took, on average, 68 seconds (ibid., S89). The same techniques were used by the two birds: “a 'snapping' technique to remove side twigs and tool twigs,” snapping close to the bases of the twigs at the junctions, and forming hooks that were near to the tool ends (ibid.). However, the juvenile crow seemed to have less experience in making hooked-twig tools.

> Three differences... suggested that the juvenile was less experienced.... First, only the juvenile repeatedly worked on the hook after first use of the tool. This behavior may have been a reaction to limited success at extracting food.... Second, after picking up tools from a horizontal position the juvenile sometimes used the non-hooked ends as the working ends... The parent never attempted to extract food using the non-hooked end of a tool. Last, the juvenile crow had noticeably more difficulty in snapping off the tool twig than did its parent... (ibid.)

These differences, given the respective ages and relation of the two crows, suggests that the exact manufacturing process is something passed from adult to juvenile, and that juveniles may steadily learn how to craft a particular tool from its parents, though this is outside the study's discussion.

The tools of wild New Caledonian crows can be said to be “crafted” (Hunt and Gray 2004, S88). Crafting, according to scientists, has three components: “(i) selection of an appropriate section or piece of material, (ii) preparatory trimming and (iii) fine, three dimensional sculpting” (ibid.), and this same process of crafting is typical of “early human tool manufacture” (ibid.). The study's authors explain that tool manufacture by animals is common among woodpecker finches and chimps, but that the “fine sculpting” seen among New Caledonian crows has been previously undocumented in any other species beside human beings (ibid.). While the manufacture of pandanus leaf tools is complex, it is not considered crafting or sculpting because “no preparatory trimming is carried out” and it involves shaping in only two-dimensions (ibid.). But, researchers were finally able to observe the manufacture of hooked-twig tools, molded in three-dimensions, and, with these observations, it seems that humans can no longer be considered the only crafters.

Hunt and Gray's discussion of their hooked-twig manufacturing findings often refers back to human manufacturing capabilities:

> New Caledonian crows appear to have a rudimentary technology analogous to that of early humans. This rudimentary technology includes the cognitively demanding task of crafting tools... This routine of complex manipulations [the four stepped process described above] is consistent with the possibility that the crows' goal was the manufacture of a hooked tool.... The tool manufacture of New Caledonian crows has four features previously thought to be unique to hominids: a high degree of standardization, the use of hooks, 'handedness' and cumulative changes in tool design.... (2004, S89-90)

The authors further point to a laboratory experiment of captive crows bending wire to get food that suggests that “these crows may have at least a rudimentary grasp of the physical properties of objects or 'folk physics'" (ibid., S90), further illustrating the similarities of New Caledonian crow tool-manufacturing with that of early humans.

New Caledonian crows in the wild have been found to work in "parallel tool industries" once thought to be special to humans and stemming from hunter-gatherer societies (Hunt and Gray 2007). In observations of 12 crows on Maré Island, the two researchers documented strong preferences for particular tools and their use among a group of 12 crows (ibid., 173). Eight of these crows exclusively used one type of tool – either a pandanus or stick tool – and all of the crows showed a preference in use for one or the other tool (7 for stick tools, 5 for the pandanus tools) (ibid., 173-174). Unlike in early human societies and surprising to researchers, the preference for one tool or another was not divided by sex of the crows; in humans, "social conformity" was likely the driving force in the division of labor by sex (ibid., referencing Bird 1999). In these crows, the documented specializations in tool-use "could either be a consequence of genetic differences or different, vertically inherited (parent-to-offspring) social traditions" (ibid.). Though captive juvenile crows have been shown to have a disposition for the employment of tools, the social organization of these crows, especially given the amount of time adults spend with their dependent juveniles, makes the possibility of parent-to-juvenile transmission of specific tool-skills a more likely account of the preferences of different crows for different types of tools (ibid.).

Folk Physics and Causal Understanding

As for the 'folk physics' knowledge of crows, in a study conducted by Alex Weir, Jackie Chappell, and Alex Kacelnik, a female New Caledonian crow in captivity was able to effectively shape wire to poke down a tube to get food (2002). The researchers had two crows – one male and one female – presented with and unbent wire and a tube with food at the bottom (Weir et al. 2002, 981). These two crows had seen similar tube apparatus in the past, but their only experiences with pliant materials had been with pipe-cleaners a year before this study. The wire was new to them (ibid.). In 10 trials, the female crow successfully bent the wire and got the food nine times; the male did not bend the wire (ibid.). In all successful attempts, the food was retrieved within two minutes (ibid.).

The female crow did not use any technique found in normal crow life to bend the wire, and the technique she used "would be unlikely to be effective with natural materials" (ibid.). With no similar experience with pliant materials or wire and with no model to possibly imitate, this "purposeful modification... without extensive prior experience" is unknown outside of human beings (ibid.).

> In experiments by Povinelli, chimpanzees (Pan troglodytes) repeatedly failed to unbend piping and insert it through a hole to obtain an apple, unless they received explicit coaching. Further experiments have shown similar lack of deliberate, specific tool modifications in primates.[61] (ibid.)

[61] The authors note that capuchin monkeys have been able to unbend wire to get at honey, so not all the primate studies are so disappointing.

The researchers of the wire-bending experiment conclude that these findings, “in a species so distantly related to humans and lacking symbolic language,” point to important questions about “the kinds of understanding of 'folk physics' and causality available to nonhumans, the conditions for these abilities to evolve, and the associated neural adaptations” (ibid.).

A 2004 study by Jackie Chappell and Alex Kacelnik further established the understanding of 'folk physics' by New Caledonian crows. In a separate study by the same authors, crows were shown to be able to select tools of appropriate lengths when presented with a task (Chappell and Kacelnik 2002). In this study, the same crows were tested for the ability to take into account tool diameter when selecting a tool for a job. In two experiments, the researchers give evidence that New Caledonian crows are capable of determining the suitability of a tool for a given task (Chappell and Kacelnik 2004). In the first experiment, researchers left three pre-made tools of different diameters and food in a tube with a hole to the female crow[62]; of the three tools presented, two were tied in a bundle, such that, to be used, the bundle must be untied (ibid., 122). The three tools were:

[62] Upon emailing one of the researchers, it turns out that this is the same female crow as the one from the Weir et al. 2002 study and the same one as the Chappell and Kacelnik 2002 study. Her name is Betty. The male crow, named Abel, refuses to participate in tasks when separated from his female friend, so he was left out of this first experiment. He wasn't keen during the Weir et al. 2004 study either. These crow researchers started naming their crows in papers in 2006. The practice of naming individual animals in research has been a source of controversy in ape studies, and it is only recently that the practice became common in these bird studies. Thanks to Jackie Chappell for so kindly responding to my emails on this matter (Personal Communication 2010).

too thick, just thin enough, and “thin enough to serve in all conditions” – called thick, medium, and thin for the purposes of the report (ibid., 121-122). The female was found to prefer the thin tool in almost all cases, even bund`led, and in post-testing phases; when all the rods were unbundled, the female chose the thin rod in 24 out of 24 trials (ibid., 123). The female crow only untied the bundle only when “the thin rod was not freely available” (ibid., 126). Researchers postulate that it may be partially ergonomics that determine this choice, as the thinner rod is necessarily lighter.

In the second experiment, the female and male crow were tested together (ibid.). The male was excluded in the first study because he would not participate without the presence of his female companion. The researchers explain that:

> Although this compromises the independence of the observations, we chose this approach [of testing the two birds together for the second experiment] because our accumulated experience showed that the crows are highly social and they tend to have shorter latencies to approach the apparatus, spend less time performing unrelated behaviors (using tools in other parts of the room) and vocalise less when they are not separated for testing. (ibid., 124)

So, to move things along, the crows were allowed to stay together for experiment 2. In this part of the test, the food tube apparatus remained the same, but, instead of the sticks, the crows were left with “fresh, bushy branch of oak” (ibid., 124). Each branch had many twigs with diameters thin enough to enter the hole in the tube (ibid.). Trials went on until one of the crows got the food or after 30 minutes; only one trial was ended due to time elapsing, and, in all other trials, the crows retrieved the food within 20 minutes (ibid.).

The crows both manufactured and used their tools (ibid.). The female obtained food in 16 of 17 trials, and the male obtained food in all 13 trials in which he participated (ibid.). The researchers describe the process:

> In each trial, the crows approached the tube and looked at it, either from the nearest perch... or they landed on the table next to the tube.... We are therefore reasonably confident that they had the opportunity to assess the size of the hole before making a tool. They then flew to the branch, snipped the leaves off large areas of twigs, and then finally removed a twig... In only two trials did one of the crows (the female in both cases) modify a tool after she had attempted to insert it, by removing projections that prevented insertion of the tool in the hole... (ibid., 124-125)

Researchers see this process as one of examining the situation and then creating the appropriate instrument based on the animal's assessment of the specifications for the task. Indeed, researchers report that the manufacturing of "such a well-fitting tool" is notable, especially when considering the "uneven nature of oak twigs and sticks" (ibid., 126.) Furthermore, when researchers changed the size of the hole to make it thinner, the birds produced tools that were thinner, demonstrating "some level of understanding of the requirements of the task" (ibid.). The researchers explain that:

> The experiments reported here are the first to demonstrate clear evidence of manufacture of an appropriate tool for a task. They also show active

> modification of tools in use to "fine tune" the specifications, a very rare observation... [C]rows certainly have the capacity to adjust the specifications of the tools they make to suit the task at hand. Furthermore, *they appear to understand the function of tools*, and (at least one of the captive crows) can make appropriate tools using novel manufacturing techniques and materials... (ibid., my emphasis added)

While I rely greatly on quotations in this section, I do so because the study's authors highlight aspects of crow tool-use in language that I worry might sound too suggestive if it were coming from someone with my particular research agenda. While these crow researchers have incentive for presenting novel, exciting bird behavior, their experience with the birds gives them authority to speak in terms of what the birds understand. The language of the crow studies researchers – crafting, adjusting to specifications, understanding the requirements of a task, appropriate tools, etc. – are classifications more often associated with engineering philosophy than with animal studies. The approach of these crows to their 'appropriate technology' is one fit to task and flexible to environmental/experimental requirements.

Betty, the New Caledonian Crow

In what I take as the most provocative crow study performed in captivity, Alex Weir and Alex Kacelnik report on Betty the crow and how she "creatively re-designs tools by bending or unbending" (2006). In this study, researchers hoped to further establish that the behavior of New Caledonian crows is consistent with an understanding of physical tasks unrivaled by any other non-human animal. They explain that:

> The act of making functional artefacts is often thought to be especially revealing about cognitive processes, because it may require reference to both the representation of the problem and the expected future use of the artefact. However, this assumption is not always valid: the artefact maker might be simply following action rules acquired by the species through natural selection.... In other cases, individuals may learn through trial-and-error, or by observing others, what sequences of actions modify the artefact effectively, but again with no cognitive representation of the problem or planning the future use of the instrument.... (Weir and Kacelnik 2006, 317)

I take their explanation of the problem of some animal studies research – establishing what *exactly* is indicated by a behavior is difficult, especially when animal minds must be taken into account. This consideration also lends itself to a better understanding of tool-use as it exists in diversity in the animal kingdom. The chimp studies indicate that trial-and-error and observation play an important part in chimp tool-making, and, similarly, with the instances of dolphin sponging and other learned foraging techniques, observation and imitation may be key in the passing on of technique. But, how does one establish that something more than imitation or trial-and-error[63] – or, worse yet, simple stimulus-response written into the animal's genetic make-up somehow – is at work for a given

[63] Although both imitation and trial-and-error play roles in human learning, let's not forget.

animal? Is what makes humans special the ability to go this step beyond – to plan, to represent in our minds –, and this ability what makes our tools technological? Is this the dividing line?

While the dolphin tool and foraging studies may give little indication as to our answer to the first of these questions, the studies of dolphin naming and calling would seem to indicate mental representations are possible for this species, and social learning almost certainly plays a role in whale calls. The chimp studies with tools seem to indicate this trial-and-error and observational learning are extremely important. Language studies in captivity perhaps do best to demonstrate the cognitive processes of which chimps are capable, although capacity in captivity does not always indicate its use in the wild. The rock-throwing chimp at the zoo is perhaps our best indication of representation and planning on the part of chimpanzees.

New Caledonian crows offer a very different case study, one less easily analogized to the human species and one with whom language or linguistic studies are not in vogue. While calls and whistles are studied in other birds, I have not found much literature on this type of crow's calls. Tool-use and tool-making can demonstrate cognitive processes and planning, but we must be careful to see how the process plays out. Flexibility in materials and methods, the use of novel techniques, and new solutions for new problems all seem to indicate something more than stimulus-response behavior or trial-and-error learning; these things seem to indicate cognitive processes more advanced and creative in the face of new situations. In the words of Weir and Kacelnik (2006):

> The more innovative the actions and the more specific, deliberate, and unusual the modification of the raw material, the more acceptable it becomes to hypothesise that the agent's behaviour is controlled by cognitive representation of a definite goal and the means of reaching it. (ibid., 318)

While no one test can conclusively show that a species has the sorts of cognitive abilities human beings do, compiled data on several species seem to point to great abilities to make tools, flexibly and creatively.

One particular crow, named Betty[64], was subject to a series of experiments involving bending wire to use as a hook, and a further set of three experiments was done with a novel material – aluminum strips – to see if Betty might prove to understand the physical tasks at hand (Weir and Kacelnik 2006.). Not only an experiment on the crow's causal reasoning, but on understanding and flexibility, this study put Betty through three new experiments (ibid.). In the earlier Betty studies, she "spontaneously and repeatedly" bent wire, making hook shapes to get a tiny bucket of food out of a tube. To her handlers, Betty's actions met three important criteria:

1. the actions seemed to be deliberate because the bending of the wire was not a part of general manipulation of the object, and the hooks were used immediately to obtain the bucket for food;

---

[64] Finally they named the crow in this publication. Betty is the same crow used in the other studies involving Kacelnik, Weir, and Chappell as authors, but she went unnamed until 2006.

2. the actions seemed specific to that situation because Betty had never produced anything like the bent wire when not given such a problem, and the final products (bent wires) were all similarly shaped;
3. the actions seemed to be novel because the wire given to Betty had not been encountered before and would not be encountered in Betty's native habitat. (Weir et al. 2002; Weir and Kacelnik 2006, 318)

But, the authors admit that no study alone can clearly establish these capacities and that further experience is essential to understanding the processes at work (Weir and Kacelnik 2006, 318). They suggest that, to help study understanding, the time it takes to get from a problem to a novel solution must be counted. They postulate that:

> …. a slow and gradual increase in proficiency would indicated that the subject relies on within-task trial-and-error learning. In contrast, immediate or step-wise acquisition would suggest that, at a minimum, the subject generalises from concepts formed during earlier experience in related tasks.... [T]he greater the understanding of the problem (namely, the degree to which abstracted general principles play a role), the greater should be the flexibility shown to produce novel transformations in line with new demands. (ibid., 318)

The researchers use three modifications of a problem that led to Betty's hook-making from wire to examine whether Betty could succeed in coming up with a novel solution – and how this process unfolds.

The first experiment involves bending a novel material in the same set-up as her 2002 trial to make a hook from wire to retrieve a treat. In this case, instead of wire researchers gave Betty a material very different material: a thin strip of aluminum, extremely pliable (ibid., 321). There was no prior coaching on the material – and no pre-training on the set-up since Betty had already encountered it (ibid.). The possible treats set up in the bucket in the tube were pieces of pig heart or waxmoth larva, with the rewards alternated so that motivation was kept high (ibid.). For some of the trials, Betty was allowed to enter the testing area freely, and there were a few trials in which she came prepared with her own tool – a twig or feather (ibid., 323)! According to researchers, "Betty adapted quickly to the new material," using the aluminum strips by the third trial and obtaining the bucket with the strips in 25 of 34 trials, obtaining the bucket with her own tools in four of the trials, and losing the aluminum strip either in the tube or behind the set up in the remaining five trials (ibid.). Betty's initial trials were less successful and took longer than the later trials. The researchers describe the overall outcome and what it suggests:

> Firstly, she learned very quickly how to effectively modify the tool, even though she had to use completely different techniques form those used with wire. In fact, from the sixth trial onwards, she only once spent more than 5 s crafting the tool. In addition, the 'hook-ness' of her tools rapidly improved and became more regular..., although even towards the end of the experiment there were occasional malformed ones. This is despite the difficulty of modifying this kind of material with a beak as her only

> manipulative appendage, and the fact that the modification techniques she used are unlike any known actions used by wild crows, or by her in other circumstances. (ibid., 326-327)

The researchers think that this experiment indicates that Betty uses more than simple trial-and-error learning and that some cognitive process is at play because:

> As argued earlier, such rapid acquisition would be unlikely to occur in an agent reliant solely on reinforcement learning, and if anything Betty's previous experience with the wire should have retarded the speed with which she learned about this new material, due to interferences... (ibid., 327).

One would have expect that a simple trial-and-error learning process would have taken more time and that Betty's other wire-bending work would have led her astray in this task. However, Betty's performance in the first experiment suggests that there is more to Betty's understanding than a trial-and-error process.

The second experiment that researchers set up for Betty was set up such that "the successful actions from the previous problem would lead to failure" in this experiment (ibid.). Betty was given aluminum strips, bent at both ends, but the set-up was different in that Betty now had to retrieve her snacks from a narrow hole. Experiment 2 was conducted at the tail end of Experiment 1 and models some chimp experiments done in captivity (ibid.). Betty was familiar with this narrow hole set up from prior experiments with other researchers, and the rewards for Experiment 2 were the same as Experiment 1 (ibid., 328). To obtain the treat, a sufficiently narrow tool needs to be inserted to a hole such that the treat cup is pushed far enough along so as to fall down a bend in the tube and onto the ground (ibid.). The now-bent aluminum strips, already shaped into hooks on both ends, could not fit into the hole while bent into hook form (ibid.). Before testing, researchers made sure Betty was given practice trials with this new instrument with straight tools and was able to obtain the food, and, in the official experiment trials, of which there were three, Betty quickly retrieved the food in every case, although in two instances not as the researchers intended (ibid.). In trial one, Betty pecked hard at the hole and the food cup was jostled enough to fall, a successful method to getting the food, even if unexpected (ibid.). In trial two and three, she used the aluminum strip – unmodified in trial two and stuck up the vertical end of the pipe, with the hook used to bring the treat cup down (ibid.). In trial three, researchers were wising up to Betty's new methods and modified the vertical tube so that a repeat of trial two would have been impossible; in this trial, Betty "performed the task as intended" by the researchers, squeezing both ends to flatten and poke through the hole, "thereby solving the problem of 'spontaneously modifying the tool to allow it to fit through the hole'" (ibid.). On this third trial, she initially tried to use the wrong end of the tool, but quickly turned it around, which "could be interpreted as Betty instantly 'understanding' what was required," since she did not continue to try it with the wrong end (ibid.).

Researchers set up this second experiment much like a chimpanzee study where all seven tested chimps "showed a strong preference for attempting to insert the 'impossible' ends of tools, and very rarely turned the tools around" (ibid., and referencing Povinelli et al. 2000). In 56 chimp trials, there were only three successes, and the researchers of this Betty study conclude that, "[i]n this context, Betty's response of turning the tool around almost instantly is impressive, even if not equivalent to human-like understanding" (ibid.).

For the third experiment, researchers were looking for something more conclusive than what they found in Experiment 2. They now presented Betty with an instrument that was more difficult to squeeze and modify. Betty now had to make the instrument longer instead of narrower in order to successfully retrieve her treat; the aluminum strips were now bent in a U shape that would need to be straightened out (ibid., 329). No training on the apparatus was given, since Betty had encountered it before, and Betty was given four trials[65] (ibid.). She was successful in obtaining her treat in three of four trials, with the first trial she "managed to reach and retrieve" her reward "by inserting her head and neck into the entrance of the tube" with the ends of the tool squeezed to together to make a straight tool; researchers modified the apparatus to prevent Betty from using her head and neck to get the material in the tube (ibid.). On the second trial, Betty tried out the unmodified tool for 1.5 minutes without success, and, on the third and fourth trials, Betty modified the aluminum to get the reward:

> Both trials involved a similar modification technique, which occurred several minutes into the trial: in the middle of a bout of probing in the tube, she raised her head and beak (still holding one end of the tool) in a distinctive and unusual manner, causing the shaft of the tool to bend backwards against the lip of the tube.... (ibid.)

[65] There would have been more trials, but Betty died (Weir and Kacelnik 2006, 329).

While researchers have no clear confirmation that this odd behavior was purposeful, it had never been witnessed on other occasions with different materials (ibid.). Perhaps most convincing about these experiments is how they compare and how Betty adapted her tool use for the different experiments. In the trials of Experiment 3, "in no trial did she modify the strip by bending or twisting it, which were the actions associated with success in Experiment 1," which suggests to the researchers that Betty could *recognize* that those actions wouldn't work in Experiment 3 without the use of trial and error (ibid.)! Betty used strategies that suited the problems with which she was presented, even when prior training could have interfered with her possible strategies, and she showed the researchers problems with the apparatus on several occasions, coming up with unanticipated ways of procuring her treats.

In their discussion of their experiments with Betty, the study's authors reflect on human understanding in relation to Betty's:

> [W]hile her innovative behavior cannot be accounted for purely by reinforcement for specific actions, it is not yet justified to assume that she possesses a full, human-like understanding of each task and that she uses it to plan and direct her behavior (although whether the full understanding that humans presumably have of the task would reveal itself by perfect first-trial performance is unclear, since humans often make mistakes despite such understanding).[66] (ibid., 331)

[66] Note that the researchers talk about 'innovative behavior'; they also use the term 'tool-oriented behavior' (ibid., 331 and 318).

They make three points: first, a subject not performing in a way foreseen by an adult human does not necessarily indicate that that subject does not understand a given task (ibid.). Citing examples from studies on humans where humans perform in a way contrary to a seeming understanding of gravity, the researchers are quick to note that “it is critical to test how humans perform on tasks that they do understand before interpreting a non-human animal's failure as evidence for lack of understanding” (ibid.). I would add to this point that what makes sense for a non-human animal may be different than that of an adult human (and, relatedly, the understanding of a toddler is different from an adult human, and, perhaps, a juvenile dolphin differs from that of an adult). Given environmental and habitat differences, different animals are attuned differently to the world – this may explain the difficulty in interpreting some whale and dolphin studies, given that their environments differ so radically from ours. In fact, it may seem that their three-dimensional thinking should be better developed than that of humans, given the way they can move in their environments compared to how humans can move in theirs.

Second, the authors of the study on Betty note that “some progress can be made by comparing behaviour of members of different species in comparable tasks” because studies can be arranged to mimic other experiments. These authors often make reference to chimp studies and even design some of Betty's tasks for comparison directly with the chimpanzee literature. Betty, of course, fared much better than the chimps, “who are often considered to be the most intelligent non-humans” (ibid.). Betty's authors do note, however, that New Caledonian crows develop tool use, even when raised in isolation and use tools widely in their natural environments, so “[t]hese birds might... have specific cognitive adaptations that make them particularly good at learning and possible reasoning about tasks involving physical interactions between solid objects, but perhaps not extraordinary at other equally difficult logical tasks" (ibid., 331-332).

Later in this dissertation, I discuss the importance of evolutionary history and environment, which matter to comparisons between species. In some ways, making these comparisons has been a problem: the standard that we humans consistently set up for intelligence is based on our own intelligence, which comes from our specific evolutionary history. Worse yet, the standard human beings have often set up for intelligence is the standard of certain privileged classes of humans, and often this leads to rather awful things – oppression, exploitation, slavery, genocide, etc. – but I will return to this topic later.

Third, the authors of the Betty study note that understanding is usually given as a all-or-none option, but that this can be a false dichotomy (ibid., 332). The authors suggest that thinking about "the minimum specifications that need to be incorporated into a robot to achieve a similar level of generalisation and creativity" might be useful in considering levels of physical understanding (ibid.). Intermediate levels of understanding should be allowed (ibid.), especially because understanding often takes place in steps. The authors also point out that situations that are causally and perceptually different have an impact on dimensions of understanding (ibid.) – there are perceptual differences among species that might account for some disparity in data on causal understanding and 'folk physics'.

Animal studies literature has presented so much exciting research on the New Caledonian crow in the past 10 years, from studies of "parallel tool industries" among the crows like those seen in human hunter-gatherer societies (Hunt and Gray 2007) to "human-like, population-level specialization" in manufacturing of pandanus leaf tools (Hunt 2000a) to handedness and social learning (Kenward et al. 2006) to decision strategies for tool-use (Hunt et al. 2006) and metatool use (Taylor et al. 2007; Taylor et al. 2010). There's even direct comparison with humans on tool selection for a given task (Silva and Silva 2010). I touch here on just a few more items.

New Caledonian Crows: Metatool Use and Learning

Considered by some to be the first step from tool use to technology, metatool use is the use of one tool on another. A 'major innovation' for human evolution, propelling us to our technological world today, metatool use presents "three distinct cognitive challenges" (Taylor et al. 2007, 1504):

- "an individual must recognize that tools can be used on nonfood objects"
- "an individual must initially inhibit a direct response toward the main goal of obtaining food, a reaction that both children and primates find difficult to suppress"
- "an individual must be capable of hierarchically organized behavior"(ibid.)

This third step requires a flexibility of hierarchical thinking – an agent must be able to include a "newly innovative behavior (tool → tool) with established behaviors as a subgoal" (ibid.). This process "has been suggested to follow a recursive pattern and to require cognitive processing similar to language production" (ibid.). All seven New Caledonian crows in a study by Alex H. Taylor, Gavin R. Hunt, Jennifer C. Holzhaider, and Russell D. Gray "spontaneously produced the correct behavioral sequence" in a trial on metatool use (2007). The crows had to use one tool to get to another to extract food, and the researchers put irrelevant tools in the study to check for trial-and-error learning (ibid.). The crows in this study did not "randomly probe the toolboxes" with unnecessary tools, and the researchers suspect that analogical reasoning played an important role in the crows' rapid solution to the task (ibid., 1506).

Adding to this finding, Alex Taylor, Gavin Hunt, F.S. Medina, and Russell Gray published another study in 2009 on causal and analogical reasoning in New Caledonian crows. They start out with a philosophical point:

> … David Hume (1711-1776) famously used the example of one billiard ball rolling into another to illustrate his argument that causal relations cannot be explicitly perceived. Instead, causal relations must be inferred from sensory information. (Taylor et al. 2009, 247)

The problem, for these researchers, is distinguishing associative learning – "the mental pairing of events that occur in close temporal and spatial proximity – from causal reasoning – or the hows and whys of why one event follows another (ibid.). Researchers employed two types of apparatus commonly used in ape studies of causal versus associative learning, a trap-tube and a trap-table, and they found that crows were able to use the causal relations required to solve the trap-tube in the very different set up of the trap-table (ibid., 251). The two apparatus look quite different, though they operate on the same causal principles, with a successful trial meaning that the crow would have to move the treat in one direction (but not too far) and then work on it from another aperture to avoid losing the meat in a trap (a hole in the bottom of the set up).

Inhibitory control presented a problem for some of the crows tested, in that some of the crows were unable “to stop pulling meat towards itself and instead walk around the apparatus” to probe into it from that end (ibid.). This inhibitory control caused failure in the tube task for three of the six crows tested, but this problem is one that is present “in problem solving for both children and non-human animals” more generally (ibid.). One of the birds (“Espanol”) “hesitated before pulling the meat into the trap” (where pulling the meat into the trap means you don't get your treat because you didn't reason out the way to get the meat out), which “suggests that Espanol may have learnt when he would fail, [but]... was unable to inhibit pulling the meat towards himself despite the presence of the trap” (ibid.). The researchers carefully rule out explanations other than causal for the behavior of the crows as implausible: chance, visual and tactile generalization, and prior dispositions (ibid., 251-252). The most plausible account of this study is that “the crows transferred knowledge of the causal relations between the hole and the reward to the perceptually distinct trap-table problem” (ibid., 252).

Researchers have also posed questions about New Caledonian innovation and problem-solving. Using a stone-dropping test that was developed for rooks (described in the next section), crows were tested with a problem that involves dropping stones off a platform into a vertical tube to collapse a platform, freeing a treat (von Bayern et al. 2009). Researchers used six birds in the study – two trained in how to nudge stones into the vertical tube (just as the rooks were, these used as a control group) and four trained by witnessing how to push down the platform with their beaks. In the trials, two of the four not trained in stone-nudging nonetheless picked up stones and dropped them into the tube, though they had never before encountered this procedure (ibid., 1965). This feat, and the behaviors of the birds in relation to the apparatus, led the researchers to the conclusion that:

> … for New Caledonian crows, learning about some functional affordances of the task (collapsibility of the platform through force or contact) is essential, whereas learning about specific visual stimuli (stones acting on the platform) or actions (picking up and dropping stones) is not... The ability to reason about invisible forces has not yet been convincingly demonstrated in nonhuman animals, but these recent observations with corvids may encourage future experiments. (ibid., 1965-1966)

The research with these crows suggests that the crows have some understanding of folk physics and gravity. Half the crows who had not been exposed to stones were able to solve the task, a task that required some understanding of force being laid on the platform for the release of a treat. Researchers suggest that "insight" into the problem is hard to account for, and that a clear linking of the activities is difficult to establish, but the research on crows and other corvid-type birds could lead to conclusions about the cognitive processes of corvids that might challenge our inherited hierarchy of man.

New Caledonian Crows: Innovation

'Innovation' is a word typically associated with only human beings, but there are at least two studies on New Caledonian crows that point to "high innovation rates in the wild" on the part of these crows (Taylor et al. 2010; Hunt and Gray 2003). The first of these studies points to a "cumulative technological evolution" – likely the product of innovation along its evolutionary history – on the part of the crows (Hunt and Gray 2003, 867). Researchers from this study carried out a survey of New Caledonia "to establish the geographical variation in the manufacture of these tools," documenting 5550 tools in 21 sites, specifically targeting pandanus tool manufacturing (ibid.). The researchers found three very distinct types of pandanus tools manufactured: a wide tool, a narrow tool, and a stepped tool (like the kind described earlier in detail by the same researchers, Hunt and Gray 1996) (ibid.). The three characteristics of cumulative technological evolution described by Hunt and Gray are: diversification in design, "cumulative changes to tool lineages" and "faithful transmission" of design through social processes (ibid.). Diversification can be described as "when a new tool design is added to one or more existing, related designs" (ibid.). For humans,

> Diversification is clearly observed in the evolution of human stone tools form simple Oldowan-type cutting flakes and hammer stones to the diverse range of shaped tool types (e.g. knives, blades, arrowheads, axeheads)... (ibid.)

That these crows have three distinct types of tools made from a single material is unusual, and it's unlikely that these tools types came about through separate paths, especially since initial cuts made to the pandanus leaves were likely similar, and researchers suggest that they come from a common origin (ibid., 872).

Notably, researchers found no poorly made step tools that might have indicated individual trial-and-error learning on the part of the crows; instead, social transmission may play a role in the making of these tools (ibid.). Additionally, researchers suspect that two of the three designs "must have evolved form cumulative change(s) to earlier versions" because "each design results from a unique, non-recapitulating manufacture process" (ibid.).

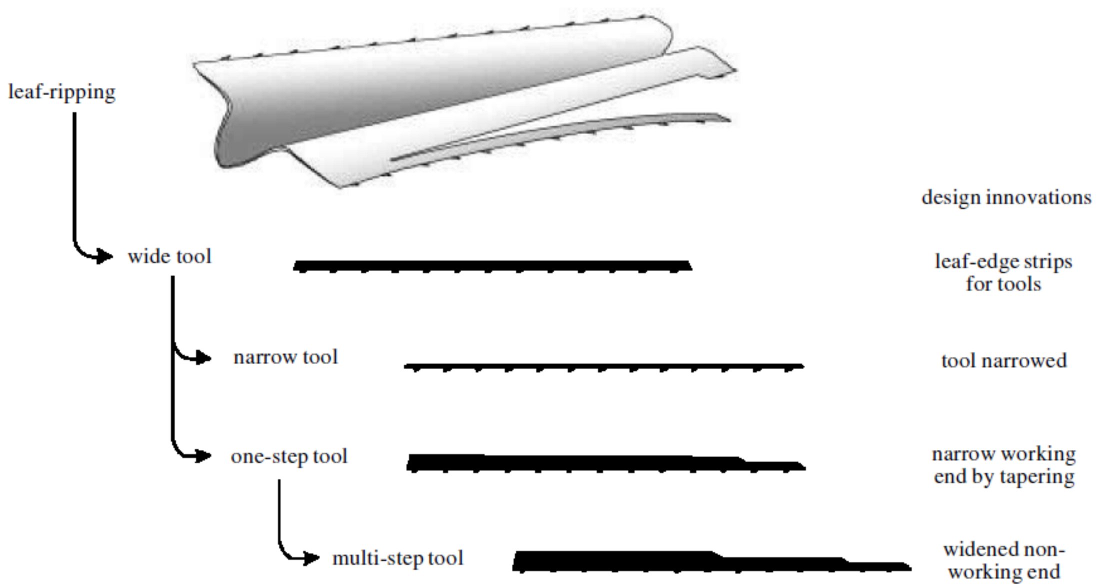

Figure 4. Proposed evolutionary history of the diversification and cumulative change in pandanus tool designs. Design innovations associated with the initial use of pandanus leaf as tools (wide design) and subsequent design changes (narrow and stepped designs) are briefly described at right of each tool. The section of pandanus leaf is *ca.* 5 cm wide.

Figure 3: Figure 4 from Hunt and Gray 2003, page 873.

The above figure from Hunt and Gray shows the differences in the tools and gives a suggested evolutionary history for their development. Hunt and Gray conclude that their findings "are the first indication that a non-human species may have evolved rudimentary cumulative technology," which is likely socially transmitted" (ibid.). They note that the striking flexibility and innovative capabilities seen in these crows, both in the wild and in laboratory, is consistent with the possibility of a cumulative technological evolution, something once considered only the domain of human beings (ibid.).

In a further study on innovative behavior, researchers tested New Caledonian crows to see if they could bring known-strategies to novel tasks and contexts. The experiment was set up to see if an abstract rule, "out of reach objects can be accessed using a tool," could be used in a completely novel context (Taylor et al. 2010, 1). In this experiment, six steps had to be followed to get the treat in a three-stage metatool problem (ibid.). Crows were divided into groups – a "component group" of crows that had been exposed to the individual components of the test before and an "innovation group" that lacked relevant contextual and metatool use background (ibid., 2). The three component group crows all successfully solved the task on the first trial in the way anticipated by the researchers (ibid.). In the innovation group, two crows (Sam and Caspar) solved the problem on the first trial – one without making any errors and "after inspecting the apparatus for 110 s" and the other stopped to reinspect after dropping a string that was part of the task (ibid., 3). The other two crows (Maya and Djinn) in the innovation group were able to complete the task, with one on her third trial and one on her fourth trial (ibid.).

With this task, researchers demonstrated that "New Caledonian crows can spontaneously link up to six learned behaviors into a novel behavioral pattern" in the case of the component group (ibid., 4). Sam's behavior (an innovation group crow that was successful in his first attempt without error) demonstrated that these crows can also spontaneously link these behaviors while using two new behaviors in a novel context (ibid.). Sam's performance matched that of the three crows in the component group, despite the new challenges involved (ibid.). Researchers rule out conditional reinforcement as an explanation of this behavior because of the complexity of the process and the use of metatools required. Other simple cognitive mechanisms are also ruled out thanks to the performance of the innovation group; while the component group had the appropriate "behavioral repertoire" and "functional generalization," the innovation group lacked the relevant experience – these crows had to come up with new behavioral patterns in a new context, which points to deeper cognitive function (ibid.). Another possible explanation would be resurgence, but resurgence does not work as an explanation for the behavior of the innovation group because it would not explain how the crows "generated metatool use" (ibid.). A final possible explanation ruled out by researchers is that of a propensity for the activities required in the task – particularly the string-pulling required (which the innovation group had no experience of); however, in separate experiments, New Caledonian crows have been shown to rarely pull on a string without meat attached to it, so string pulling seems outside the normal behavioral repertoire of these crows (ibid., 5). The 'spontaneous' nature of the innovation on the part of the innovation group involves two component: "immediacy and lack of explicit training" (ibid.). In summary, the researchers conclude:

> The crows' performance here shows that behavioral innovation, particularly the use of behaviors in novel contexts, can be underpinned by cognitive mechanisms that are more complex that, but supplement, simple learning mechanisms. (ibid., 6)

Important terms associated with these studies of New Caledonian crows are 'cumulative technological evolution', 'behavioral innovation', 'causal reasoning' – these are things normally associated with human technology and learning. Other birds have confirmed these studies. It doesn't seem that New Caledonian crows are completely unique in all their abilities, although their native tool-use has yet to find its match, except among humans.

Rooks and Calculation

Crows and rooks are both part of the corvid family of birds. Rooks are not known to produce any tools in the wild. However, in laboratory studies, researchers have established that rooks are "capable of insightful problem solving related to sophisticated tool use." This finding means that there are species capable of the *reasoning* necessary for tool use and production who *do not actually produce or use tools* in their native environments. In a 2009 study authored by Christopher Bird and Nathan Emery, four rooks were put through a series of trials after demonstrating the ability to drop a rock down a vertical tube to collapse a platform containing a worm. These four birds came to perform the task either by first accidentally nudging a stone or by watching other birds solve the task (Bird and Emery 2009, 10370). One subject in the study, named Fry, "spontaneously picked up the stone and dropped it into the tube" after watching "her partner Cook successfully complete the task" (ibid.).

Using Benjamin Beck's famous definition of tool use:

> the external employment of an unattached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds or carries the tool during or just before use and is responsible for the proper and effective orientation of the tool (Beck 1980, as quoted in Bird and Emery 2009)

the behaviors of these rooks fit the definition and "present the opportunity to investigate insightful reasoning" in follow-up testing (Bird and Emery 2009, 10370). After demonstrating they could perform this initial task, the rest of the trials were performed in isolation in a testing room that could not be viewed from the aviary, although it was open to fly into such that birds could come in an be observed in the experiment (ibid.).

The tests involved the selection of stone size, ability to retrieve the appropriate tool, the use of sticks, decisions between two sticks, a spontaneous metatool use task, modification of a stick, and tests with hooks and their manufacture. Many of these experiments were similar to ones presented to New Caledonian crows, of which the researchers were aware and actively used as a comparison. The rooks performed astonishingly well for a species that does not use or make tools in the wild. These four rooks picked stones based on their "functional relevance" to the tests, choosing stones capable of collapsing platforms with worms (ibid., 10371). They could find an appropriate stone in their aviary when an appropriate one was not provided in the testing room (ibid.). They picked out stones of the appropriate shape to fit into the vertical tube of the testing apparatus (ibid.). These rooks demonstrated the ability of "goal directed action" instead of conditioned response when they showed the ability to use the completely new tool of a light, long stick to push down the platform (ibid.). Given the choice of one nonfunctional and one functional tool (sticks and stones of varying weights and sizes), rooks could correctly chose the functional tool "regardless of the tool type" (ibid., 10372).

Tested on their ability to figure out a metatool task, this one involving the use of "a large stone to access a small stone that could be used to release the inaccessible food," all four rooks solved the task on the first trial (ibid.). Tested on the ability to manipulate a stick tool, rooks tore off twigs of an elm stick, successfully modifying the tool to function in a way to access a treat (ibid., 10373). In a next phase of tests, rooks were tested on a New Caledonian crow task – using a hook tool to obtain a bucket of waxworm, and they performed successfully (ibid.). A second phase of hook-tool experimenting had the rooks presented with a choice of two hook tools, one functional hook and one that would not work. More often than not, the rooks in this test chose the functional tool, with three out of four rooks choosing correctly in the first trial, with researchers claiming that the test subjects "actively discriminated" between the two tools (ibid.). In the final phase of hook-testing, rooks were presented with straight wire that would need to be made into a hook to pull up a bucket with a treat from a vertical tube – an experiment done with Betty. The results were surprising, especially given that only one New Caledonian crow had been shown to perform this task: "all 4 rooks spontaneously manufactured a hook and used it successfully to extract the bucked, 3 of the 4 subjects achieving this on the first trial" (ibid., 10374).

The tests with these four rooks show the abilities of rooks to rival those of New Caledonian crows – *on every task given*. The evidence given in this paper speaks against tool use as a driving force in advancing human cognition. In the words of Bird and Emery,

> Our results contradict suggestions that tool use was the driving force behind the evolution of advanced physical intelligence. It appears more likely that corvid tool use is a useful by-product of a domain-general "cognitive tool-kit" rather than a domain-specific ability that evolved to solve tool related problems. Whether or not each species taps into this capacity for tool use may depend on their ecology. (ibid.)

This study challenges the notion that tools somehow make humans more human by some cognitive transformation that takes place in using tools.

When technologists and historians make claims like

> Technology has driven our brains. Our expanded physical capabilities made technology – extended toolmaking – inevitable. (Leinhard 2000, 4)

and

> We now realize that man could not have become a thinker had he not at the same time been a maker. Man made tools; but tools made man as well. (Kranzberg and Pursell 1967, 8)

Man may have made tools, but he's not the only one capable of making tools – technological or tool-ish reasoning is possible even without native tool experience. *Given the right environmental conditions and situations, other species can and do use tools – and other species may have the capacity to do so, even in the absence of actual tool-use in the wild.* Taking the rook studies at face value, we can no longer consider our ability to use tools as fundamental to our advanced cognition.

Western Scrub-Jays and the Ability to Plan

Another member of the corvid family of birds, the Western Scrub-Jay, has shown the ability to plan for its future, once considered the domain of only humans. A growing body of research, much of it led by or involving Nicky Clayton, an experimental psychologist at University of California at Davis, points to the abilities of scrub-jays to plan for the future, anticipating future needs and recalling information well into the future (Wohlforth 2010). Clayton's finding have revealed that "scub-jays plan for the future, recall incidents from the past, and mentally model the thinking of their peers" (ibid., 46). In caching food for later consumption, scrub-jays have been found to dupe other birds by caching food in one place if they are being watched, and then moving that food to a safer location later (ibid., 47). Clayton's laboratory studies are conducted mostly within the scrub-jays' own enclosures – because scrub-jays prefer to cache in their own territory[67] (ibid., 46).

Clayton's group has demonstrated that scrub jays can plan for the future in sophisticated ways, with skill and memory:

> Given the opportunity in the evening to place a cache in either of two cages – on in which they had previously been hungry at breakfast time and one in which they had previously been fed – the birds made the correct choice, without practice, provisioning the cage where breakfast had not been provided in the past. (ibid., 46-47)

This type of recall demonstrates to researchers the ability of jays to perform mental time travel – the ability to think of the past and plan for a future based on that past. Mental time travel was once considered the domain of humans alone (Correia et al. 2007):

> Many people have assumed that nonhuman animals were cognitively stuck in time, incapable of acting on the basis of either the recollection of specific past episodes (retrospective cognition) or the contemplation of possible states of affair beyond the immediate future (prospective cognition). (ibid., 1).

However, scrub-jays demonstrate that they can "provision for a future motivational state" and can indeed cache food with regard to their future preferences, perhaps indicating prospective cognition (ibid., 1). The caching of food in areas where they were once hungry indicates a type of retrospective cognition. Researchers in one study showed that

[67] There is a reason for this: what good with a cache do outside the jay's territory?

scrub-jays “can dissociate their current and future motivational states” (ibid., 2). In this study, birds were allowed to cache a number of types of food after being pre-fed one type, and their cache preferences were not affected by their pre-feeding, rather “the birds can anticipate and take appropriate action toward the satisfaction of a future need, one that is not currently experienced” (ibid., 4).

Scrub-jays, perhaps in relation to their retrospective and prospective cognition, are complex social thinkers, able to deceive others. In one of Clayton's experiments, scrub-jays “remembered if they were being watched by other birds when they cached and by which ones” (Wohlforth 2010, 47). Observations show that these birds “wait until a potential thief was distracted.... or would chose a spot that was dark or otherwise difficult... to see” (ibid.). If another bird could possibly hear where the cache was being made, scrub-jays “would chose quieter material in which to dig – sand rather than pebbles” (ibid.). When caching with other birds looking on, scrub-jays return to the cache spot and relocate the items “when conditions permitted privacy” (ibid.).

Clayton and her colleagues worried that this seemingly deceptive behavior was conditioned, instead of learned. Raising a group of scrub-jays by hand, and never allowing them the opportunity to intrude upon the caches of other birds, these “naive jays” did “not take precautions to avoid being victims of theft” (ibid.):

> Apparently, the ability to avoid theft by others depended on projecting a bird's own experience. It took a thief to know a thief. (ibid.)

Other experiments with ravens involving caching have been recorded, so it seems as if scrub-jays are not unique in their abilities (ibid.). While this has little to do with tool-use, per se, it seems as if some of the things we typically connect with the mental capacities necessary to appreciate technology – the ability to plan for future use and imagine potential states of affairs – can no longer be considered the exclusive domain of human beings.

Conclusions

The state of the current research indicates that New Caledonian crows are able to use, craft, manufacture, etc. a variety of tools, even using metatools on occasion to do so. The research demonstrates abilities that were once considered the hallmark of humanity – or at least of hominidity. The research on rooks and scrub-jays also indicates a greater cognitive sophistication in relation to tool-use than was once appreciated in birds – and the rook research points to the importance of environment in the use and expression of capacities for tool-use. While a rook may not use tools in its native environments, the *capacity* for tool-use among these birds was a surprising finding, one that indicates the need for more research on the subject.

In my next chapter, I present contrast cases to the research I've presented so far on apes, cetaceans, and corvids. These contrast cases help to flesh out fuller map of technological behaviors – some more intentional or goal-oriented than others. I do not think that all animals have the capacity for tool-use or technological behavior – or that all seeming cases of tool-use are equally complex or cognitively-taxing. In fact, even some cases that seem on the surface to be cases of tool use can stem from instinct or can be an expression of an animal's extended phenotype. I also argue that there's no significant difference between tool use and other construction behaviors found much more widely in the animal kingdom, such as the building of nests and dams and webs. Constructions are those things that are made-objects, but do not have to be detached for use. Tool use has often been taken as something important and critical for higher intelligence, but constructions can require just as much learning and technique as tool use in some instances.

Chapter 7: Contrast Cases, or Why Beavers Aren't Engineers After All

In this chapter, I provide some cases of animal tool-use that may not count as technology or tool use. Spiders spin webs, beavers build dams, and bees dance, but I doubt these actions reflect intention in the way the tool-use of chimps and crows and dolphins can.[68] Given the flexibility of the linguistic and technical maneuvering of objects by these animals, along with their extended time bonding as juvenile-adult pairs, the technical products (the tools and techniques) made by these animals reflects a standardization, an ingenuity, and complex cognition that is not reflected in a host of other cases of animal tool use. However, cases of animal construction – beaver dams and spider webs – can still be considered alongside other animal constructions in terms of what is necessary to implement the constructions and what knowledge is instantiated in the process.

Beavers Dams and Spider Webs

Beavers are often recognized as excellent engineers for their dam-building activities, inspiring several universities to take up the beaver as their mascot (MIT, Oregon State, American River College). Beavers transform ecosystems, cause difficulty with waterways, and seemingly destroy wildlife areas by felling trees. In a study on the 'hydrogeomorphological effects' of dam-building, one geographer explains:

---

[68] Bee dances are representational, and they actually meet several criteria of intentionality discussed by Millikan (1984).

> A characteristic of beaver ecology is their ability to build dams, and, thus, to modify the landscape to increase its suitability for their occupation. This ability to modify their habitat gives beaver enormous significance as geomorphic agents and has caused them to be described as 'ecosystem engineers'. The consequent direct and significant control on ecosytem structure and dynamics has led them to be considered a 'keystone species'. (Gurnell 1998)

Beavers always construct their dams at the narrowest part of streams, requiring fewer materials and less effort than at wider stretches. These dams also help beavers exploit the stream by making food-finding easier. Dam-building is often referenced "as proof of the beaver's intelligence and engineering skill" (Jung 2007).

In one study,[69] pairs of beavers with "proven dam building track records" were moved to different environments (where no stream was present[70]). The results were:

> Those [beavers] released in ponds and large rivers burrowed into the bank, set up beaver housekeeping and then showed no more desire to construct anything beyond their holes. Those released along streams, however, found likely looking pools and then proceeded to deepen them by constructing dams at the narrow, shallow, downstream end. (Jung 2007)

As part of phase two of this study, the researcher then recorded the sound of water rushing, and then set up speakers around areas known to have beaver. The recording was

[69] I like to think of this study as "Trading Places: Beaver Edition."

[70] Which is important because beavers only build dams on streams.

played during one night, and the researcher returned to find "the speakers buried under several feet of sticks, gravel and mud – thus effectively silencing the sound" (ibid.). This same procedure, repeated at several locations – along dammed streams, large rivers, lakes, and ponds – produced the same result: beavers always muffled the speakers to get rid of the sound of rushing water (ibid.). This study demonstrates "why beavers always pick the narrowest and most shallow section of stream to build their dams – it's because that's where the noise is" (ibid.). Beavers do *not* seem to set out with an idea to a build dam because they carefully consider its usefulness or plan out where the best place for a pool might be – beavers are compelled to literally bury the sound of rushing water, thus dam-building activity occurs. Dams come not from some well-intentioned goal or plan[71], but stem from some helpful irritation that serves as an environmental cue.

The building-activity of beavers is not intentional in the way dolphin techniques for hunting and the use of tools by New Caledonian crows, but instead it is something that is done as instinct or compulsion.[72] Such instinct or compulsion can also be seen in spiders. The spinning of webs involves the production of silk threads – coming from the animal itself, but nonetheless altering the spider's external environment to make it more useful or productive for the spider. All spiders can produce silk threads, but only web spiders built webs (Foelix 1996). Orb webs, particularly, are considered "the evolutionary

[71] And one might infer this simply from the *mess* that goes into constructing a dam – beavers fell trees in a helter-skelter fashion that is much the bane of wildlife preservationists!

[72] The patching of dams and lodges might actually involve more know-how on the part of beavers than the original structure building, but dam-building itself does not seem to be the planned activity that it would first appear.

summit of web-building spiders" (ibid., 145). Some speculate that silk threads were first used for tripping prey and then were enlarged, over the spider's evolutionary history, to be larger living and dining spaces (ibid., 148). Fossil evidence indicates that the 'invention' of the orb web was about 100 million years ago (ibid., 145), but this form has not seen any significant improvements in quite some time. Although spiders subjected to drug experiments have created some unusual webs, this new production cannot be said to be the natural product of the spider,[73] nor does this seem to count as ingenuity or creativity or something with an intentional character (indeed, many of those webs are likely less effective than the normal orb web). No possibility of a socially transmitted material culture or social learning of technique exists. Such know-how would have no way to be passed along by anything other than a genetic route, as spiderlings spend no time with their parents or in large groups.

One seemingly collaborative spider project has been documented near Lake Tawakoni in Texas (*ScienceDaily* 2007). In what *looks* like a giant collaborative project (and was reported in popular news media in this way), millions of spiders and spiderlings produced silk threads that likely rode air currents to produce a ridiculously large spider web – covering a large area of trees; researchers on the scene identified at least 11 different spider groups involved in the production of the massive web, but trace its cause not to intentional planning or coordinated behavior, but to a particularly good year for

[73] Insofar as natural products would be only those un-tampered with by humankind. I'm not committed to sustaining the natural-artificial distinction, but the drug webs of spiders would be considered unnatural in most discourse that uses these concepts.

spiders and their survival – wet summer conditions leading to many small insects for prey (ibid.). More available prey and the proper environmental conditions led to a great population boom for spiders residing in that area, and silk thread converged into one giant web, according to researchers.[74]

The Extended Phenotype

Richard Dawkins provides an analysis of spider webs and beaver dams in his *The Extended Phenotype* (1982). A phenotype is the set of characteristics of an organism, springing from an organism's genes and environment. The extended phenotype, for Dawkins, is "all effects of a gene upon the world" (ibid., 293). To Dawkins, beaver dams and spider webs are parts of the extended phenotypes of beavers and spiders, respectively. A spider web, regarded in these terms, is an extension of the spider's genes upon the world. Dawkins explains that:

> … An animal artefact, like any other phenotypic product whose variation is influenced by a gene, can be regarded as a phenotypic tool by which that gene could potentially lever itself into the next generation... It is as though some species have shifted the burden of adaptation from bodily phenotype to extended phenotype. (199-200)

---

[74] I actually wonder whether the experts haven't actually tried to explain away this large construction by citing the weather conditions. If more giant webs were found, researchers would be forced to make a more careful study about these formations.

A beaver dam enables a beaver (or set of beavers, they often build in mated pairs) to travel more easily by water (in the newly made pond) to move wood and to forage for food without as much danger in becoming the prey of some other animal (ibid., 200). In this way, Dawkins asserts that *the entire lake* may be seen as part of the beaver's extended phenotype, “extending the foraging range of the beaver in a way which is somewhat analogous to the web of a spider” (ibid.). Spiders prove to be even more straightforward cases for Dawkins (because they build webs only as individuals). Though Dawkins knows of no genetic analysis of spiders or beavers related to the matter,

> [i]t is known that individual spiders have consistent idiosyncrasies which are repeated in web after web. One female *Zygiella-x-notata*, for instance, was seen to build more than 100 webs, all lacking a particular concentric ring. Nobody familiar with the literature on behaviour genetics would be surprised if the observed idiosyncrasies of individual spider turned out to have a genetic basis. Indeed, our belief that spiders' webs have evolved their efficient shape through natural selection necessarily commits us to the belief that, at least in the past, web variation must have been under genetic influence. (198-9)

Dawkins suggests that the ways in which some spiders consistently build their webs with the same apparent flaw points to some genetic defect to their inherited web building genetic blueprints. In the same way, genetic influence explains the standardization of orb webs among orb web builders, as well as other standardized uses of silk thread among spiders that do not build webs.[75] How a web is constructed seems to be determined by genetics, though the phenotypic manifestation has environmental determinants.

Worried that genetic influence might dictate tools and techniques among dolphins and crows, crow researchers have attempted to document increasingly better forms of a tool (as if to indicate that the crow had to learn how to make the tool and improved their skills over time), and dolphin researchers have tried to rule out genetic factors as the cause of certain dolphin foraging techniques and hunting style. This analysis is made more difficult because transmission of the knowledge of technique is often passed from parent to juvenile as a social or cultural process – and parents and their young share a genetic resemblance. However, researchers have constructed a strong case that dolphins actually learning techniques, rather than performing a behavior out of genetic influence, a claim bolstered by the sorts of behaviors they are able to learn in captivity from trainers (who obviously bear little genetic resemblance to their dolphins subjects). Dolphins learn techniques and learn tasks from researchers, if not from their parents. Nothing similar can be said for orb web construction – there is no learning process, whether by trial-and-error or socially modeled or taught, for spiderlings. There seem to be no teaching or learning possibilities for spiderlings whose parents are not present for their youth or instruction.

A Few More Cases

[75] Comparisons of the orbs of orb-weaving spiders does show variation and design choice, some of which might be ascribed to different working conditions/substrates.

Cows are known to preen themselves on upturned sticks and fence-posts. This preening behavior requires little planning, but does eliminate some parasites and can be considered advantageous for the survivability of the cows. The use of some object external to one's body alone, while it may be some sort of proto-tool-use, does not seem to be an example of the concentrated tool-like behaviors we see even in spiders or beavers. A recent study found octopuses using coconuts as defensive tools (Finn et al. 2009, R1069). The octopus researchers specifically refer to this usage as tool-use and talk about the possibility of invertebrate tool-use, given their findings. They observed "soft-sediment dwelling octopuses carrying around coconut shell halves, assembling them as a shelter only when needed" (ibid.). Carrying these half-shells requires the octopus to walk in a "novel and cumbersome way," which itself seems to be less efficient and safe than normal walking (ibid.). This use of coconut shells was significant because of the dexterity and manipulation required of this maneuver.

So, what hallmarks of technology should get our attention? First is that of *intentionality*, and relatedly, *anticipation or planning for the future*. These defensively-oriented octopuses are anticipating something, and I've already provided more detailed accounts of scrub-jay caching, as well as Santino the chimp's rock-hoarding. Next we might consider whether there is a *material culture or social learning* component to the tool use. Chimp and dolphin groups give us the clearest examples of these, but New Caledonian crows also spend time modeling tool-use in juvenile-adult pairs that seems to map onto the normal ways in which we as humans pass down our knowledge of technique. Third, *variety, complexity, and standardization* of tools, techniques, and forms of tools may also be important. Chimp tool-kits and the vast array of New Caledonian crow tool use, making, and standardization seem to fit within this set of criteria. Other animals perhaps show less diversity of tool-use and -making, but the *techniques* of cetaceans might also be considered complex and varied. We might also consider spider webs as complex and specialized objects, certainly standardized. Fourth, we might consider whether forms of tools or techniques *improve or change over time* and whether innovative behavior takes place. Chimp examples of this innovation (Kanzi is best known), as well as cases of crows and rooks who are able to solve problems with material solutions (Betty the crow), exist. Fifth, we might take into account *cognitive abilities*; this goes along with the first criterion of intention or planning. Much of the current research on birds and cetaceans relates to their cognitive capacities – that goes beyond tool use and into the roots of empathy, the capacity for understanding, the anticipation of intentions in others, etc. Sixth, we might take *causal reasoning* as the most important part of tool use: that the use of tools demonstrates physical causal reasoning like no other characteristic. Great apes, Capuchin monkeys, and some birds seem to count as causal reasoners, as demonstrated in their sequential use of tools for a purpose (metatool use) and some understanding of 'folk' physics.

Some may object to the far reaches of the many criteria and cases I have set up here. Some researchers refer to the fact that simple behaviors, "such as the use of an object (or objects) as shelter [that] are not generally regarded as tool use, because the shelter is effectively in use all the time, whereas a tool provides no benefit until it is used for specific purposes" (Finn et al. 2009). This is why birds' nests and dens are not usually considered tools. This definitional limit rules out hermit crab shell use and dolphin sponging because both are consistently attached in their functional use when being handled (bodied or nosed, respectively, in these cases). This limitation also brings into question the consideration of beaver dams and spider webs as tools.

Given the requirements of production and manipulation in the case of dams and webs, these constructions have at least some of the traits typically associated with tools – they are made and useful and complex and have some level of standardization, which can also be said of hermit crab shells and birds' nests, as well as a host of things that rarely, if ever, get considered as instances of tool use. My aim is not to defend a certain definition of tool use. We can consider these definitions and delimiting objects and behaviors alongside one another to produce a range or map that accounts for all these sorts of behaviors, behaviors share a family resemblance.[76] Where one might have tool use begin or end may depend on what line or set of criteria one cares to identify, and I would like to expand this map of technological behavior to also include other construction behaviors because of the family resemblance these items share. There are overlapping characteristics shared by technologies and technological behaviors, though there may be no essential feature.

Though humans have often pegged tool use as special and important in separating human from animal, Mike Hansell and Graeme D. Ruxton, ecological biology

[76] To borrow the term from Ludwig Wittgenstein (1953): Wittgenstein discusses games that share many features in common, but there is no one characteristic that helps us identify the entire class of games. They share a family resemblance. The same might be said of technologies.

researchers, have argued that the line between construction behaviors and tool use is far less clear than it has been depicted. In "Setting tool use within the context of animal construction behaviour" (2007), they argue that there remains little reason to consider tool-use as categorically different from other construction behavior in the animal kingdom, considering such a separation as arbitrary. I would argue along their same lines that any good (meaningful, useful) categorical distinction between tools and technology is arbitrary.

Construction Behaviors and Tool Use

We should not bar spider webs and beaver dams from consideration on a graph of technological behavior. Literature on animal architecture is relevant to many discussions of tool-use and technology. If a philosopher wishes to describe the construction process, he must do more than look at human construction – because animals construct all sorts of things, whether or not these implements get considered tools or technologies. The definition of tool use most often referred to in the literature is Benjamin Beck's; it stipulates that a tool is an object that is not part of the animal itself, is not attached to the environment itself, and can be manipulated to achieve some outcome (Beck 1980). Tool use alone, by this definition, indicates no prerequisite cognitive ability (Hansell and Ruxton 2007, 74), though it is often conflated with intelligence in common communications on the matter – a side-effect of human-claused definitions of technology.[77] Tool-users themselves are often considered more advanced in some respect, which is perhaps a product of the human clause in definitions of technology and discussions of tool use.

Animal architecture expert Mike Hansell develops an account of animal construction behavior that he thinks should be better situated within a wider discussion of tool use (Hansell 2007, Hansell 2005, Hansell and Ruxton 2007). The common attribute, according to Hansell, of animal architecture is that animal constructions (beaver dams, spider webs, bird nests, etc.) “extend the control of the builder over some aspect of the environment” (Hansell 2005, 1). Definitions of technology seem to highlight this very aspect of construction behavior – technology is somehow meant to extend the control over one's environment or world.

Carl Mitcham, in *Thinking Through Technology*, quotes Jose Ortega y Gasset, who wrote that “human beings are technical, are capable of modifying their environment to fit their sense of convenience...” (1994, 56). He also quotes Martin Heidegger: “Humanity humanizes the world, injects it, impregnates it with its own ideal substance...” (ibid., 56-7). Historians of technology Melvin Kranzberg and Carroll W. Pursell, Jr. have called technology “man's efforts to cope with his physical environment... and his attempts to subdue or control that environment by means of his imagination and ingenuity in the use of available resources” (1967, 4-5). Historian Thomas P. Hughes titles one of his books “*Human-Built World*,” as if to emphasize humanity's construction of environments

[77] Frederick Ferre, in a vein that encourages the tradition of conflating intelligence with the use of tools, defines technology simply as “practical implemented intelligence” (1995, 140).

(2004), and engineer and historian Henry Petroski has entitled one of his popular books "*Remaking the World*," highlighting the ways in which engineers have remade the environment (1998).

Don Ihde, in *Philosophy of Technology* (1993), explains that modification to the environment, though not uniquely human, can be extended with technological capabilities:

> Even without technologies animals, and ourselves as human animals, modify at least local environments. And lions modify the very local environment of the sand by making the funnel shaped holes into which their prey may fall just as humans, in building shelters, modify environments, whether minimally as with desert nomads, or maximally as with contemporary urban dwellers... Technologies, however, allow this modification to be amplified or magnified. (51)

Beaver construction behavior – dam building activities – go far beyond many of the modifications made by desert nomads. Beavers are the scourge of wildlife resource managers for this reason: they wreak havoc on just those environments that wildlife specialists try to maintain, preserve, and protect. Using the amount of environmental modification as a guide for technological or construction behaviors creates problems, especially if you incorporate the size of the organism with the scale of its modification![78]

---

[78] This is not to say that human beings don't have a very large impact on the environment. Indeed, we've crapped up the atmosphere and have caused other major environmental damages and serious modifications. However, I would still maintain that using environmental modification will be inadequate as a scale for technology since, scaled to body-size, a few humans may cause less disruption

Richard Dawkins discusses how an extended phenotype can manifest itself for miles: "Just by talking about a few examples of animal artefacts [webs and dams], then, we have pushed the conceptual range of the gene's phenotype out to many miles" (1982, 200). Mike Hansell also notes that the "height of a large termite mound is the equivalent of three times the height of our highest buildings" (2007, 180).

Hansell works to reconsider nest building, spider webs, and beaver dams as belonging beside other forms of tool use identified by Beck, like woodpecker finch stick-tool making and chimpanzees using tools for termite fishing (Hansell and Ruxton 2007, 74). Both Beck and Hansell still exclude sea gull mollusc-shell dropping (to crack open), chimp fence-climbing to reach food, elephants rubbing themselves on trees[79] (ibid.). Hansell offers a definition of construction behavior that includes two parts: (1) "something must be constructed" and (2) "it must necessitate behavior" (ibid.). By this definition, sculpting and burrowing to make nests would count as construction behaviors, as would dolphin sponging for foraging, crow and rook stick and leaf tools, spider web building, etc. Construction does not require intentionality or learning, something harder to measure or judge, only behavior. By treating construction and tool-use as different behaviors, Hansell and Ruxton argue that two distortions are made. First, construction behavior is left out of discussions of the evolution of intelligence, when such information might prove relevant and helpful to such discussions. Second, construction behavior has

than a few beavers. It seems as if the scale of modificaiton may or may not be related to the sophistication, complexity, and intentionality . And sustainable technologies would not have as large a footprint.

[79] And the same for cows preening on sticks, I'd imagine.

not received attention that it deserves as a topic of study because of the focus on tool use over construction. Both these constraints are to the detriment of evolutionary biology, more generally, and evolution of intelligence, more specifically (ibid.) because their classification excludes them from interest in many studies that would benefit from their inclusion. Even when a species has both tool-use and construction behaviors, the construction behaviors often go unexplored because of the emphasis on tool-use and intelligence (ibid., 74-75).

Hansell and Ruxton explain that construction behaviors often involve *more* complexity than tool use or making:

> Consider the nest building of the red-headed weaver bird... To make its nest of fresh 'green' twigs, this weaver bird first trims the leaves from a twig, then breaks it away from the main stem in such a way as to include a long, flexible strap of bark projecting from the broken end. This strap is then wound round the end of a narrow tree branch so that, on drying, the twig is firmly attached. Drying bark straps are the principle by which the whole nest is held together. The bird now attaches more twigs to form a stout nest attachment hanging below the branch. Below this a globular nest chamber and a downward-directed entrance tube are added. In the light of this, we have no reason to suggest that as a generality tool use will require higher levels of cognition than other construction behaviors shown by the same or closely related taxa... *it is important to avoid the presumption that*

> *all construction behavior (and indeed all tool use) requires a similar level of cognitive complexity.* (ibid., 75, my emphasis added)

Most people consider nest as constructions which require little intelligence, a product of instinct. However, at least for some species, like the weavers described above, "there is experimental evidence of a significant learning component to nest building" (ibid.). And, for bowerbirds:

> [t]here is also good circumstantial evidence of a learned component to bower construction by male bowerbirds... [who, as juveniles,] habitually visit the bowers of mature males and observe their behaviour over a period of five or six years. (ibid.)

Not all construction behaviors, nor all tool-use, require the same complexity. In many cases, construction behaviors actually demonstrate a greater flexibility and more complexity than cases of tool-use do. Therefore, when constructing a map of technological behaviors, putting tool-use and technology on the same plane, we should also place construction behaviors within the same realm.

I count spider web construction on one far end of one axis of technological behaviors, at least insofar as they require know-how: webs certainly fit some of the criteria of a tool, or at least of a construction: they are external objects that help aid their makers, they demonstrate a significant level of complexity and standardization (though genetically dictated). But webs fail on a number of other possible criteria: they don't seem to be the product of intentional behavior, and, as such, demonstrate no innovation or creativity or ingenuity or simple improvement over time, and they are not the product of a material culture or social learning, as we might see with some nest construction.

Picking Up Tool Use

Computer Scientists Robert St. Amant and Thomas E. Horton, in "Revisiting the Definition of Animal Tool Use," also suggest that Beck's definition of tool use is inadequate, not on the grounds that it does not properly include construction behaviors, but because it fails to account for behaviors that "mediate the flow of information" (2008, 1199). Motivated by the cases of dolphin sponging and tool use observed in gorillas (using a stick to test a water's depth before wading through), St. Amant and Horton explain that, popularly, these instances have been regarded as tool use, even though Beck's definition would simply rule them out (ibid., 1200). Additionally, these two researchers worry that detachment – one of Beck's necessary conditions, that a tool is something that can be moved around – should not be a necessary condition of tool use. While detachment may be *useful* to the tool-user and may be the case with most tools, it should not be a critical part of the definition of tool use, according to St. Amant and Horton (ibid.). They would have us think that, in many situations, a tool acts "as mediating information flow between organisms," citing for example the implicit communication of a brandished stick (ibid.).

St. Amant and Horton attack every portion of Beck's three-pronged definition: detachment, alteration of the object, and alteration of the environment. First, while tools are often detachable, this is better regarded as a contingent property, and not a necessary one (ibid., 1201). They give three scenarios from the bird studies literature about experimental apparatus – Beck's definition would include only one of these scenarios, although they all work by the same principle. All the examples have to do with pulling on a string with either a reward or a hook to use to get a reward, so the action used by the subject of the experiment is the same, though the use of a tool would be dissimilar on Beck's definition. St. Amant and Horton explain that:

> Part of the problem in these two scenarios [one that involves pulling up a reward bucket through a transparent tube and the other that has a hook with which to grab a bucket] is deciding what constitutes an object. In simple cases, the property of being unattached from its environmental substrate is sufficient to define an object, but in other cases this poses problems, such as deciding whether some composition of materials should be treated as a single object or multiple objects... [M]anipulability of an object is a more informative indicator of tool use than whether the object is unattached. (ibid., 1201)

These authors give further examples – one where an elephant sprays water from its trunk to cool itself and another where a chimp cups water and splashes it on its body. They maintain that Beck would accept the elephant example as tool use, but reject the chimp example, but think this is extremely counter-intuitive.

The second condition Beck formulates for what counts as a tool is that the condition that an object or organism must be changed by the tool's use. I think here of cows using sticks to preen. While it may not meet the other criteria Beck sets forth, cows are arguably changing their condition by the use of the stick: they reduce parasites through this use of an external object. St. Amant and Horton refer to an example of a chimp finding a hat and placing it on his head – this meets Beck's definitional requirements, for the chimp has altered his own state, but few would think of this as tool use. For this reason, St. Amant and Horton tighten this second condition of Beck's definition to rule out behaviors like this hat-monkey scenario. They explain that "[a] plausible resolution of this problem is to view tool use in terms of dynamic, mechanical interactions rather than alteration of general conditions" (ibid., 1202). In the case of the chimp with the hat, the hat may change the chimp's state somehow, but not enough is done to "produce dynamic interactions between the candidate tool and the environment" (ibid.).

The third leg of Beck's definition is that an environment must be altered somehow by use of some tool. St. Amant and Horton describe three scenarios of vultures dropping stones – one onto an egg where the egg is successfully cracked open, another where the impact is not enough to crack the egg (a failed attempt), and a third in which the stone misses the egg (ibid.).[80] They claim that Beck would only count this first action as tool

[80] What St. Amant and Horton describe relates well to literature on the failure of design in philosophy of engineering. In engineering, we might very well describe the way an intended structure or design was supposed to work out – and then explain how the intentional action did not lead to the intended result. In fact, more often than not, engineers are stymied in the design process, having to seek new materials or revise designs to properly meet new specifications, whether financial, physical, environmental, or even social. The intended outcome or goal of a design still works toward something, even when that

use, but it seems like we would want to count the other attempts because the physical actions (and *intent*, if we dare read that into the situation) remain the same, despite differing outcomes (ibid.). The authors explain that:

> [W]hen Beck's definition specifies that tool use requires 'the proper and effective orientation of the tool', we automatically fill in a dynamic, mechanical account. This shift is enough to capture our intuitions about these scenarios: in each case, the behaviour involves manipulating or dropping an object to generate an impact on a target.... even if the target is missed, the goal of producing the impact is apparent. (ibid.)

St. Amant and Horton hold that there are two factors that go neglected in Beck's account of tool use (as well as similar definitions proposed by Jane Goodall and John Alock): first, these definitions seem to leave out the importance of *goals* in the use of tools, and, second, these definitions neglect the need for *deliberate control* over the object (ibid., 1202).

Both of these criteria emphasized by St. Amant and Horton point to intention as important to what constitutes tool use. They think that, even when the actions by animals are the same – wasps pounding a pebble into the ground to compact the ground and chimps holding a stone and pounding a nut, both resulting in pounded ground – the goals and understanding of action can differ widely, and that these differences matter (ibid.). Deliberate control over an object, and not just goal-oriented behavior, matters to whether

---

goal may not work out. We still call failed technologies 'technologies'. Likewise, we should call tools that fail to produce the intended result 'tools'.

we should consider something a tool; accidentally breaking off a branch should not count, while actually dislodging a branch for some purpose should (ibid.). St. Amant and Horton actually suggest a continuum for describing control:

> We can see differing categorizations of these examples as falling along a continuum of control. In Beck's definition, the control component of tool use falls under a binary criterion: is the candidate tool user responsible for the orientation of the external object or not? We think that this is overly restrictive, that the degree of control an animal applies to a candidate tool object influences the categorization of a behaviour as tool use or not. As interactions move from being accidental to incidental to controlled, a behavior approaches the category of tool use. (ibid., 1203).

Note that "*behavior approaches tool use*" – it is not so much the object that counts in their scheme of things but how it is employed in intentional action. With these two stipulations – one which points to intentional behavior and the other which points to controlled action[81] –, St. Amant and Horton provide a revised definition of tool use. This dovetails with Hansell and Ruxton's account of construction behavior because both sets of authors reject Beck's definition, in part, on grounds that it does not reasonably accommodate groups of things that we would like to think of as on par with the sorts of things considered under Beck's original definition. St. Amant and Horton give their definition more formally:

[81] Though "intentionality" is not part of the language they use, they prefer to talk of goal-orientation.

> Tool use is the exertion of control over a freely manipulable external object (the tool) with the goal of (1) altering the physical properties of another object, substance, surface, or medium (the target, which may be the tool user or another organism) via a dynamic mechanical interaction, or (2) mediating the flow of information between the tool user and the environment or other organisms or the environment. (ibid., 1203)

Hansell and Ruxton might not accept the part about the tool being freely manipulable, but the construction behaviors in which they are interested do alter physical properties of the environment and mediate a flow of information between the builder and the world. St. Amant and Horton concede that “tool use arguably does not constitute a distinct category of behaviours” (ibid., 1207). This new definition accommodates the examples of a chimp testing a water's depth with a stick and dolphin sponging – the environment is not transformed, but there is a flow of information, use of a tool to make a determination or to feel along a surface (ibid., 1204). Both of these real scenarios present a “mediation of sensory input” (ibid.). These movements against Benjamin Beck's original definition of tool use highlight the importance of both information and intention. I address both of these categories – information and goal-orientation, as they relate to constructions, tools, and technologies – in the account I provide.

Integrating Two Types of Technological Knowledge

Tools and technologies often act as mediators of knowledge, knowledge of a world or environment between an artifact and its user. Information alone is never enough to constitute knowledge. Without proper environmental or cognitive context, information has no meaning. The information of how to build an orb web resides within the genotype of an orb web spider and manifests itself in the world as an extension of the spider itself. The information is given a context – a physical space in the world – without the spider necessarily knowing that this information is made manifest through its spinning, nor designing the web in the way we typically think about design in engineering (the design is "programmed" in some sense). However, a gorilla using a walking stick to test a water's depth seems to involve an informational flow from the test object to the gorilla, providing information that may serve useful to the gorilla as she attempts to cross a pool of water (Breuer et al. 2005).

That the gorilla in question ("Leah") repeatedly tested the depth with her walking stick as she walked through the pool only strengthens the idea that this action was not accidental and was goal-oriented (ibid., e380).[82] It would be appropriate to call this stick a measuring device (since that seemed to be its function) and to call what the gorilla infers from her test of the waters as knowledge.[83] We might also refer to the demonstrated use of this technique as know-how on Leah's part.

---

[82] One may object here on the grounds that Leah would not be able to express her goal, but there are plenty of cases where users and designers of a technology cannot explain why they do the things they do, so I'd like to dismiss this objection straightaway.

[83] Once again, it doesn't matter what Leah would call it. We can talk about the printing press as a technology, even though the term 'technology' did not enter the vernacular until the last century. Not a problem.

There are two large categories of technological knowledge that I have discussed – knowledge residing in the maker/user/designer[84] (knowing-how, know how, or technological knowledge) and knowledge instantiated or encapsulated within the object (a.k.a. “thing knowledge”). We can consider each of these types of technological knowledge – know-how and 'thing knowledge' – as axes of interest as we map out technological behaviors. Some behaviors require more or less skill or learning than others, just as Edwin Layton has discussed the know-how of typists and great engineers (1974). Obviously, the sets of knowledge these two groups of people contain different elements and contexts; they also differ in the amount of training necessary and the amount of skill required. Not everybody would be equally proficient at typing or engineering even with equal training, so this knowledge requires more than simple learning. Skill plays a major role in whether someone can be said to have know-how. Finesse is necessary to performing some tasks properly: in some scientific laboratory settings where some experimentalists simply have “the touch” with an instrument or apparatus. Some people who, though once interested in experimental science, end up in

[84] In the case of bees and ants and other building insects, there may be no maker/user/designer, but a configuration of the group that leads to some constructive project. Social hunters, like in lion prides, employ group hunting techniques, like dolphins. Because many human technological projects are also collaborative, I think these collective constructions can be handled in terms of technological knowledge/information, though I don't discuss them at length here. In these cases, the know-how or knowledge would be held by the collective, not the individual. Individuals may have some part of the knowledge – just as engineers working on a large building project usually work on or specialize in one component – plumbing, electrical, structural, etc.

another field because they lack a certain knack for tinkering, a skill set that cannot be put into words. Something similar might be said about specialization of dolphin foraging techniques: some techniques that individual dolphins prefer may reflect skill and experience. Know-how is not merely a product of learning, but often also sometimes involves some skilled component.

"Thing knowledge," imported into the context of animal cases, might be better described in terms of *encapsulated information.* 'Knowledge' seems to imply that someone knows something. In the case of Davis Baird's 'thing knowledge', instrument makers and developers understand the principles at work in their machines (even if they cannot properly describe them in propositional terms), but this knowledge is represented, instantiated within a material form (2004). This material form, a scientific instrument for Baird, bears knowledge of the world or theory it attempts to model. Information implies that there may or may not be some knower present. Indeed, Baird talks about how scientific instruments come to "de-skill" processes that once required skill or training. De-skilling allows less skilled technicians and workers to produce results or images or data without an understanding of the principles behind the operation of every part of the instrument. Indeed, many labs have the results of their apparatuses interpreted by computerized set-ups, with code often written by large instrument companies, rather than by skilled workers within the laboratories. The knowledge needed to, say, read the data from an instrument is no longer necessary with such de-skilling. The data can be integrated and presented in a way that can be understood without the same level of training or skill or work.[85] Built-up experimental apparatus, like many measuring and imaging devices, offer a way to do the work without the knowledge once required for the task. These devices still require some skill or training, but the instrument performs some of the work, with the information encapsulated by the device.

In Chapter 3, I discussed the way in which Baird separates function from intention. Intention can be best captured by know-how in technological knowledge – one cannot really know *how* to do something if he does not know *what* that something is, if one does not have some sort of goal or direction in mind. Intention fits interestingly alongside discussions of the role of knowledge in animal construction and tool use. Spider web construction cannot properly be said to stem from the know-how of the spider, but we could make some claim about the information required in web construction. This information that the web-building spider harbors (from which he builds a web) cannot be said to have a knower (or at least the spider is not the knower); it's useful to speak of information rather than knowledge. Claims about information are easier to establish than claims about knowledge. We can also think of encapsulation of information (something along the lines of Baird's 'thing knowledge') as a continuum or spectrum of possibilities. Some blueprints are more complex than others, some technologies and constructions require more information to build and to use than others.

85 I'm thinking here of computerized, commercialized probe microscopes, contrasted against the requirements of early probe microscopies, something Davis Baird has actually written about elsewhere. See Baird and Shew 2004.

Conclusions

In this chapter, I discussed the definition of tool use – and some objections that might lead us to reconsider some animal artifacts and constructions as worthwhile to place on a map of technological behaviors. Ihde says that "[d]efinitions are *not neutral*" (his emphasis, 1993, 47). The definitions of construction and tool use and technology offered by biologists and philosophers are not neutral and definitely give a human-centered image of tools. Tool use remains an unclear concept, one still subject to great amendment. Relating construction and technology – two things we already see a related in important ways, though not in any formal sense[86] – along the lines of technological knowledge allows for more cross-talk about what lines we really do want to draw. More importantly, it makes those lines we wish to draw explicit – so that we can be careful not to cover up relationships that are truly conceptually alike. A full-bodied approach to epistemology of technology requires that the assumptions made in our demarcation of technology are clarified. What I offer in the next chapter maps out animal cases and human cases – often different in degree – along the same conceptual lines, conceptual lines imported from philosophy of technology.

[86] There's a family resemblance between constructions, tools, artifacts, and technologies.

Chapter 8: Niche, Environment, and Unifying Technological Knowledges

An evolutionary history brought about the traits we have as human beings. The categories we have – of body and of brain – remain products of that history.[87] The same is true for other species groups and other categories. Evolutionary pressures can bring about similar adaptations between two populations that are not necessarily related or that are not trying to fill out niches in the same environment. We see examples of similar bird-beak curvature among bird species that are not as closely related that have similar food sources, but are in different regions. We have also touched on similar brain structures in humans and dolphins back in Chapter 5. Even without similar environments or pressures, similarities in terms of structures and capabilities occur. New Caledonian crows and rooks can perform similarly on tests of intelligence and tool use in captivity, but only one group actually uses tools in the wild. If tools are so incredibly useful and provide a survival advantage, how could this be?

New research actually suggests that the use of tools, in many cases, confers *no survival advantage* for some species (or even a negative one!). Rooks do not need to use hook tools in the wild – because they do not need to extract their prey from any space that would require a hook. Their environmental circumstances are such that they have no need to fashion tools or use foraging strategies that would employ a tool set. In fact, the fashioning of tools might actually slow them down (or physically weigh them down),

---

[87] Ruth Garrett Millikan discusses this at length in her *Language, Thought, and Other Biological Categories* (1984).

making them more vulnerable to predators and making it harder to quickly nab prey, negatives in terms of survival outcome.

When Tools Aren't Useful[88]

The literature on technology and tool use often contains as an assumption that tools are useful for the survival of their users, with researchers trying to figure out how a tool or technique helps an animal perform some task, how the task confers some survival value. In other words, what does the animal (or person) get from the use of a specific tool? What survival advantage does that tool confer? However, tool use doesn't always confer an advantage; the lack of tool use we see in the animal kingdom reflects this fact more than a lack of intelligence on the parts of different species of animals. Hansell and Ruxton explain that:

> To use a tool, the bird must hold it in its beak; thus in using a tool, the bird is sacrificing the use of the organ specifically adapted to foraging. There might be only a few contexts in which a tool is superior. Most examples of tool use do involve manipulation of the tool during use. It is therefore interesting to note that, although crows and finches provide the most numerous examples of tool use in birds, the parrots, noted for their general intelligence, provide few examples of tool use in the wild. A possible explanation for this is that parrots, with their ability to grasp objects in

[88] Which happens to be most of the time.

> their feet as well as to manipulate them with their beaks, find few circumstances in which a tool would offer an added advantage. (2007, 77)

In this way, *tools simply aren't useful* in a variety of environmental contexts, especially given the physical capabilities and environmental pressures (competition or predators) of many species. Constructions are more widespread in nature than tool use. A stumbling block to our considerations of technological behaviors in animals is that we expect their constructions to look like ours. Our deep interest as a species in chimp behavior points to this obstacle – we like to see the interesting things our "cousins" can do, and we can understand what they are doing as they employ tools (Hansell 2007).

What counts as important in our own lives should not be our expectation of other species. Context matters, and evolutionary histories take place in a context. Hansell and Ruxton argue that "tool use has had little evolutionary impact" in contrast with other construction behaviors (2007, 77). Tools "are generally not particularly important to animals, in ecological or evolutionary terms" (ibid.). These animal architecture researchers think that tool use is likely "more special to researchers than to the animals that use them" (ibid.). Given the emphasis put on tool use and technology, and its importance to our humanity or our set of defining characteristics, this is not unlikely. "The Human Edge" series broadcast by NPR definitely points in that direction.[89] We emphasize technologies because we are so adept with them.

Why, then, have I chosen tool use as an avenue of investigation? The answer is that it *is* so important to *us humans* – and we perhaps have more to learn about our work

[89] With its impressive human fingers, no doubt.

in the world when we contrast it against the sorts of tools used by other species in the world. We can better situate what it is *we* do with technologies and how *we* categorize the things we do when examined alongside what it is that other creatures in the world do. I want to enlarge the scope of consideration from simply tools to other constructive behaviors and techniques. Our work can only be properly understood in the context of other work – work not limited, at least in terms of anything fundamental, by detachability or material production. The topic of tools relates well to both construction behavior and technological behavior; no good demarcation point between these two types of behavior exists. Technological behavior often aims at the construction of something, at least for human beings.

Considerations in Developing a Map of Technological Behaviors

I acknowledge a great range of technological behaviors (and I'm now going to use that term as encompassing construction behaviors also, or use them interchangeably). Not all technological behaviors involve an artifact or tool; instances of tool use are simply the easiest to spot, since we humans are always on the look out for tool use, and animal studies have recently reported more tool use among animals than once imagined. Several things should be kept in mind before examining the map I propose.

First, we should *not* necessarily infer intelligence or flexibility from the use of constructive or technological behaviors. As humans, champions of technology, we often make this leap (from tool use to intelligence), but there are many examples in nature of construction behavior that wouldn't be considered intelligent or learned. Rather, like a spider's web, building behavior can stem from a more structured, inflexible process than a trial-or-error or learned technique. Mike Hansell goes so far as to label one of his chapters “You Don't Need Brains to Be a Builder” (2007). Instances where we would not infer an animal's intelligence in the midst of tool use exist; laboratory studies (and even some good inferences from wild behaviors from people who spend a very long time studying a particular species) can lead to claims about intelligence. However, not every example of technological behavior I put on the map stem from a creative or intelligent source. In fact, I chose some examples that do not seem to demonstrate intelligence or learned technique for this very purpose: to show this contrast. However, these technological behaviors can still be mapped along the same axes of interest.

While sometimes further study is necessary, with experiments that try to tease out the learning processes in action for animals, we may even be able to infer intelligence and decision-making in animals, especially in animals with which we have experience and understanding. For instance, inferences of intelligence that come from years of observation done on chimps and gorillas, both in captivity and the wild, seem reasonable. Or, for a domesticated animals, like dogs, our species' histories may have so long been intertwined that we are better able to make sense of and respond to one another. Writer Ted Kerasote explains that,

> Those studies [on dolphin, chimp, parrot, etc. communication] have corroborated what I've felt about dogs for a long time – that they're speakers of a foreign language and, if we pay attention to their vocalizations, ocular and facial expressions, and ever-changing postures,

> we can translate what they're saying. Sometimes we get the translation spot-on ("I'm hungry"), sometimes we make a reasonable guess ("I'm sad"), and occasionally we have to use a figure of speech to bridge the divide between their culture and our own ("I love you so much, my heart could burst").
>
> Dog owners who hold "conversations" with their dogs will know exactly what I mean. Those who don't – as well as those who find the whole notion of conversing with a dog absurd – may want to consider that humans have shared a longer and more intimate partnership with dogs than with any other domestic animal, starting before civilization existed. (2007, 10-11)

When our evolutionary history has coincided for a long time with that of another species, like dogs and cats, we can make especially good inferences about what that animal wants or needs, or *what an animal is trying to do* – in part because that species' history (*especially* for domesticated animals) has made that animal better able to communicate to human beings about their states.[90] Because context matters to how an organism acts, it won't always be possible to judge whether some object or action is the product of learning or a shared culture. These things can be difficult to test, and there simply won't

[90] You might be able to understand from your dog's drools and intense stare as you eat a steak that your dog wants steak. To say that you understand your dog's intentions – to get that steak by means of looking cute and/or pitiful (it has worked before) – is something I think would be a reasonable inference. These sorts of inferences, of course, require experience on the part of whomever is making the inference.

be enough information about some of the material products and techniques of non-human animals for us to judge how something should be situated in relation to other things on the map.

Second, and a corollary to the first point, we should not expect every intelligent species to make or use tools to construct things. Though people often (incorrectly) look for as a hallmark of intelligence, tool use or construction behaviors on their own actually tell us very little beside the fact that the development of this particular skill or technique proved advantageous in a given evolutionary history or environmental context.

Third, the map I provide does not a rank species or objects (by whatever criteria one wishes to judge tool use). As we've seen in the lab studies, rooks are surprisingly adept tool users – but their tool use is witnessed only in captivity. Some species that can use tools or demonstrate techniques unseen in their natural habitats perform well under the right conditions, but we just do not know or have not done the laboratory studies or have not set up the right situation or context to determine whether the animal could be a tool user. Additionally, the map of technological behaviors I propose arranges only particular *instances* of construction or technique or tool use, not all the *possible* construction behaviors of a given species. For this reason, New Caledonian crows can appear several times for their many different constructions and behaviors: they have to be placed in different places on the map for different things they do and make. Not every object they create encapsulates similar levels of information or know-how – something that can equally be said of human-made things.

Handling the mapping of behaviors in terms of individual technologies or techniques makes more sense than providing a map that ranks individual species. Even for humans, some of our tools and technologies require more or less know-how than others; we would not expect the wedge to be considered on par with the printing press – *we might not even consider all printing presses on par with one another in terms of operational skill necessary*. Some printing presses may be automated or require more or less training on the part of the operator (perhaps the press has been de-skilled). In the same way, not all cars require the same amount of skill or know-how for driving: I would have a very difficult time driving a car with manual transmission, even though I have no trouble with the automatic transmission. I lack the proper skill or know-how to use one with a manual transmission. We might say something similar about the technologies and techniques of New Caledonian crows – some tools requires fewer steps or less finesse to make or to use. The account I offer here has two dimensions, two different brands of technological knowledge: know-how and thing knowledge serve as the x and y axes of the graph on which I map technological behavior. I described these axes in Chapter 3.

Principles of Ordering

More formally, we can use several criteria for considering where to place technological behaviors on the map. These judgments are qualitative. In some cases, researchers may not have performed enough study to indicate where an object or technique should appear on the map, and we may only be able to make our best guess – or no guess at all. Furthermore, the environmental context of a technique or construction matters and evolutionary history of the species count as important in our determinations of where technological behaviors fall on the map. We humans often read our own interests into the situation – it is why we are interested in tool use at the outset. The ordering I suggest consists of individual techniques and constructions, and therefore provides no hierarchy of being or ranking of species. As witnessed in the cases of rooks, some species might actually perform well under the proper conditions while they have no such tool behaviors in their normal context. Many species that might be quite intelligent will fail to show up on this map at all, either because researchers have witnessed no techniques or tools among the group or the appropriate contexts have not been observed. Some creative, social beings might go unrecognized and unreported on the map. The map serves only to situate actions in terms of technological knowledge – it shows the relation of know-how to encapsulated information for a given technology, integrating these concepts. This integration allows for a wider array of techniques and technologies to be situated together and discussed along the provided axes. My use of animal studies has been instrumental in creating this graph because of the more subtle distinctions that can be captured by looking at non-human tools and constructions in concert with human ones.

The axes of know-how and encapsulated information have different criteria or principles for ordering. Throughout this dissertation, I refer to a wide range of criteria that are taken as important to the using a tool (knowing how): problem solving, learning, cultural transmission, metatool use, folk physics, causal understanding, ingenuity, creativity, innovation. We can judge know-how by these signposts. Something plotted at 0 on the x-axis (know-how axis) would indicate that the behavior that led to the production or use of some artifact did not involve the use of any of the criteria. The problem that a spider web solves (catching prey) isn't actively solved by the spider, but by a genetic expression that the spider then calibrates to the world. Web construction fails to meet the rest of the list. Beaver dams might be situated a little further out from 0 than spider webs: beavers are problem solving, but the problem they solve (dampening a maddening noise) is not what we would have expected.[91] What weavers do in building their nests involves a learned component, something culturally transmitted. They would rest a little further to the right, indicating more know-how. Whale songs are situated past that since they involve cultural transmission with changes over time; these changes cannot be called innovative (since there's no new method of singing introduced), but they do follow a learned, shared pattern. Many of the techniques of dolphins could be situated past this: dolphins techniques demonstrate a higher level of social and cultural transmission, as well as the use of causal understanding, creativity, and sometimes even innovation (the sponging technique, for instance). Chimp tool kits could be placed in the same location as dolphin sponging since these also involve cultural transmission, something like a causal understanding, creativity, and possibly innovation. Crafted crow tools, with their standardization and variety, also demonstrate advanced tool making and an understanding of folk physics and causation. Human tools like the the wheel indicate a

[91] We shouldn't expect that what matters to a given animal will also matter to us humans. An animal's goal and context matter to whether we judge a behavior to be socially transmitted, creative, etc.

similar standardization, use of causal knowledge, and often involve the use of other tools (metatools) to produce the artifact of wheel.[92]

On the y-axis, encapsulated information, we can talk about increasing levels of de-skilling as a way to judge where an artifact and associated behavior belong. Encapsulated information allows for a task to be performed with less understanding necessary. Spider webs, though they remain relatively low in terms of know-how necessary for construction, actually encapsulate information about the world and the spider's situation. A spider need not be skilled or trained in how to produce and use its web for successful functioning to occur. Beaver dams and weaver nests also encapsulate knowledge about the world, more than Leah the gorilla's measuring stick or dolphing sponging do. This difference in amount of information encapsulated has to do, in part, with the complexity of the artifact produced and used. While complexity and de-skilling do not map onto one another, the complexity of a creation often indicates that more information is presented within the object. Leah's walking stick and the dolphin sponges are fairly simple items, claimed from the environment and employed, relatively uncomplicated to make and use – if the animal knows how to use the item.

Solving Theoretical Conundrums with the Map

[92] Different wheels might actually be located in different places – depending on what is required of the user or maker to use or produce the artifact. Since the design of the wheel is no longer being improved, innovation and creativity would not be ascribed to its production or use.

My two-dimensional approach[93] to technological knowledge solves two of conceptual conundrums that have irritated me – (1) the relationship between two radically different conceptions of technological knowledge and (2) the relationship between biological and engineering design. This two-dimensional approach also allows us to deal with conceptual issues that stem from differing definitions of technology.[94] Some definitions of technology only count objects that involve some particular level of know-how and beyond (Ferre's "practical implemention of intelligence," for instance).

By putting know-how and thing knowledge (encapsulated information) together, we can map out the similarities and contrasts between constructive projects in terms of technological knowledge. I do not limit this map to physical objects or artifacts. I would also take social technologies, like language or the courts system or whale songs, to map

---

[93] Some people have asked: why only two dimensions? We could add other axes of interest when we talk about animal cases – intentionality, intelligence, etc. – but I focus here more tightly on technological knowledge. We could tease more out of these animal studies and create many possible spectrums that we be used as other axes. I use technological knowledge as a way to limit my project. Using these animal cases, we can formulate this graph to help us sort definitions of technology and unify two accounts of technological knowledge.

[94] While something is lost in the compression information into a graph or model or account – something is always simplified or reduced to fit – the compression I suggest here allows for a richer account of technological knowledge, one that takes into account the information in the user/maker and the information in the object. Sandra Mitchell writes in *Unsimple Truths* (2009) that: "We choose at what level of abstraction we represent the features of the world we are attempting to explain...There is the ontological reality, but there are also pragmatic choices about the representations we fashion to deal with that reality" (115).

out on this coordinate system too. Whale songs, while not resulting in a physically manifested object, do encapsulate some information of place and relation, and they require know-how that involves a strong social, learned component. Male humpbacks sing songs based on the regional group they are in, and these songs can change when new individuals are added into the social milieu. There may be objections to the inclusion of social technologies and techniques. I find dolphin foraging techniques and whale songs compelling examples of know-how, even if no material product can be referenced. Others have argued that social technologies should count as technologies because they act in similar ways as artifacts and can produce similar effects (Pitt 2000, for instance). I graph techniques on the same axes as other constructions and tools and technologies.[95]

The Map of Technological Behavior

[95] If readers have strong objections to their inclusion, well, they can just imagine the graph without the social technologies and techniques on them. This project does not succeed or fail based on their inclusion.

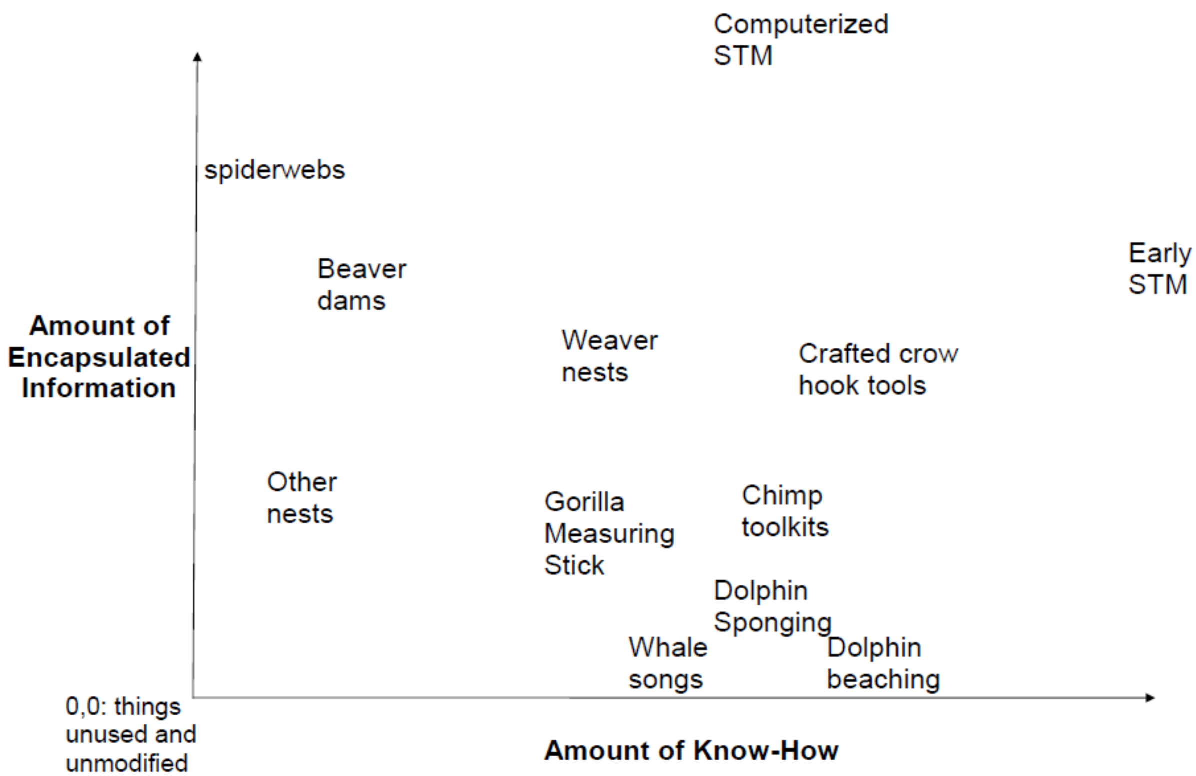

Figure 4: A Map of Animal and Human Tools, with regard to two types of technological knowledge. This image can also be found in the Appendix.

Encapsulated information is on the vertical axis, and know-how constitutes the horizontal. Some things require more know-how to make or operate than others: we can say that early scanning probe microscopies required much more user know-how than current computerized, commercial probe microscopes. Some things require more encapsulated information than others: computerized probe microscopes encapsulate more information than the early ones that had to be mapped out by hand did. Similarly, we can map out animal constructions on these *same* two axes. Weaver nests, for instance, require more finesse or know-how (indicated by the ways in which juvenile male wavers study nest building for years before constructing their own) than other nest projects, and the nests themselves encapsulate information about the environmental context and specific knowledge of the weaver. The same goes for dolphin foraging and hunting techniques. Some of these techniques require practice and skill such that they demonstrate a good deal of know-how.[96] Whale songs rank similarly in terms of know-how, but encapsulate less information.[97] For techniques, we'll often find that they rank low in terms of encapsulated information – no information is represented in a physical object in the use of a technique, mainly because it's rare that a physical object is employed with these techniques.. However, and perhaps apart from discussions of technological knowledge, we could discuss some sort of linguistic encapsulation on the part of dolphins and whales (if language is a tool, this might actually make sense within philosophy of technology).[98]

Beaver dam-building activity, initiated by a sound, may involve even less know-how than these other examples and more (biologically) encapsulated information. Beavers perform their dam building activities without a sort of know-how about the process – and hence we witness a side-effect of environmental damage not directly in relation to the dam, with trees felled in all directions. The relationships set up on this

---

[96] In fact, breaking down all the steps to these techniques and learning required for each would enrich a graphical representation like this. I could provide a more detailed graph on know-how in this manner. However, in the interest of staying on task, I've lumped their behaviors together – but, ideally, a more in-depth study of dolphin techniques could allow for a better picture of dolphin behaviors in terms of technological knowledge.

[97] We could argue about this. I don't think enough research has been done on whale songs about what the information communicates to make a resounding case for this.

[98] In fact, we could draw out a new graph, with linguistic representation/encapsulation versus know-how.

graph of technological knowledge are not on any quantitative scale, only resting in relationship to one another. I'm not sure how to really quantify these things, or if it would make sense to set up some sort of scale for this sort of thing. The axes I provide and integrate here help situate “natural” constructions against those of human manufacture. We can consider technological knowledge in two dimensions of interest, and we can map both the products and techniques of humans and animals on these dimensions.

Conclusions

My goals with this dissertation have been two-fold: (1) to argue that we can consider animal constructions as belonging in philosophy of technology and then (2) to initiate this consideration. The map initiates and integrates this work, and I've tried to highlight concepts of interest in philosophy of technology, like innovation and creativity and metatool use, throughout this dissertation, especially as I discussed the animal cases. Because I see no reason to separate the whole of animal construction from the projects humans make, integrating information from animal studies into philosophy of technology is an important move toward a more wide-reaching discussion of design, function and material culture. By looking at the things animals do and make, we can make more sense of the things humans do and make. Rather than thinking of ourselves as a special technologically-gifted species, we can see how our creations stem from our situation in the world, just as the things some animals produce (or fail to produce, even when they may be productive in other contexts) is situated within their environmental and evolutionary contexts.

In the past few years, technological knowledge has not been a hot topic in philosophy of technology, though it once enjoyed much more debate and discussion. As philosophy of technology moved from science-technology demarcation, the topic of technological knowledge, so often contrasted with theoretical or scientific knowledge, has enjoyed a lot less excitement. E*ngineering* knowledge has become a much more exciting program of research for many philosophers. Meanwhile, animal studies have enabled a wider discussion of tool manufacture and use, a discussion taking place outside of philosophy of technology. We can productively bring together discussions of the products of engineering and biology if we situate them in terms of technological knowledge. In this way, epistemology of technology has something to offer those in a much wider variety of fields as a way to sort out different animal constructions and behaviors. Movements already exist in animal studies to talk about tools and technology and their meaning; philosophers of technology can help clarify and integrate these issues.

A two-dimensional map of technological knowledge also allows for cross-talk between philosophers of technology about their definitions. In Chapter 2, I provided some excerpts from philosophers and historians of technology as well as anthropologists that show what a confused thing 'technology' can be. I provide no alternative definition of technology to defend here. If Joseph C. Pitt wishes to continue to push “humanity at work” as his definition of technology, my work does not counter his. It just seems to me that Pitt has set the bar for technologies such that only humans can make it – without any further look into the animal cases.[99] When Frederick Ferré gives an account of technology whereby technology is "the practical implementation of intelligence (1988, 26), we can actually take out the graph and set a bar along the horizontal axis such that only those actions that demonstrate a sufficient amount of know-how count as the practical implementation of intelligence.[100] Sociological approaches to defining technology – such as ones given by Don Ihde (1993) and Andrew Feenberg – often involve social or cultural interactions as important to what counts as technology or as technological. If we detach the human component, social interaction, learning, and change can still remain important to what counts as a technology. We can identify those items on the graph that involve learned components and cultural transmission. When we talk about the context of use, about "attempts to subdue or control" environments through the implementation of tools and technologies (Kranzberg and Pursell 1967, 5), we can do so in a way inclusive of non-human animals. Instead of considering humans as the only source of "imagination and ingenuity in the use of available resources" (ibid.), we can recognize the ingenious ways in which objects are created and employed in a more general way.

I am reminded of a satirical piece found in *The Onion*, entitled "Study: Dolphins Not So Intelligent on Land" (2006). In this "study," researchers took dolphins from their

---

[99] And, more damningly, to the exclusion of any intelligent, technologically-capable non-human species that we might encounter in science fiction scenarios.

[100] Keep in mind that the practical implementation of intelligence does not deny that those creatures, like rooks, that do not construct or use tools in the wild are intelligent. Rather, they are not practically implementing their intelligence in the wild.

tanks, put them on land in front of some obstacle courses to navigate by echolocation, gave them tests in reading comprehension and finding land mines, and more. According to one fake researcher:

> ... our study group offered only three types of response to every question we posed: a nonsensical, labored wheezing, an earsplitting barrage of unintelligible high-pitched shrieks, and in extreme cases, a shrill, distressed scream. ("Study:..." 2006)

Researchers note that the dolphins' learning curve was unimpressive – dolphins actually performed more poorly as the tests continued to be administered. The article ends with the following note:

> Many scientists believe these findings may help to explain why dolphins, for all their vaunted intelligence, have never developed technology or agriculture, or harnessed the power of fire – skills still exclusively the domain of *Homo sapiens*. (ibid.)

I spent the early part of this dissertation arguing against the use of a 'human clause' in our accounts of technology. We set up a system whereby the cognitive properties of non-humans cannot even be discussed when we tie intelligence to technology and technology to human beings. Only in recent years has there been a relaxation of the taboo against anthropomorphism. In some cases, not ascribing categories of mind and intention to non-humans is terribly unfair. *The Onion* article amusingly highlights the ways in which we often use our own experience and categories to "read" the behavior of animals such that non-humans are often set up for failure on human-made tasks.

Better research methods and observation – and simply more experience with some animals – have produced better animal studies that can make decent inferences about the capacities of some animals. Cases that surprise the researchers – like Kanzi's innovative technique for stone flaking, like the complicated crafting of hook tools by New Caledonian crows, and like Leah the gorilla's measuring stick – serve to demonstrate that the human-centered accounts shared by scholars about material culture and technology do not properly appreciate the material production of those outside of our species.

WORKS REFERENCED

Basalla, George. 1988. *The Evolution of Technology*. New York: Cambridge University Press.

Baird, D. 2004. *Thing Knowledge: A Philosophy of Scientific Instruments*. Berkeley: University of California Press.

———. 2002. “Thing Knowledge – Function and Truth.” *Techné: Research in Philosophy and Technology* 6 (2).

Baird, Davis, and Ashley Shew. 2004. “Probing the History of Scanning Tunneling Microscopy. “ In D. Baird, A. Nordmann, and J. Schummer (eds.), *Discovering the Nanoscale*. IOS Press: 145-156.

Beck, Benjamin B. 1980. *Animal Tool Behavior: The Use and Manufacture of Tools by Animals.* New York: Garland Press.

Bekoff, Marc, and Jessica Pierce. 2009. Wild Justice: The Moral Lives of Animals. Chicago: University of Chicago Press.

———. 2009 (October 18). “Moral in Tooth and Claw.” *The Chronicle of Higher Education*.

Bird, R. 1999. “Cooperation and conflict: the behavioral ecology of the sexual division of labor.” *Evolutionary Anthropology* 8: 65-75.

Bird, Christopher D., and Nathan J. Emery. “Insightful problem solving and creative tool modification by captive nontool-using rooks.” *Proceedings of the National Academy of Sciences* 106 (25): 10370-10375.

Bluff, Lucas A., Alex A. S. Weir, Christian Rutz, Joanna H. Wimpenny, and Alex Kacelnik. 2007. “Tool-related cognition in New Caledonian crows.” *Comparative Cognition and Behavior Reviews* 2: 1-25.

Boesch, Christophe, and Hedwige Boesch. 1990. “Tool Use and Tool Making in Wild Chimpanzees.” *Folia Primatologica* 54: 86-99.

Breuer, Thomas, Mireille Ndoundou-Hockemba, and Vicki Fishlock. 2005. “First Observation of Tool Use in Wild Gorillas.” PloS Biology 3 (11): e380. [Online] Available:
http://www.plosbiology.org/article/info:doi/10.1371/journal.pbio.0030380

Chappell, Jackie, and Alex Kacelnik. 2004. “Selection of tool diameter by New Caledonian crows *Corvus moneduloides*.” *Animal Cognition* 7: 121-127.

———. 2002. “Tool selectivity in a non-mammal, the New Caledonian crow (*Corvus moneduloides*). *Animal Cognition* 5: 71-78.

Correia, Sergio P.C., Anthony Dickinson, and Nicola P. Clayton. 2007. “Western Scrub-Jays Anticipate Future Needs Independently of Their Current Motivational State.” *Current Biology* 17: 1-6.

CorellianScoundrel. 2008. “So, this bird walks into a convenience store and....” [Video] Available: http://www.youtube.com/watch?v=-Z2dyM2Buqs (Posted 21 August 3008, Accessed 08 November 2010)

Dawkins, Richard. 1982. *The Extended Phenotype: The Long Reach of the Gene*. New York: Oxford University Press.

De Vries, Marc J. 2003. “The Nature of Technological Knowledge: Extending Empirically Informed Studies into What Engineers Know.” *Techné: Research in Philosophy and Technology* 6 (3). [Online] Available: http://scholar.lib.vt.edu/ejournals/SPT/v6n3/devries.html

Feenberg, Andrew. 1999. *Questioning Technology*. New York: Routledge.

Ferré, Frederick. 1995. [1988]. *Philosophy of Technology.* Athens, Georgia: University of Georgia Press.

Fimrite, Peter. 2005 (14 December). “Daring rescue of whale off Farallones / Humpback nuzzled her saviors in thanks after they untangled her from crab lines, diver says.” *San Francisco Gate*. [Online] Available: http://articles.sfgate.com/2005-12-14/news/17403910_1_humpback-crab-pots-whale

Finn, Julian K., Tom Tregenza, and Mark D. Nordman. 2009 (15 December). “Defensive tool use in a coconut-carrying octopus.” *Current Biology* 19 (23): R1069-R1070.

Foelix, Rainer F. 1996. *Biology of Spiders*, 2nd ed. New York: Oxford University Press.

Forbes, R.J. 1967. “The Beginnings of Technology and Man.” In *Technology in Western Civilization*, Volume 1, Edited by M. Kranzberg and C. Pursell, Pages 11-26. New York: Oxford University Press.

Gazda, Stefanie K., Richard C. Connor, Robert K. Edgar, and Frank Cox. 2005. “A division of labour with role specialization in group-hunting bottlenose dolphins (Tursiops truncatus) off Cedar Key, Florida.” *Proceedings of the Royal Society B* 272: 135-140.

Griffin, Donald. 1976. *The Question of Animal Awareness: Evolutionary Continuity of Mental Experience.* New York: The Rockefeller University Press.

Gurnell, Angela M. 1998. “The hydrogeomorphological effects of beaver dam-building activity.” Progress in Physical Geography 22 (2): 167-189.

Hall, A. Rupert. 1978. “On Knowing and Knowing How to….” *History of Technology*. 3: 91-103.

Hansell, Mike. 2007. *Built by Animals: the Natural History of Animal Architecture.* New York: Oxford University Press.

———. 2005. *Animal Architecture.* New York: Oxford University Press.

Hansell, Mike, and Graeme D. Ruxton. 2007. “Setting tool use within the context of animal construction behavior.” *Trends in Ecology and Evolution* 23 (2): 73-78.

Henderson, Mark. 2009 (10 March). “Chimpanzee's plan to attack zoo visitors shows evidence of premediated thought.” The Times Online. [Online] Available: http://www.timesonline.co.uk/tol/news/science/article5877764.ece

Herman, Louis M., Douglas G. Richards, and James P. Wolz. 1984. “Comprehension of sentences by bottlenosed dolphins.” *Cognition* 16 (2): 129-219.

Horton, Thomas E., Robert St. Amant, John M. Daughtry, and Colin G. Butler. 2010. “Tool-based direct manipulation environments.” Department of Computer Science Technical Report TR-2010-23. North Carolina State University.

Hughes, Thomas P. 2004. *Human-Built World: How to Think about Technology and Culture.* Chicago: University of Chicago Press.

Hume, David. 1888. [1978]. *A Treatise of Human Nature.* New York: Oxford University Press.

Hunt, Gavin R., and Russell D. Gray. 2007. "Parallel tool industries in New Caledonian crows." *Biology Letters* 3: 173-175.

Hunt, G.R. and Gray, R.D. 2006b. "Tool manufacture by New Caledonian crows: chipping away at human uniqueness." *Acta Zoologica Sinica* 52 (Suppl.), 622-625. *(*Proceedings of the 23rd International Ornithological Congress).

Hunt, G.R. and Gray, R.D. 2004. "The crafting of hook tools by wild New Caledonian crows." *Proceedings of the Royal Society, London* B (suppl.) 271, S88-S90.

Hunt, G.R. and Gray, R.D. 2003. "Diversification and cumulative evolution in tool manufacture by New Caledonian crows." *Proceedings of the Royal Society, London* B 270, 867-874.

Hunt, G.R. 2000a. "Human-like, population-level specialization in the manufacture of pandanus-tools by New Caledonian crows *Corvus moneduloides*." *Proceedings of the Royal Society, London* B 267, 403-413.

Hunt, G.R. 1996. "Manufacture and use of hook-tools by New Caledonian crows." *Nature* 379, 249-251.

Idhe, Don. 1993. *Philosophy of Technology: An Introduction*. New York: Paragon House.

"information." 2003. *The American Heritage Dictionary of the English Language, Fourth Edition*. [Online] Available: from http://www.thefreedictionary.com/information (Accessed 06 October 2010)

Inoue-Nakamura, Noriko, and Tetsuro Matsuzawa. 1997. "Development of Stone Tool Use by Wild Chimpanzees (Pan troglodytes)." *Journal of Comparative Psychology* 111 (2): 159-173.

Jane Goodall Institute. 2007. "Tool Making." Chimpanzee Central. [Online] Available: http://www.janegoodall.org/chimp-central-toolmakers (Accessed 10 November 2010)

Janik, Vincent M. 2000 (25 August). "Whistle Matching in Wild Bottlenose Dolphins (*Tursiops truncatus*)." *Science* 289:1355-1357.

Janik, Vincent M., L.S. Sayigh, and R.S. Wells. 2006. "Signature whistle shape conveys identity information to bottlenose dolphins." Proceedings of the National Academy of Sciences 103 (21): 8293-8297.

Jung, Jim. 2007. [2003]. "Why Beavers Build Dams." The Waterman and Hill-Traveller's Companion, a Natural Events Almanac. [Online] Available: http://www.naturealmanac.com/archive/beaver_dams/beaver_dams.html

Kenward, Ben, Alex A.S. Weir, Christian Rutz, and Alex Kacelnik. 2005. "Tool manufacture by naïve juvenile crows." *Nature* 433: 121.

Kenward, Ben, Christian Rutz, Alex A.S. Weir, and Alex Kacelnik. 2006. "Development of tool use in New Caledonian crows: inherited action patterns and social influences." *Animal Behaviour* 72: 1329-1343.

Kerasote, Ted. 2007. *Merle's Door: Lessons from a Freethinking Dog*. Harcourt Books.

Kranzberg, Melvin, and Carroll W. Pursell, Jr. 1967. "The Importance of Technology in Human Affairs." In *Technology in Western Civilization*, Volume 1, Edited by Kranzberg and Pursell. New York: Oxford University Press.

Krützen, Michael, Janet Mann, Michael Heithaus, Richard C. Connor, Lars Lejder, and William B. Sherwin. 2005. "Cultural transmission of tool use in bottlenose dolphins." *Proceedings of the National Academy of Sciences* 102 (25): 8939-8943.

Kummer, H., and Jane Goodall. 1985. "Conditions of Innovative Behavior in Primates." *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 308 (1135): 203-214.

Laudan, Rachel, ed. 1984. *The Nature of Technological Knowledge*. Dordrecht: D. Reidel Publishing Company.

Layton, Edwin. 1987. "Through the Looking Glass, or News from Lake Mirror Image." Technology and Culture. 28, 3: 594-607.

———. 1974. "Technology as knowledge." *Technology and Culture*. 15: 31-41.

———. 1971. "Mirror-Image Twins: The Communities of Science and Technology in 19th-Century America." *Technology and Culture*. 12, 4: 562-580.

Lee, K. 2009. "Homo faber: the Unity of the History and Philosophy of Technology**."** In Jan Kyrre Berg Olson, Evan Selinger, and Søren Riis (eds.), *New Waves in Philosophy of Technology*, Palgrave Macmillan.

Leinhard, John. 2000. *The Engines of Our Ingenuity: An Engineer Looks at Technology and Culture*. New York: Oxford University Press.

Marino, Lori. 2002. "Convergence of Complex Cognitive Abilities in Cetaceans and Primates." *Brain, Behavior and Evolution* 59: 21-32.

Marino, Lori, Richard C. Connor, R. Ewan Fordyce, Louis M. Herman, Patrick R. Hof, Louis Lefebvre, David Lusseau, Brenda McCowan, Esther A. Nimchinsky, Adam A. Pack, Luke Rendell, Joy S. Reidenberg, Diana Reiss, Mark D. Uhen, Estel Van der Gucht, and Hal Whitehead. 2007. "Cetaceans Have Complex Brains for Cognition." *PloS Biology* 5 (5): e139.

Mawler, Stuart. 2006. "The Elitist Language of Physicists." (Talk.) Brian Bertoti Graduate Student Conference, Virginia Tech.

McGinn, R.E. 1978. "What is technology?" *Research in Philosophy and Technology*, Volume 1*:*179-197.

Millikan, Ruth Garrett. 1984. *Language, Thought, and Other Biological Categories.* Cambridge, Massachusetts: MIT Press.

Mitcham, Carl. 1994. *Thinking Through Technology: The Path between Engineering and Philosophy*. Chicago: University of Chicago Press.

Mitcham, Carl, and Robert Mackey (eds.). 1972. *Philosophy and Technology*. New York: The Free Press.

Mitchell, Sandra D. 2009. *Unsimple Truths.* University of Chicago Press.

Morelle, Rebecca. 2010 (April 20). "Clever crows can use three tools." BBC News. [Online] Available: http://news.bbc.co.uk/go/pr/fr/-/2/hi/science/nature/8631486.stm

National Public Radio (NPR). 2010. "The Human Edge." (Radio Series.) [Online] Available: http://npr.org.templates/story/story.php?storyId=128245649

Noad, Michael J., Douglas H. Cato, M.M. Bryden, Micheline-N. Jenner, and K. Curt S. Jenner. 2000. "Cultural revolution in whale songs." *Nature* 408: 537.

Osvath, Mathias. 2009. "Spontaneous planning for future stone throwing by a male chimpanzee." *Current Biology* 19 (5): R190-191.

Petroski, Henry. 2006. *Success Through Failure: The Paradox of Design.* New York: Vintage Books.
———. 2003. *Small Things Considered*. New York: Vintage Books.
———. 1998. *Remaking the World.* New York: Vintage Books.
———. 1992. *The Evolution of Useful Things*. New York: Alfred Knopf.
———. 1985. *To Engineer is Human: The Role of Failure in Successful Design*. New York: Vintage Books.
Personal Communication. 2010 (July 1). Email Communication with Jackie Chappell, Lecturer in Animal Behavior, Centre for Ornithology, University of Birmingham.
Pitt, Joseph C. 2000. *Thinking About Technology: Foundations of the Philosophy of Technology*. New York: Seven Bridges Press.
Povinelli, D.J., L.A. Theall, J.E. Reaux, and S. Gimbrone. 2000. "The tool-insertion problem: the question of shape." In D.J. Povenelli (ed.), *Folk Physics for Apes*. Oxford University Press: 173-205.
Pryor, Karen, and Kenneth S. Norris, eds. 1998. *Dolphin Societies: discoveries and puzzles*. Berkeley: University of California Press.
Rowlands, Mark. 2005. "Environmental Epistemology." *Ethics and the Environment* 10 (2): 5-27.
Ryle, Gilbert. 1946. "Knowing how and knowing that." *Proceedings of the Aristotelian Society* 46.
Sanz, Crickette M, and David B. Morgan. 2007. "Chimpanzee Tool Technology in the Goualougo Triangle, Republic of Congo." *Journal of Human Evolution* 52 (4): 420-433.
Sanz, Crickette M., Caspar Schöning, and David B. Morgan. 2009 (Sept. 3). "Chimpanzees prey on army ants with specialized tool set." *American Journal of Primatology* 71: 1-8. [Online] Available: http://www3.interscience.wiley.com/cgi-bin/fulltext/122582343/PDFSTART
Sargeant, B.L., J. Mann, P. Berggren, and M. Krützen. 2005. "Specialization and development of beach hunting, a rare foraging behavior, by wild bottlenose dolphins (*Tursiops* sp.)." *Canadian Journal of Zoology* 83: 1400-1410.
Savage-Rumbaugh, Sue, and Roger Lewin. 1994. *Kanzi: The Ape at the Brink of the Human Mind*. Wiley.
Scheldeman, Griet. 2009 (05 August). "Orangutan ruse misleads predators." BBC News. [Online] Available: http://news.bbc.co.uk/go/pr/fr/-/2/hi/science/nature/8184015.stm
Schick, Kathy D., and Nicholas Toth. 1993. *Making Silent Stones Speak: Human Evolution and the Dawn of Technology*. New York: Simon and Schuster.
ScienceDaily. 2007 (13 September). "Enormous Spider Web Found in Texas." [Online] Available: http://www.sciencedaily.com/releases/2007/09/070912145919.htm
Shew, Ashley. 2008. "What Dolphins Want: Animal Intentionality and Tool Use." MA Thesis in Philosophy, Virginia Tech. [Online] Available: http://scholar.lib.vt.edu/theses/available/etd-04172008-144940/
———. 2007. "Spider Webs, Beaver Dams, and The Sticky Wicket: An Investigation on What Counts as Technology and What Counts as Knowledge." MS Thesis in

Science and Technology Studies, Virginia Tech. [Online] Available: http://scholar.lib.vt.edu/theses/available/etd-05152007-135849/

Silva, Francisco J., and Kathleen M. Silva. 2010. "How do adult humans compare with New Caledonian crows in tool selectivity?" *Learning and Behavior* 38 (1): 87-95.

St. Amant, Robert, and Thomas E. Horton. 2008. "Revisiting the definition of animal tool use." *Animal Behavior* 75: 1199-1208.

"Study: Dolphins Not So Intelligent On Land." 2006. *The Onion* 42 (07). 2006-02-15. Online: http://www.theonion.com/content/node/45360/print/

Taylor, Alex H., Douglas Elliffe, Gavin R. Hunt, and Russell D. Gray. 2010. "Complex cognition and behavioural innovation in New Caledonian crows." *Proceedings of the Royal Society B*. [Online] Available: http://rspb.royalsocietypublishing.org/content/early/2010/04/16/rspb.2010.0285.abstract

Taylor, Alex H., Gavin R. Hunt, Jennifer C. Holzhaider, and Russell D. Gray. 2007. "Spontaneous Metaool Use by New Caledonian Crows." *Current Biology* 17: 1504-1507.

Taylor, Alex H., G.R. Hunt, F.S. Medina, and R.D. Gray. 2009. "Do New Caledonian crows solve physical problems through causal reasoning?" *Proceedings of the Royal Society B* 276: 247-254.

Tenner, Edward. 1997. *Why Things Bite Back: New Technology and the Revenge Effect.* London: Fourth Estate.

Tyack, Peter L. 2000 (25 August). "Animal Behavior: Dolphins Whistle a Signature Tune." *Science* 289: 1310-1311.

Vincenti, Walter. 1990. *What Engineers Know and How They Know It*. Baltimore, Maryland: John Hopkins University Press.

Visalberghi, Elisabetta, Dorothy M. Fragaszy, and Sue Savage-Rumbaugh. 1995. "Performance in a Tool-Using Task by Common Chimpanzees (*Pan troglodytes*), Bonobos (*Pan paniscus*), an Orangutan (*Pongo pygmaeus*), and Capuchin Monkeys (*Cebus apella*)." *Journal of Comparative Psychology* 109 (1): 52-60.

von Bayern, Auguste M.P., Robert J.P. Heathcote, Christian Rutz, and Alex Kacelnik. 2009. "The Role of Experience in Problem Solving and Innovative Tool Use in Crows." *Current Biology* 19: 1965-1968.

Weir, Alex A.S., Jackie Chappell, and Alex Kacelnik. 2002. "Shaping of Hooks in New Caledonian Crows." *Science* 297: 981.

Weir, Alex A.S., and Alex Kacelnik. 2006. "A New Caledonian crow (Corvus moneduloides) creatively re-designs tools by bending or unbending aluminum strips." *Animal Cognition* 9: 317-334.

Westergaard, Gregory Charles. 1995. "The Stone-Tool Technology of Capuchin Monkeys: Possible Implications for the Evolution of Symbolic Communication in Hominids." *World Archaeology* 27 (1): 1-9.

Wohlforth, Charles. 2010 (March). "Who are you calling bird brain?" *Discover Magazine* (March 2010): 45-49.

Wittgenstein, Ludwig. 1973. [1953.] *Philosophical Investigations.* Prentice Hall.

Other Works Consulted and Additional Reading:

"At Home in the Sea." 2008. *Dolphins: Close-Encounters*. PBS Feature. [Online.] Available: http://www.pbs.org/wnet/nature/dolphins/sea.html

Beisecker, David. 1999. "The Importance of Being Erroneous: Prospects for Animal Intentionality." *Philosophical Topics* 27 (1): 281-308.

Blad, Sylvia. 2010. "The Impact of 'Anthropotechnology' on Human Evolution." *Techné: Research in Philosophy and Technology* 14 (2): 72-87.

Chomsky, Noam. 1971. "The Case Against B.F. Skinner." *The New York Review of Books*, December 30.

Davidson, Donald. 1975. "Thought and Talk." *In Mind and Language: Wolfson College Lectures*, 1974. Oxford: Oxford University Press.

Dennett, Daniel. 1995. "Do Animals Have Beliefs?" In Herbert Roitblat, ed., *Comparative Approaches to Cognitive Sciences*. MIT Press.

———. 1995. *Darwin's Dangerous Idea: Evolution and the Meanings of Life.* Simon and Schuster.

———. 1987. *The Intentional Stance.* Cambridge, Massachusetts: MIT Press.

Descartes, Rene. 1637. *Discourse of the Method for Conducting One's Reason Well and for Seeking the Truth in the Sciences.* Part Five. [As printed in Ariew, Roger, ed. 2000. *Rene Descartes Philosophical Essays and Correspondence.* Indianapolis: Hackett Publishing Company.]

Drexler, K. Eric. 1986. *Engines of Creation: The Coming Era of Nanotechnology*. New York: Anchor Books.

Dougmore, A. Radclyffe. 1914. *Romance of the Beaver*. Philadelphia: J.B. Lippincott Company.

Fisher, John Andrew. 1991. "Disambiguating Anthropomorphism: An Interdisciplinary Review." In P.P.G. Bateson and P.H. Klopfer (eds.), *Perspectives in Ethology*, Volume 9: 49-85.

Foelix, Rainer F. 1996. *Biology of Spiders*, 2nd ed. New York: Oxford University Press.

Galison, Peter. 1997. *Image and Logic*. University of Chicago Press.

Hacking, Ian. 1983. *Representing and Intervening*. Cambridge University Press.

Haemig, P.D. 2006. "Ecology of the Beaver." Available [Online]: http://www.ecology.info/beaver-ecology.htm (Accessed 24 November 2006).

Hanser, Matthew. 1998. "Intention and Teleology." *Mind* 107(426): 381-401.

Hughes, R.I.G. 1997. "Models and Representation." *Philosophy of Science* 64 (Proceedings): S325-S336.

Hunt, G.R., Rutledge, R.B. and Gray, R.D. 2006a. "The right tool for the job: What strategy do wild New Caledonian crows use?" *Animal Cognition* 9: 307-316.

Hunt, G.R. and Gray, R.D. 2002a. "Species-wide manufacture of stick-type tools by New Caledonian crows." *Emu*, 102, 349-353.

Hunt, G.R., Sakuma, F. and Shibata, Y. 2002b. "New Caledonian crows drop candle-nuts onto rock from communally-used forks on branches." *Emu* 102, 283-290.

Hunt, G.R. 2000b. "Tool use by the New Caledonian crow *Corvus moneduloides* to obtain Cerambycidae from dead wood." *Emu* 100:109-114.

Kuhn, Thomas. 1962. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Longino, Helen. 2002. *The Fate of Knowledge*. Princeton, New Jersey: Princeton University Press.

———. 1990. *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry.*Princeton, NJ: Princeton University Press.

Millikan, Ruth Garrett. 1999. "Wings, Spoons, Pills, and Quills: A Pluralist Theory of Function." *The Journal of Philosophy* 96.4, pp.191-206.

———. 2001. "What has Natural Information to do with Intentional Representation?" in Denis Walsh, ed., Naturalism, Evolution and Mind, Cambridge: Cambridge University Press, 105-125.

Nagel, Thomas. 1974. "What is it like to be a bat?" *Philosophical Review* 83: 435-450.

NOVA. 2008. "Ape Genius." Originally aired February 19th at 8pm on Public Broadcasting Corporation (PBS).

Pickering, Andrew. 1984. *Constructing Quarks: A Sociological History of Particle Physics*. Edinburgh: Edinburgh University Press.

Pitt, Joseph C. 2001. "What Engineers Know." *Techné: Research in Philosophy and Technology* 5 (3). [Online] Available: http://scholar.lib.vt.edu/ejournals/SPT/v5n3/pitt.html

———. 2003."Against the Natural/Artificial Distinction." *Philosophical Dreams, Oneonta Studies in Philosophy*, Douglas Schrader (ed.). SUNY/Oneonta Press, p. 241-260.

Preston, Christopher J. 2005. "Restoring Misplaced Epistemology." *Ethics, Place and Environment: A Journal of Philosophy and Geography* 8 (3): 373-384.

———. 2003. *Grounding Knowledge: Environmental Philosophy, Epistemology, and Place*. University of Georgia Press.

———. 2002. "Animality and Morality: Human Reason as an Animal Activity." *Environmental Values* 11: 1-16.

Riskin, Jessica. 2002. *Science in the Age of Sensibility: The Sentimental Empiricists of the French Enlightenment.* Chicago: University of Chicago Press.

Skinner, B.F. 1972. *Beyond Freedom and Dignity.* New York: Bantam Vintage.

Tauritz, L. 2001. "Sitting Pretty: the Social Construction of the Ergonomic Desk Chair." Presentation. SHOT Annual Meeting.

"Teleological Notions in Biology." The Stanford Encyclopedia of Philosophy. [Online] Available: http://plato.stanford.edu/entries/teleology-biology/ (Accessed 15 March 2007).

Walsh, Denis M., ed. 2001. *Naturalism, Evolution and Mind*. Royal Institute of Philosophy Supplement 49. Cambridge University Press.

APPENDIX A: The Proposed Map