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User innovation: a novel framework for studying animal innovation within a comparative context

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Abstract

Much work has been dedicated to defining and describing animal innovation. Despite this, efforts to compare human and animal innovation have been hindered by perceived fundamental differences between how, and why, humans and animals innovate. Furthermore, there is not a useful framework for comparisons across different taxa. Here, we provide an overview of the current understanding of human 'user' innovation, provide some examples of user innovation, and highlight the parallels between animal innovation and user innovation by humans. User innovation, put simply, is the process by which people invent to satisfy their own needs, not necessarily with the aim of distributing their invention, or marketing it for profit. Thus, it is much more closely aligned to the manner in which nonhuman animals innovate. Our intention is that this discussion will help to re-frame how we consider animal innovation and foster more direct comparisons between human and animal innovation, while propagating new avenues for research, both experimental and observational.

Keywords: user innovation; free innovation; problem solving; play; social learning

Introduction

We are a species renowned for our innovative abilities, both to invent independently and to copy and refine the innovations of others. At the core of our complex cultural world is the fidelity with which we copy others, allowing for the faithful transmission and adoption of innovations within a community, and also our specialism at building upon the ideas of others (Griffin 2016). Innovation is a social process in that individuals are more exploratory with social support (Forss et al. 2017) and innovations, which may themselves arise from collaborative efforts, are distributed widely within communities (Davids and Frenken 2017). Indeed, we are typically more efficient at solving problems when working in a group setting than individually (e.g., Laughlin et al. 2006), as social groups allow individuals to overcome their own cognitive limitations and to share expertise (Krause et al. 2010). Furthermore, innovations that build upon those of previous innovations negate having to ‘reinvent the wheel’ and this process promotes the development of ever-sophisticated and efficient technologies (i.e. cumulative cultural evolution, Mesoudi and Thornton 2018). As von Hippel (2005) noted, “to say an innovation is minor is not the same as saying it is trivial: minor innovations are cumulatively responsible for much or most technical progress.” Ultimately, it has been proposed that innovation begets future innovation, although the resultant increase in knowledge, and the complexity of that resultant knowledge, may become more burdensome to learn with successive generations (Mesoudi 2011).

Individuals can innovate in a methodical, planned way or spontaneously, without forethought or clear understanding of a goal. Innovation may rely on identifying needs or arise from simple (serendipitous) trial-and-error problem solving (i.e. innovation as an active *versus* a passive process; Reader et al. 2016). When we consider animal innovation, however, creativity and intention are not typically inferred (van Schaik et al. 2015, although see Kaufman and Kaufman 2015), but those studying human innovation often consider it to be insightful – entrepreneurs aim to spot gaps in the market and launch the product

to market. It is also important to note that innovation does not simply refer to the creation of a novel product; an invention can also be the application of an already-existing invention repurposed in a new way; the combination of new existing technologies to create a novel product; or the refinement of an existing product in a way that creates a novel innovation (Mesoudi et al. 2013). Thus, the patent system recognizes the value of both ‘pioneering’ and ‘improvement’ patents, as noted by United States Code of statutes, which states “Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor” (35 U.S.C. §101. Inventions patentable). There is a feedback between the inventor, their community, and the inventions produced (Muthukrishna and Henrich 2016). How, though, does the process of innovation described for humans compare with what we consider as innovation by animals?

Innovation in Nonhuman Animals

Although animals have not created the diversity and complexity of material technologies that humans have (as evidenced by their lack of cumulative cultural evolution: Tennie et al. 2009; Dean et al. 2014; Reindl et al. 2017, although see Hunt and Gray 2003; Sanz et al. 2009; Sasaki and Biro 2017), they nonetheless innovate (Reader and Laland 2003). Innovations by animals have been reported in a range of realms including tool construction and use (e.g., *Cacatua goffini*, Auersperg et al. 2012; *Corvus moneduloides*, St. Clair et al. 2018; *Pan troglodytes*, Hobaiter et al. 2014; *Tursiops* sp., Patterson and Mann 2011); the eating and processing of novel foods (e.g., *Macaca fuscata*, Leca et al. 2007; *Poecile atricapillus*, Prasher et al. 2019); and the invention of novel gestures to communicate meaning and maintain social bonds (e.g., *Pan troglodytes*, Hopkins et al. 2007; *Mandrillus sphinx*, Laidre 2008) (see Reader and Laland 2003 for a review). Innovations in animals have been observed and documented serendipitously as they arise (e.g., Hirata et al. 2008; Nishida et al. 2009; Hobaiter et al. 2014) or have

been induced via experimental manipulation (Matsuzawa and Yamakoshi 1996; Thornton and Samson 2012). They have also been inferred via the ‘method of exclusion’ in which the behavioral profiles of individuals or groups are compared to reveal behaviors that are not species universals, and which may, therefore, be candidates for innovations (Whiten et al. 1999). While much research effort has been invested in describing how, why, and when animals innovate (Brosnan and Hopper 2014; Kaufman and Kaufman 2015; Ramsey et al. 2007; Reader and Laland 2001, 2003), there appears to be a disparity between what we think of as “innovation” when performed by humans *versus* animals. Specifically, when we think of human innovation we often ascribe insight and planning to the process, and we also consider the commercial value associated with innovation and entrepreneurship, as well as the social, political and economic drivers of innovative success (and failure) (Isaacson 2014; Rogers 2003). This allows for only limited comparison between our understanding and description of human innovation and that by animals. Perhaps a new definitional framework is required.

In contrast to innovation by humans, animals do not *aim* to create a product, tool, or skill for others to adopt, or we certainly do not infer that they do. Rather, animals innovate to solve problems that they themselves are facing (i.e., to meet their own needs). Furthermore, unlike humans, animals typically do not *actively* teach their young or groupmates new skills, and any transmission of information is typically passive (e.g., Matsuzawa et al. 2001, but see Hoppitt et al. 2008). We propose, therefore, that animal innovation can be more usefully likened to ‘user innovation’ by humans. User innovators are individuals who create products or innovate techniques to fulfill a personal need, rather than creating a product to go to market (von Hippel 2005). These user-driven innovations can be in the form of modifications to existing tools, the invention of a completely novel tool or technology, as well as the adoption of novel and useful behaviors, such as diets, and are found within a number of realms as we outline below. Animals, like human user innovators, typically invent for their own needs, or adapt the inventions of

others. In both cases, their inventions are for use by them personally, rather than to distribute within their community (let alone sell for a profit!). Any distribution that is observed, would likely be unintentional on the part of the inventor, and happen passively by social learning.

User Innovation in Humans

Eric von Hippel (2017) defined 'free innovation' as "a functionally novel product, service, or process that (1) was developed by consumers at private cost during their unpaid discretionary time ... and (2) is not protected by its developers, and so is potentially acquirable by anyone without payment - for free." Free innovation is also the process by which such products are created. User innovation is a very similar concept, but includes a proviso that the user innovator derives at least some self-reward from the personal use of the innovation (von Hippel 2017). User innovation refers to the process by which individuals or groups "produce functionally novel product innovations in order to address their own needs, or the needs of those close to them" (von Hippel 2005). Once a user innovation has been created, and implemented to solve a user's problem, the user has been fully rewarded. In other words, the incentive to innovate in this situation is the satisfaction of user need. Users may decide to disseminate their innovations to others for free, a phenomenon made much easier by the internet, but this is not the primary aim of the inventor. Users may also innovate collaboratively with other users.

It is important to distinguish user innovation from the traditional model of innovation. In the classic model, firms or entrepreneurs innovate in order to satisfy market needs, and, in doing so, seek to earn profits (Schumpeter 1924). In this "Schumpeterian" paradigm, innovation does not take place without the incentive provided by the prospect of financial reward. However, a growing body of empirical evidence suggests that considerable innovation occurs outside the commercial sphere (von Hippel 2017). In fact, the total quantity of user innovation may dwarf that of commercial innovation due to

much larger numbers of user innovators (von Hippel 2017). Explanations for the prevalence and growth of user innovation include decreases in the cost of designing and disseminating innovations, disproportionately empowering user innovators (Baldwin and von Hippel 2010).

User innovation has been documented in myriad contexts, from sports equipment to medical treatments, and computer software to machine tools. Users frequently innovate to produce novel tools. In fact, important tools across many industries were originally developed by users. Even Adam Smith (1776) noticed that workers employed in manufacturing were frequently the creators of labor-saving devices. In the realm of scientific instruments, von Hippel (1988) observed that a remarkable 80% of the most significant innovations originated with users of those instruments. Human user tools are often roughly improvised for limited or single uses. However, sometimes tools are disseminated by their user innovator and widely adopted by others.

It is unsurprising that users often engage in medical innovation, either to help alleviate their own health problems or the problems of people close to them (DeMonaco et al. 2019). The prevailing regimes of patents and regulatory approval limit the number of medical innovations approved for the marketplace. To address diagnostic or therapeutic needs not yet alleviated through traditional approval mechanisms, many people create or adapt therapies or diagnostic methods to help meet their own needs. One such example is The Nightscout Project (<http://www.nightscout.info/>), a loose confederation of innovators united by a desire to improve the lives of people suffering from Type-1 Diabetes, including members of Nightscout. Though a combination of collaboration and chutzpah, Nightscout substantially improved the functionality of a continuous glucose monitor (CGM) manufactured by Dexcom, Inc.. Despite protestations by the company, and the U.S. Food and Drug Administration, NightScout published videos, tweets, and detailed descriptions explaining precisely how to “hack” Dexcom’s commercially-available

CGM to extend its usefulness. So successful were these improvements that subsequent CGM models incorporated innovations pioneered by Nightscout.

Beyond medical devices, user innovation has been important in the field of sports equipment and methods (Hyysalo 2009). Of course, many people develop their own rules to common board games, but user innovation has impacted sport much more broadly. A recent review of German athletes by Franke and Shah (2003), for example, described a bewildering array of user innovations. These innovators included “canyoners” (who explore canyons), boardercrossers (i.e. competitive snowboarders who race each other through challenging downhill courses), bicyclists with disabilities who require novel equipment, and sailplaners (i.e. people who pilot gliders towed into the air by airplanes). True to the nature of user innovation, Franke and Shah found from their survey that more than 40% of the innovations they identified solved “urgent problems” for the innovators and nearly 15% could be considered a new product.

Perhaps the best-known example of user innovation involves open source software. Traditional software development involves centrally-planned development of computer programs, often carried out entirely within a single company. Software created by this method is often “buggy” and requires multiple updates. Few companies possess the resources to hire enough software engineers to keep up with the demand for updated and improved software. However, individual software coders discovered that, if they shared their source code with one and all over the internet, others would be able to fix bugs, add features, and improve the quality of the original programs. Originally criticized by commercial software firms as amateurish and disorganized, open source software has proved itself to be as, if not more, robust, in many applications (O’Mahony 2003). For example, the crucial software that runs computer servers was once written by commercial firms, who dismissed the possibility that open source

code could ever compete; yet, almost all server software is now open source, produced by diffuse and informally-organized worldwide communities of user innovators.

Of course, such high-tech user innovations were preceded by many other examples of technical user innovation. Indeed, it is likely that early hominin tool users were user innovators, although it is a non-trivial task to identify when, let alone why, innovative behavior occurred in prehistory (Haidle and Bräuer 2011). However, a consideration of examples of early user innovations perhaps provides a more analogous link to innovations seen among nonhuman animals. Perhaps the most famous example of simple human user innovation is the creation of the sandwich, which was supposedly the creation of John Montagu, the 4th Earl of Sandwich, who, it is told, created the sandwich so he could eat while playing cards (Butler 2014). More reliable examples of human user innovation have also been documented, such as the invention of shoes, slings, and, of course, the wheel. Adam Smith noted the importance of user innovations in 1776, observing in Book 1, Chapter 1, of *The Wealth of Nations* that “a great part of the machines made use of in those manufactures in which labor is most subdivided, were originally the invention of common workmen, who, being each of them employed in some very simple operation, naturally turned their thoughts towards finding out easier and readier methods of performing it.” He cited the example of a boy whose user innovation improved the function of early fire engines (likely a Newcomen atmospheric engine): “One of those boys, who loved to play with his companions, observed that, by tying a string from the handle of the valve which opened this communication to another part of the machine, the valve would open and shut without his assistance, and leave him at liberty to divert himself with his playfellows. One of the greatest improvements that has been made upon this machine, since it was first invented, was in this manner the discovery of a boy who wanted to save his own labour.”

How does user innovation differ between humans and other animals?

To date, little work has attempted to directly compare how humans and animals innovate. Nevertheless, the terminology needs to be in place and definitions clarified. As described, we believe that human user innovation is much more analogous to innovation by animals than is human innovation in a more traditional sense. Animals typically innovate to solve problems they themselves face, not intentionally to benefit others and nor to create a new product for profit. However, of course, the processes are not identical, so what are the parallels and differences? User innovation by humans not only satisfies that individual's needs, it also acts as feedstock for producer innovation. A user may invent a device or method that advances the technological arts, but rarely will that same user become a commercial manufacturer or supplier of her invention. User innovations are often freely revealed to the world, especially now that the internet has made dissemination relatively costless and accessible. In fact, users sometimes freely reveal their innovations to producers in the hope that those producers will develop an inexpensive, but high quality, version. By contrast, animals tend not to reveal their innovations to others deliberately (i.e. social learning is passive, although see Musgrave et al. 2016), nor do they have access to the design and manufacturing capacities of human firms. Consequently, it would seem much easier for a human user innovation to become widely-available and widely-known. While many species are capable of learning from the actions of others (or the associated products of those actions) (i.e. social learning, Hoppitt and Laland 2013), animal user innovations tend to be hyper-local in distribution, and they often disappear along with the innovating individual (Nishida et al. 2009).

Aside from finding solutions to needs, humans also appear to innovate for fun or pleasure. They often tinker and experiment in ways that seem aimless, only sometimes creating innovations they view as new and useful. It is unclear whether or not nonhuman animals engage in this form of 'innovation for fun,' although there have been reported cases of animals inventing novel forms of play (Behncke 2015).

Furthermore, it is likely that there are environmental influences on animals' innovative tendencies, for example between captive and wild settings (Cheng and Byrne 2018) or dependent on animals' exposure to different stimuli (e.g., wild animals' exposure to human artefacts, van de Waal and Bshary 2010). Captive orangutans (*Pongo* sp.), for example, have been shown to be more neophilic and exploratory than their wild counterparts (Forss et al. 2015) and the lack of predation or need to forage for extended periods has been proposed to explain why captive animals are more innovative than their wild counterparts (i.e. the 'spare time' hypothesis, Kummer and Goodall 1985; Kendal et al. 2005). Yet whether animals innovate for fun or innovate means to have fun has not been established. Indeed there is still much debate over whether and why animals experience fun (e.g., Byrne 2015; Emery and Clayton 2015), and while play among many species has been widely documented (Burghardt 2005), the link between innovation and play is yet to be explored fully (although see Tebbich et al. 2016, who highlight the link between play, exploration, neophilia and innovation).

Conclusion

Both human and animal user innovation share the initial phases of invention to satisfy personal needs and we believe that the human user framework allows for a novel way with which we can describe and define animal innovation, and one with more directly allows for cross-species comparisons. However, we also note that human and animal innovation diverge at the diffusion and commercial phases. Furthermore, human user innovators often collaborate in the innovative process, freely sharing prototypes of their invention with other in their community (i.e. 'collective innovation', Franke and Shah 2003), yet such collaborative inventing is rarely, if ever, observed among animals. Future research using the user innovation framework will allow us to more clearly find parallels and differences between how animal and humans innovate. One key element of innovation that we have not considered here is the emergence and process of innovation from a developmental perspective and how user innovation can

describe that. Of course, much work has been dedicated to studying how and when children innovate (e.g., Becker 1994; Cutting et al. 2014; Carr et al. 2015; Ebel et al., 2019) but less work has focused on innovation by immature animals. Applying the concepts of user innovation should not only facilitate more direct cross species comparisons but also within-species investigations of the development of innovation.

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References

- Auersperg AMI, Szabo B, von Bayern AMP, Kacelnik A (2012) Spontaneous innovation in tool manufacture and use in a Goffin's cockatoo. *Curr Biol* 22(21):R903-OR904.
- Baldwin CY, von Hippel E (2010) Modeling a paradigm shift: from producer innovation to user and open collaborative innovation. *Harvard Business School Finance Working Paper, No. 10-038; MIT Sloan Research Paper, No. 4764-09*. Available at SSRN: <https://ssrn.com/abstract=1502864>

- Becker JA (1994) 'Sneak-shoes', 'swords' and 'nose-beards': a case study of lexical innovation. *First Lang* 14(41):195-211.
- Behncke I (2015) Play in the Peter Pan ape. *Curr Biol* 25(1):R24-R27.
- Brosnan SF, Hopper LM (2014) Psychological limits on animal innovation. *Anim Behav* 92:325-332.
- Burghardt GM (2005) *The Genesis of Animal Play: Testing the Limits*. MIT Press: Cambridge, MA.
- Butler S (2014) *The story of the sandwich*. <https://www.history.com/news/the-story-of-the-sandwich> [accessed July 31 2019].
- Byrne RW (2015) The *what* as well as the *why* of animal fun. *Curr Biol* 25(1):R2-R4.
- Carr K, Kendal RL, Flynn EG (2015) Imitate or innovate? Children's innovation is influenced by the efficacy of observed behaviour. *Cognition* 142:322-332.
- Cheng K, Byrne RW (2018) Why human environments enhance animal capacities to use objects: evidence from keas (*Nestor notabilis*) and apes (*Gorilla gorilla*, *Pan paniscus*, *Pongo abelii*, *Pongo pygmaeus*). *J Comp Psychol* 132(4):419-426.
- Cutting N, Apperly IA, Chappell J, Beck SR (2014) The puzzling difficulty of tool innovation: why can't children piece their knowledge together? *J Exp Child Psychol* 125:110-117.
- Daivids M, Frenken K (2017) Proximity, knowledge base and the innovation process: towards an integrated framework. *Region Stud* 52(1):23-34.
- Dean LG, Vale GL, Laland KN, Flynn E, Kendal RL (2014) Human cumulative culture: a comparative perspective. *Biol Rev* 89(2):284-301.
- DeMonaco HJ, Olivier P, Torrance AW, von Hippel C, von Hippel EA (2019) When patients become innovators *MIT Sloan Management Review*. Available at SSRN: <https://ssrn.com/abstract=3355803>
- Ebel SJ, Hanus D, Call J (2019). How prior experience and task presentation modulate innovation in 6-year-old-children. *J Exp Child Psychol* 180:87-103.

- Emery NJ, Clayton NS (2015) Do birds have the capacity for fun? *Curr Biol* 25(1):R16-R20.
- Franke N, Shah S (2003) How communities support innovative activities: an exploration of assistance and sharing among end-users. *Res Pol* 32(1):157-178.
- Forss SIF, Koski SE, van Schaik CP (2017) Explaining the paradox of neophobic explorers: the social information hypothesis. In *J Primatol* 38(5):799-822.
- Forss SIF, Schuppli C, Haiden D, Zweifel N, van Schaik CP (2015) Contrasting responses to novelty by wild and captive orangutans. *Am J Primatol* 77(10):1109-1121.
- Griffin AS (2016) Innovativeness as an emergent property: a new alignment of comparative and experimental research on animal innovation. *Phil Tran R Soc B* 371(1690):20150544.
- Haidle MN, Bräuer J (2011) From brainwave to tradition – how to detect innovations in tool behavior. *Paelo Anthro* 144-153 doi: 10.4207/PA.2011.ART48
- Hirata S, Watanabe K, Masao K (2008) “Sweet-potato washing” revisited. In: Matsuzawa T. (Ed) *Primate Origins of Human Cognition and Behavior*. Pp. 487-508. Springer, Tokyo.
- Hobaiter C, Poisot T, Zuberbühler K, Hoppitt W, Gruber T (2014) Social network analysis shows direct evidence for social transmission of tool use in wild chimpanzees. *PLoS Biol* 12(9):e1001960.
- Hopkins WD, Taglialatela JP, Leavens DA (2007) Chimpanzees differentially produce novel vocalizations to capture the attention of a human. *Anim Behav* 73:281-86.
- Hoppitt WJE, Brown GR, Kendal R, Rendell L, Thornton A, Webster MW, Laland KN (2008) Lessons from animal teaching. *Trends Ecol Evol* 23(9):486-493.
- Hoppitt W, Laland KN (2013) *Social Learning: An Introduction to Mechanisms, Methods, and Models*. Princeton University Press.
- Hunt GR, Gray RD (2003) Diversification and cumulative evolution in New Caledonian crow tool manufacture. *Proc R Soc B* 270(1517):867-874

- Hyysalo S (2009) User innovation and everyday practices: micro-innovation in sports industry development. *R&D Manage* 39(3):247-258.
- Isaacson W (2014) *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution*. Simon & Schuster: New York, NY.
- Kaufman AB, Kaufman JC (2015) *Animal Creativity and Innovation*. Academic Press: London, UK.
- Kendal RL, Coe RL, Laland KN (2005) Age differences in neophilia, exploration, and innovation in family groups of Callitrichid monkeys. *Am J Primatol* 66:167-188.
- Krause J, Ruxton GD, Krause S (2010) Swarm intelligence in animals and humans. *Trends Ecol Evol* 25(1):28-34.
- Kummer H, Goodall J. (1985) Conditions of innovative behaviour in primates. *Phil Trans R Soc Lond Ser B* 308:203–214.
- Laidre ME (2008) Do captive mandrills invent new gestures? *Anim Cogn* 11(2):179-187.
- Laughlin PR, Hatch EC, Silver JS, Boh L (2006) Groups perform better than the best individuals on letters-to-numbers problems: effects of group size. *J Pers Soc Psychol* 90(4):644-651.
- Leca JB, Gunst N, Watanabe K, Huffman MA (2007) A new case of fish-eating in Japanese macaques: implications for social constraints on the diffusion of feeding innovation. *Am J Primatol* 69(7):821-828.
- Matsuzawa T, Biro D, Humle T, Inoue-Nakamura N, Tonooka R, Yamakoshi G (2001) Emergence of culture in wild chimpanzees: education by master-apprenticeship. In *Primate Origins of Human Cognition and Behavior*, T. Matsuzawa (Ed.), pp.557-574. Springer.
- Matsuzawa, T., & Yamakoshi, G. 1996. Comparison of chimpanzee material culture between Bossou and Nimba, West Africa. In *Reaching into Thought: The Minds of the Great Apes*, A.E. Rousson, K. Bard, & S. Parker (Eds.). pp. 211–232. Cambridge University Press: Cambridge, UK

- Mesoudi A (2011) Variable cultural acquisition costs constrain cumulative cultural evolution. *PLoS ONE*, 6(3):e18239.
- Mesoudi A, Laland KN, Boyd R, Buchanan B, Flynn E, McCauley RN, Jürgen R, Reyes-García V, Shennan S, Dietrich S, Tennie C (2013) The cultural evolution of technology and science. In *Cultural Evolution: Society, Technology, Language, and Religion*, P.J. Richerson & M. Christiansen (Eds.), pp. 193-216. MIT Press: Cambridge, MA.
- Mesoudi A, Thornton A (2018) What is cumulative cultural evolution? *Proc R Soc B* 285:20180712.
- Musgrave S, Morgan D, Lonsdorf E, Mundry R, Sanz C (2016) Tool transfers are a form of teaching among chimpanzees. *Sci Rep* 6:34783.
- Muthukrishna M, Henrich J (2016) Innovation in the collective brain. *Phil Trans R Soc B* 371(1690) <https://doi.org/10.1098/rstb.2015.0192>
- Nishida T, Matsuzaka, McGrew WC (2009) Emergence, propagation or disappearance of novel behavioral patterns in the habituated chimpanzees of Mahale: a review. *Primates* 50(1):23-36.
- O'Mahony S (2003) Guarding the commons: how open source contributors protect their work. *Res Policy* 32(7):1179–1198.
- Patterson EM, Mann J (2011) The ecological conditions that favor tool use and innovation in wild bottlenose dolphins (*Tursiops* sp.) *PLoS ONE* 6(7):e22243.
- Prasher S, Thompson MJ, Evans JC, El-Nachef M, Bonier F, Morand-Ferron J (2019) Innovative consumers: ecological, behavioral, and physiological predictors of responses to novel food. *Behav Ecol* DOI: 10.1093/beheco/arz067
- Ramsey G, Bastian ML, van Schaik C (2007) Animal innovation defined and operationalized. *Behav Brain Sci* 30:393-437.
- Reader SM, Laland KN (2001) Primate innovation: sex, age and social rank differences. *Int J Primatol* 22(5):787-805.

- Reader SM, Laland KN (2003) *Animal Innovation* Oxford University Press: Oxford, UK.
- Reader SM, Morand-Ferron J, Flynn E (2016) Animal and human innovation: novel problem and novel solutions. *Phil Trans R Soc B* 371(1690):20150182.
- Reindl E, Apperly IA, Beck SR, Tennie C (2017) Young children copy cumulative technological design in the absence of action information. *Sci Rep* 7:1788.
- Rogers EM (2005) *Diffusion of Innovations (Fifth Edition)*. Free Press: New York, NY.
- Sanz C, Call J, Morgan D (2009) Design complexity in termite-fishing tools of chimpanzees (*Pan troglodytes*). *Biol Lett* 5(3):293-296.
- Sasaki T, Biro D (2017) Cumulative culture can emerge from collective intelligence in animal groups. *Nature Comm* 8:15049
- Schumpeter JA (1942). *Capitalism, Socialism and Democracy*. Harper & Brothers: New York, NY. ISBN 978-1617208652.
- Smith A (1776) *An Inquiry into the Nature and Causes of the Wealth of Nations*. W Strahan and T Cadell: London, UK.
- St Clair JJH, Klump BC, Sugawara S, Higgott CG, Colegrave N, Rutz C (2018) Hook innovation boosts foraging efficiency in tool-using crows. *Nat Ecol Evol* 2:441-444.
- Tebbich S, Griffin AS, Peschl MF, Sterelny K (2016) From mechanisms to function: an integrated framework of animal innovation. *Phil Trans R Soc B* 371:20150195.
- Tennie C, Call J, Tomasello M (2009) Ratcheting up the ratchet: on the evolution of cumulative culture. *Phil Trans R Soc B* 364:2405-2415.
- Thornton A, McAuliffe K (2006) Teaching in wild meerkats. *Science* 313:227-229.
- Thornton A, Samson J (2012) Innovative problem solving in wild meerkats. *Anim Behav* 83(6):1459-1468.

- van de Waal E, Bshary R (2010). Contact with human facilities appears to enhance technical skills in wild
vervet monkeys (*Chlorocebus aethiops*). *Folia Primatol* 81:282-291.
- van Schaik CP, Burkart J, Damerius L, Forss SIF, Koops K, van Noordwijk MA, Schuppli C (2016) The
reluctant innovator: orangutans and the phylogeny of creativity. *Phil Trans R Soc B*
371:20150183.
- von Hippel E (1988) *The Sources of Innovation*. Oxford University Press: New York, NY.
<http://web.mit.edu/evhippel/www-old/books/sources/Sofl.pdf> [Accessed 5/12/2019].
- von Hippel E (2005) *Democratizing Innovation* The MIT Press: Cambridge, MA.
<http://web.mit.edu/evhippel/www/democ1.htm> [Accessed 5/29/2016].
- von Hippel E (2017) *Free Innovation* The MIT Press: Cambridge, MA.
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2866571 [Accessed 5/7/2019].
- Whiten A, Goodall J, McGrew WC, Nishida T, Reynolds V, Sugiyama Y, Tutin CEG, Wrangham RW, Boesch
C (1999) Cultures in chimpanzees. *Nature* 399:682-685.