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Précis of *Cognitive Gadgets: The Cultural Evolution of Thinking*

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Abstract

Cognitive gadgets are distinctively human cognitive mechanisms – such as imitation, mind reading, and language – that have been shaped by cultural rather than genetic evolution. New gadgets emerge, not by genetic mutation, but by innovations in cognitive development; they are specialised cognitive mechanisms built by general cognitive mechanisms using information from the sociocultural environment. Innovations are passed on to subsequent generations, not by DNA replication, but through social learning: People with new cognitive mechanisms pass them on to others through social interaction. Some of the new mechanisms, like literacy, have spread through human populations, while others have died out, because the holders had more students, not just more babies. The cognitive gadgets hypothesis is developed through four case studies, drawing on evidence from comparative and developmental psychology, experimental psychology, and cognitive neuroscience. The framework employed – cultural evolutionary psychology, a descendant of evolutionary psychology and cultural evolutionary theory – addresses parallel issues across the cognitive and behavioural sciences. In common with evolutionary developmental biology (evo-devo) and the extended evolutionary synthesis, cultural evolutionary psychology underlines the importance of developmental processes and environmental factors in the emergence of human cognition. In common with computational approaches (deep learning, predictive coding, hierarchical reinforcement learning, causal modelling), it emphasises the power of general-purpose mechanisms of learning. Cultural evolutionary psychology, however, also challenges use of the behavioural gambit in economics and behavioural ecology, and rejects the view that human minds are composed of "innate modules" or "cognitive instincts."

1. Introduction

What makes us such peculiar animals? What is it about the human mind that has enabled us to transform our environments, to become so dependent on cooperation for survival, and thereby to construct the edifices of knowledge and skill in which our lives are embedded: craft, technology, agriculture, science, religion, law, politics, history, music, trade, art, literature, and sport? Contemporary answers assume that adult humans have mental faculties different from those of all other extant animals, and the differences have two sources: nature and nurture. Whether distinctively human faculties are understood to be symbolic or sub-symbolic, model-based or model-free, general- or special-purpose, modular or holistic, optimal or kluge-ridden, it is assumed that, insofar as they do their jobs well, it is because these faculties have been shaped by natural selection operating on genetic variants (nature) and by interaction between the neurocognitive system and its environment in the course of an individual's development (nurture).

Cognitive Gadgets: The Cultural Evolution of Thinking (Heyes 2018; henceforth *Cognitive Gadgets*) argues that the most strikingly distinctive features of the human mind come from a third source: culture. Natural selection operating on cultural variants – traits inherited through social interaction – doesn't only give us beliefs, tools and techniques; it also produces new neurocognitive mechanisms. In a slogan: Cultural evolution shapes not just what we think but how we think it. In a saintly metaphor: Cultural evolution changes not only the grist but also the mills of the human mind (Aquinas 1272; Heyes 2012a). In a contrapuntal catchphrase: Distinctively human cognitive mechanisms – such as language, theory of mind, causal reasoning, episodic memory, imitation, and morality – are not "cognitive instincts" (Pinker 1994) but "cognitive gadgets." These mechanisms, which are absent or merely nascent in other animals, were not designed by human minds, but they are the products of human rather than genetic agency. They are gadget-like in being relatively small but crucially important parts of the mind. The bulk of our behaviour is controlled by mechanisms we share with other animals, but cognitive gadgets are what make human minds and lives so very odd.

Literacy is a cognitive gadget. The capacity to read printed matter depends on dedicated neurocognitive mechanisms. Written language emerged only 5,000 to 6,000 years ago, too recently in human history for the genetic evolution of neurocognitive mechanisms specialised for reading. Therefore, insofar as those mechanisms do their jobs well, it must be because they have been shaped by cultural evolution.

Cognitive Gadgets is an academic book written by a psychologist for accessibility to psychologists, neuroscientists, evolutionary biologists, anthropologists, archaeologists, computer scientists, economists, philosophers, and others interested in human evolution. I worked hard to make it short, hoping it would be read even in disciplines in which books are rare beasts. One of the consequences of brevity is that the logical geography in chapter 1 is local. Focussing on closely related ideas in the recent past, chapter 1 identifies the framework developed in the book as "cultural evolutionary psychology," a direct descendant of "evolutionary psychology" (Barkow et al. 1992; Pinker 1994) and "cultural evolutionary theory" (Boyd & Richerson 1985; Campbell 1965; Cavalli-Sforza & Feldman 1981; Dennett 1990; 1991; Henrich 2015) (see Fig. 1). Cultural evolutionary psychology is like evolutionary psychology in having the human mind as its explanatory target, and like cultural evolutionary theory in emphasising the importance of social learning as a force in human evolution, but it differs from both of these approaches in suggesting that distinctively human cognitive mechanisms get their adaptive characteristics from cultural rather than genetic evolution.

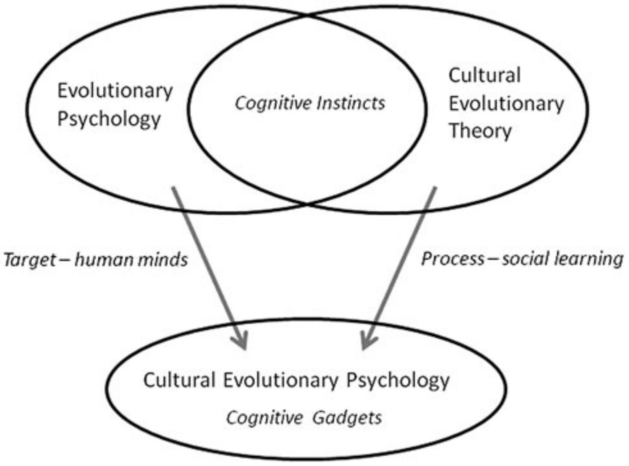

Figure 1. Relations between evolutionary psychology, cultural evolutionary theory, and cultural evolutionary psychology.

Viewed more broadly and with greater historical depth, the central thesis of *Cognitive Gadgets* addresses the modularity debate in cognitive science (Fodor 1983; Samuels 2012) and discussions of functional specialisation in ethology (de Waal & Ferrari 2010; Lorenz 1969). It suggests that, at least in humans, specialised cognitive mechanisms are built by general-purpose cognitive mechanisms; modules are acquired (Karmiloff-Smith 1995). In making this case, *Cognitive Gadgets* joins the battle initiated by the British Empiricists 300 years ago over the power of general-purpose mechanisms of learning, siding with advocates of deep learning, predictive coding, hierarchical reinforcement learning, causal modelling, and Bayesians of almost every stripe (Lake et al. 2017). It also challenges the use of the behavioural gambit in economics and behavioural ecology (Fawcett et al. 2012; Nettle et al. 2013), discouraging a black box approach to neurocognitive mechanisms (Heyes 2016a), and builds on research in developmental psychology and elsewhere documenting the importance of cultural learning and cross-cultural variation in the way minds work (Haun et al. 2006; Legare & Nielson 2015; Nisbett 2010; Shiraev & Levy 2014; Tomasello 1999). At the broadest level, in common with evo-devo (West-Eberhard 2003; 2005), and the extended evolutionary synthesis (Laland et al. 2015), *Cognitive Gadgets* stresses the critical, formative roles of developmental processes and environmental factors in the emergence of human cognition.

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Cognitive Gadgets has four foundational chapters (1–4), four case study chapters (4–8) each focusing on one cognitive gadget, and a concluding chapter (9).

2. Nature, nurture, culture

2.1. Biological information

The development of every aspect of human behaviour and cognition, like the development of all biological systems, depends on a rich, turbulent stew of factors. There are no pure cases of nature or of nurture; no biological characteristic is caused only by "the genes" or only by "the environment." Nonetheless, drawing on the teleosemantic conception of information (Millikan 1984; Shea 2013), I argue in chapter 2 that psychologists and biologists can and should seek to isolate the contributions of nature (genetically inherited information), nurture (information derived from direct interaction between the developing system and its environment), and culture (information inherited via social interaction) to human cognitive development. Without this purpose and discipline, there is a risk that explanations of cognitive development will be no more than unwieldy descriptions, like Lewis Carroll's fictional map with a scale of one mile to one mile, or manageable only because they privilege some causes over others in an arbitrary way. Arbitrary privilege dominated the behavioural sciences of the twentieth century. As the pendulum swung from instinct theory (Kuo 1922) to behaviourism (Watson 1930) and back again to evolutionary psychology via classical ethology (Lorenz 1965; Tinbergen 1963) and sociobiology (Wilson 1975), researchers fixated on nature, then on nurture, and finally put the genes back in the ascendant.

2.2. Cultural evolution

The importance of culture (*sensu* information inherited via social interaction) in shaping human behaviour has been emphasised by cultural evolutionists with increasing force since the 1980s (Boyd & Richerson 1985; Campbell 1965; Cavalli-Sforza & Feldman 1981; Henrich 2015; Morin 2015; Sperber 1996). The idea of cultural evolution comes in three strengths: historical, populational, and selectionist (Fig. 2; Brusse 2017; Godfrey-Smith 2009; Lewens 2015). When the term *cultural evolution* is used in the

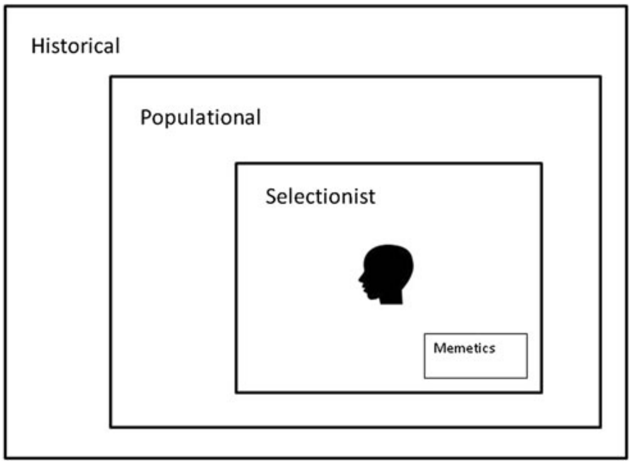

Figure 2. Relations between purely historical, populational, and selectionist conceptions of cultural evolution.

weakest historical sense, it means nothing more than change over time in some characteristic that varies between human groups. The stronger populational conception assumes that large-scale changes of this sort (e.g., changes in the distribution within a population of the use of particular technologies, or the consumption of certain foods) are the aggregate consequences of many episodes of social learning – of episodes in which individuals learn from others to use a particular technology or to eat a certain food. The strongest conception of cultural evolution, the selectionist view, shares the populational assumption and claims that the conditions necessary for Darwinian or natural selection are present in the cultural domain: There are mechanisms for introducing variation, selection processes, and mechanisms preserving selected variants (Campbell 1974). *Cognitive Gadgets* pursues the selectionist approach because this approach has the potential to explain the adaptive character of distinctively human cognition mechanisms – why they do their jobs reasonably well. It assumes that genetic evolution and cultural evolution are based on the same variation-and-selective-retention heuristic, and proposes that, rather than being on a short "genetic leash" (Lumsden & Wilson 2005, p. 144), cultural evolution is highly autonomous with respect to genetic evolution.

2.3. Cultural evolution of cognitive mechanisms

To apply a selectionist view of cultural evolution not only to beliefs and behaviour (the grist of the mind) but also to cognitive mechanisms (the mills), it is necessary to identify variants, routes of inheritance, and mechanisms of inheritance.

2.3.1. Variants

Variants, or traits, are the things to be quantified in calculations of fitness. In the case of mental grist, it is difficult to isolate variants in a principled way, because the only guide is folk psychology. We are forced to consult common sense or intuition for hypotheses about where one belief ends and another begins – about whether a practice, such as eating spicy food, constitutes one behaviour or many. In contrast, cognitive science is a rich source of empirically grounded hypotheses about variant cognitive mechanisms (mills). It stipulates that there is only one token of each type of cognitive mechanism in each brain and distinguishes types of cognitive mechanisms in a functional way, according to the kind of information it can process and the computations and representations it uses to process the information. For example, in the dual-route cascade model of reading (Coltheart et al. 2001), a "reading aloud mechanism" is defined as a mechanism that can convert script into speech, and one reading aloud mechanism can differ from another in terms of the range of script sequences it can convert into speech (only regular, or regular and irregular words) and the types of representations (sensory and/or structured) it uses.

2.3.2. Routes of inheritance

The cultural inheritance of cognitive mechanisms, like that of beliefs and behaviour, can be vertical (from biological parents to their offspring), oblique (from individuals of one biological generation to genetically unrelated or distantly related individuals of the next generation), and/or horizontal (between individuals of the same biological generation) (Cavalli-Sforza & Feldman 1981). The importance of each route may vary across cultures and types of cognitive mechanism, but a distributed pattern is likely to be common, in which all three routes see heavy traffic at different times in development. For example, in contemporary Western societies, the foundations of mindreading – the capacity to ascribe thoughts and feelings – are laid in early childhood through interaction with parents (vertical; Slaughter & Peterson 2012) and other members of the parental generation (oblique; Lewis et al. 1996). Later, when children and adults talk to one another about people's motivations and misapprehensions and read literary fiction, the development of mindreading is influenced predominantly by peers (horizontal; Kidd & Castano 2013).

2.3.3. Mechanisms of inheritance

It is risky to use words like "copying" and "transmission" to describe any mechanism of cultural inheritance. The processes that send beliefs and behaviour along the vertical, oblique, and horizontal routes are seldom analogous to DNA replication (Heyes 2017a), and a cognitive mechanism is certainly not a pellet of information that can be copied inside your head, sent through the air, and planted wholesale in my head. Rather, cognitive mechanisms are culturally inherited through social interactions, sometimes with many agents over an extended period of developmental time; these interactions gradually shape a child's cognitive mechanisms so that they resemble those of the people around them. Reading is a clear example. Everyone agrees that children are typically taught to read, that literacy training produces new neurocognitive mechanisms, and that we do not genetically inherit specific predispositions to develop these mechanisms. Cultural evolutionary psychology merely draws attention to the fact that literacy training is a set of social interactions that provide demonstrations, instructions, feedback, and encouragement in formal and informal settings. If literacy training were achieved by planting a "reading chip" in each child's brain, the cultural inheritance of reading would be more like the genetic inheritance of eye colour, but it would not necessarily be more effective in preserving selected variants.

2.4. Nature, nurture, culture – In practice

The final section of chapter 2 turns to a practical question: By what empirical methods can we tease apart the contributions of nature, nurture, and culture to the development of cognitive mechanisms? I argue that the methods required are means of distinguishing "poverty of the stimulus" (Chomsky 1965) from "wealth of the stimulus" (Ray & Heyes 2011) – cases in which the developmental environment provides too little (poverty) or at least enough (wealth) usable information to explain the properties of a cognitive mechanism. Poverty is a sign that the development of an adaptive cognitive trait depends on genetically inherited information (nature), whereas wealth is a sign that development depends on learning in a broad sense (nurture) and/or on culturally inherited information (culture). Where there is wealth, nurture is indicated when cognitive development varies with features of the environment in which development is actually occurring, with information that can be acquired by asocial learning, and by the kinds of social learning found in a broad range of animals. Culture is indicated when cognitive development varies with longer-term features of the environment: features that may not be present when a particular individual is developing or that can be acquired only via the kinds of social learning known as cultural learning.

Training studies can help distinguish the roles of nature, nurture, and culture (e.g., De Klerk et al. 2015; Lohmann & Tomasello 2003), but most of the empirical methods with the power to parse cognitive development examine patterns of spontaneous covariation. They relate differences in cognitive ability to opportunities for learning and social learning across (1) time points in development, (2) groups or individuals within a human population, (3) human populations, or (4) species. Examples of these methods are found in developmental psychology, cognitive psychology, cognitive neuroscience, behavioural genetics, cross-cultural psychology, and ethology, but there is currently a tendency in all of these fields to document cognitive variation without asking where it comes from, or laced with the assumption that nature is the dominant force.

3. Starter kit

Cognitive Gadgets suggests that the genetic starter kit for human cognition, although extensive, is very similar to the starter kits of other animals, including chimpanzees. In the course of hominin evolution, natural selection operating on genetic variants tweaked the mind in small but important ways. Genetic evolution has not given us programmes for the development of powerful domain-specific cognitive mechanisms, such as mindreading and language, but it has made us friendlier than our primate ancestors; enhanced our attentional biases towards other agents; and expanded our capacities for domain-general learning and executive control. These are the "Small Ordinary" gene-based changes that enable developing humans to upload "Big Special" cognitive mechanisms – cognitive gadgets – from their culture-soaked environments (Heyes 2018, pp. 52–53).

3.1. Emotion and motivation

There is evidence that modern humans are more socially tolerant (less aggressive to conspecifics) and more socially motivated (more inclined to seek and value social rewards) than our primate ancestors, and that these propensities are due to genetic evolution. Some of the most striking evidence of heightened social tolerance comes from archaeological work showing that, in the last 200,000 years, human skulls have undergone "craniofacial feminization" (Cieri et al. 2014). Combined with studies of domestication in a range of nonhuman species, including wolves (Darwin 1868; Wilkins et al. 2014), these craniofacial changes suggest a reduction in androgen activity favoured by genetic evolution because it made humans less likely to initiate and elicit aggression from conspecifics. In the case of social motivation, there are signs that humans have an exaggerated, inborn tendency to enjoy "response-contingent stimulation" – events, typically social in origin, that are predicted or controlled by their own actions (Floccia et al. 1997). This may be due to upregulation of oxytocin, a neuropeptide that has been tweaked by genetic evolution in numerous ways over the last 700 million years (Roney 2016).

Increments in social tolerance and motivation are quantitative changes in temperament, not the kind of thing one would normally expect to support a cognitive revolution. But they are important because they give developing humans access to a wide range of teachers and expert models, not only mothers, and incline them to act and think in any way that yields social rewards.

3.2. Attention

Social tolerance and motivation get developing humans up close and personal with a wide range of people who are equipped to fill and shape their minds with culturally inherited information. Genetically inherited input biases ensure that, from birth, human children target their attention on these experts, ready to drink in the information they have to offer (Heyes 2003).

In common with many other animals, human newborns attend more to biological than nonbiological motion (Bardi et al. 2011; 2014). Unlike other primate species, we also have inborn preferences for faces and voices. At birth, human babies turn their heads for longer to track a face-like triangle of dark blobs than an inversion of the same stimulus (Johnson et al. 1991; Reid et al. 2017). They also suck harder to hear speech sounds than synthetic sounds with similar pitch contour and spectral properties (Vouloumanos & Werker 2007). In the first year of life, both of these attentional biases become more specific. For example, the neonatal "blob bias" becomes a preference for human over other primate faces at three months (Dupierrix et al. 2014), and for human faces making direct eye contact at four months (Vecera & Johnson 1995). Gaze-cuing, a tendency to direct attention to the object or area in front of moving eyes, appears at two to four months (Hood et al. 1998). At between 6 and 12 months, gaze-cuing becomes more selective and active: Infants become more inclined to follow gaze when a gaze shift is preceded by direct eye contact (Senju & Csibra 2008), and to look back and forth between an adult's face and an object to check that they have the right spatial target (Carpenter & Call 2013).

Each stage in this developmental sequence makes infants more teachable by increasing the extent to which their attention is controlled by knowledgeable adults. Some researchers see a number of genetic adaptations coming online in the course of the sequence, including mindreading, but in *Cognitive Gadgets,* I argue – using the parsing methods outlined in chapter 2 – that there is no compelling evidence for this view. As long as social rewards are more likely to follow direct eye contact than a glimpse of averted gaze, and as long as gaze shifts after eye contact better predict an encounter with an interesting object, reinforcement learning can build the full panoply of gaze-cuing phenomena on the foundation of a simple, genetically inherited face preference (Moore & Corkum 1994; Paulus et al. 2011; Triesch et al. 2006).

3.3. Cognition

Associative learning is a set of domain-general processes, including stimulus-stimulus and reinforcement learning, that have been investigated using Pavlovian and instrumental conditioning procedures (Pearce 2013). Associative learning has been found in every vertebrate and invertebrate group where it has been sought, and in a wide range of functional contexts from foraging to predator avoidance, mate choice, and navigation (Heyes 2012b; MacPhail 1982; Shettleworth 2010). Comparisons across extant species suggest that genetic evolution has made some qualitative changes to associative learning in the course of its multi-million-year history, fashioning it into a powerful method of tracking causal/predictive relationships between events (Dickinson 2012). There is no evidence that associative learning has undergone major, qualitative changes in the recent past and certainly not in the hominin line, but it is likely that, compared with other apes, we are genetically prepared to forge associations faster, learn more of them in parallel, and to attach associations to specific contexts more readily (Fagot & Cook 2006; Holland 1992).

When associative learning was thought to control nothing more than "spit and twitches" (Rescorla 1988), our expanded capacity for this kind of domain-general learning seemed to have nothing to do with the peculiarity of human lives. However, recent work, much of it social cognitive neuroscience, indicates that associative learning plays a critical role in our capacities to teach and engage in group decision-making. For example, associative learning enables us to keep track of the relationship between a pupil's actions and their outcomes (Apps et al. 2015), and to weigh advice from another agent against our own experience (Behrens et al. 2008; Garvert et al. 2015).

Although not as phylogenetically widespread as associative learning, executive functions – inhibitory control, working memory, and cognitive flexibility – are also found in a range of species (Cook et al. 1985; MacLean et al. 2014; Matzel & Kolata 2010). No one doubts that executive functions play a major role in human cognition, that they are more highly developed in humans than in other animals, or that a good deal of this expansion is due to nurture and culture (Diamond 2013). However, there is reason to believe that genetic evolution – nature – has also played a part in expanding the power, capacity, and agility of executive function. The most widely cited evidence comes from neuroanatomical studies showing that the prefrontal cortex, which is focally involved in executive function, is disproportionately larger (Passingham 2008; Passingham & Smaers 2014; Rilling 2014) and more extensively connected with phylogenetically older brain areas (Anderson & Finlay 2014; Peterson & Posner 2012; Zilles 2005) in humans than in chimpanzees.

4. Cultural learning

Cultural evolutionary psychology is both a framework for research and a hypothesis. As a framework, it recognises that distinctively human cognitive mechanisms can be shaped by culturally inherited information, as well as by genetically inherited information and learning (chapter 2). As a hypothesis, it proposes that cultural inheritance has played the dominant role in shaping all or most distinctively human cognitive mechanisms. To advance the hypothesis, chapters 5–8 each look in detail at evidence relating to one type of distinctively human cognition: selective social learning, imitation, mindreading, and language. These are all varieties of cultural learning.

Cultural learning is especially important for two reasons. First, both evolutionary psychologists and cultural evolutionary theorists, although divided on many issues, are united in assuming that the mechanisms of cultural learning are genetically inherited. Therefore, cultural evolutionary psychology warrants pursuit as a descendant of evolutionary psychology and cultural evolutionary theory only if there are good reasons to challenge this consensus. Second, from the perspective of cultural evolutionary theory, which I broadly share, mechanisms of cultural learning play a crucial role in making human lives so different from those of other animals. Like other distinctively human faculties, cultural learning meets challenges that arise in an individual's lifetime, enabling each of us to navigate the world of people (cf. face processing) and things (cf. causal understanding). However, unlike other faculties, cultural learning also underwrites a whole new inheritance system: cultural evolution. It is a gift that goes on giving. Cultural learning enables each person and social group to benefit from the accumulated experience of innumerable other people, past and present, and thereby collectively to acquire knowledge and to develop skills that are way beyond those of other species.

Cultural learning is typically understood to be a subset of processes known as social learning, and social learning processes are thought to overlap with those of asocial or individual learning (e.g., Henrich 2015). This way of thinking (shown in Fig. 3) has been shaped by the anthropologists, biologists, economists, and mathematicians who have pioneered research on cultural evolution, and it has done some good service. However, from a cognitive science perspective, the framework in Figure 3 has two significant problems:

1. Cultural evolutionists tend to treat as processes phenomena that cognitive scientists would regard as effects, that is, as things to be explained rather than things that do the explaining. They ignore the cognitive and neurological processes that produce observable changes in behaviour (e.g., Whiten & Ham 1992).
2. Cultural learning is understood to be a "sophisticated subclass of social learning" (Henrich 2015, p. 13), but there are no ground rules, empirical or conceptual, for deciding whether a particular type or example of social learning is or is not an example of cultural learning.

To enable dialogue between cultural evolutionary theory and cognitive science (Heyes 2017b), I propose a subtly different way of situating cultural learning, shown in Figure 4. In this alternative framework, the superordinate category is learning – encoding for

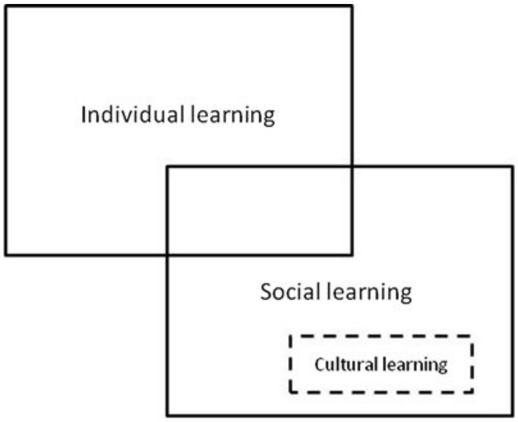

Figure 3. The received view of relations between individual learning, social learning, and cultural learning.

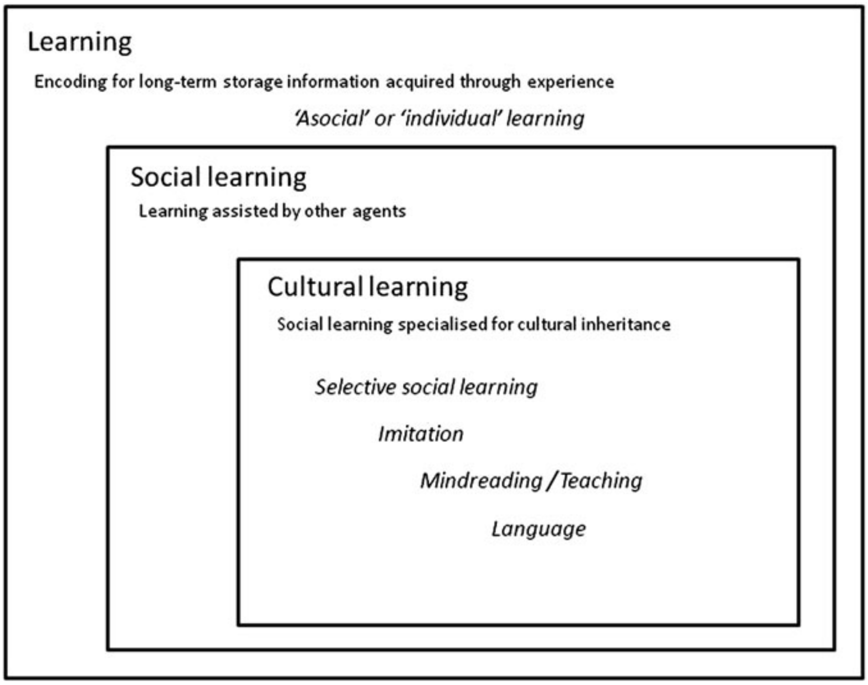

Figure 4. A framework for research on the relations between learning, social learning, and cultural learning, enabling dialogue between cognitive science and cultural evolutionary theory.

long-term storage information acquired through experience. When learning is assisted by contact with other agents, it is called social learning. When learning is not assisted by other agents, it is called asocial learning or individual learning. Cultural learning is a subset of social learning involving cognitive processes that are specialised for cultural evolution – for example, processes that enhance the fidelity with which information is passed from one agent to another. This framework does not allude to processes in distinguishing asocial from social learning, and therefore avoids the misleading impression that social learning is known to depend on different cognitive mechanisms from asocial learning. Furthermore, although it makes the conventional assumption that cultural learning involves processes specialised for cultural inheritance, it does not embody any assumptions about how or why these processes are specialised. Rather, it is a framework for investigation of three questions that cultural evolutionists rarely tackle:

1. *Cognition question*: How do the mechanisms of cultural learning differ from those of social learning at the cognitive level?
2. *Specialisation question*: How have genetic evolution and/or cultural evolution contributed to the specialisation of cultural learning?
3. *Contribution question*: In what ways do the features that distinguish cultural learning from social learning contribute to cultural inheritance? For example, do they make "improved" cultural variants more likely than "unimproved" variants to be passed on?

Rather than appealing to sophistication, implying that we already know what is distinctive about the mechanisms of cultural learning at the cognitive level (question 1 above), this framework defines cultural learning by ostension – by pointing at putative examples of cultural learning. The cultural learning box in Figure 4 lists the five categories of psychological phenomena (each containing behavioural effects and weakly specified cognitive processes) most commonly said by cultural evolutionists to be types of cultural learning:

1. Selective social learning (also known as learning biases, transmission biases, social learning rules, and social learning strategies)
2. Imitation (called *true imitation* when *imitation* is used as a synonym for *social learning*)
3. Teaching (or *pedagogy*)
4. Mindreading (also called *theory of mind*, *mentalising*, *shared intentionality*, *folk psychology*, and *social understanding*)
5. Language (so good they named it once)

These five categories are a natural place to start asking the cognition, specialisation, and contribution questions about cultural learning.

5. Selective social learning

In both of the schemes shown in Figures 3 and 4, social learning names a rag bag of behavioural effects – from a snail following a slime trail, to a student reading about calculus – in which learning by one agent, the "observer," is influenced in some way by contact of some sort with another agent, the "model" or "demonstrator." Social learning is said to be selective primarily when the influence of the model varies with the circumstances of the encounter ("when" selectivity; e.g., greater influence when the observer's environment has recently changed, known as a *copy when uncertain* social learning strategy), or with some feature of the available models ("who" selectivity; e.g., greater influence by older than younger models, known as a *copy older individuals* social learning strategy).

Selective social learning has been a focus of cultural evolutionary studies since the 1980s, but it barely appears on the radar of cognitive scientists. Consequently, whereas chapters 6–8 bring cultural evolutionary theory to bear on problems in cognitive science, chapter 5 brings cognitive science into closer contact with cultural evolutionary theory. More specifically, chapter 5 tackles head-on the cognition, specialisation, and contribution questions.

Addressing the cognition question, I suggest that most social learning is (1) mediated by the same domain-general, associative processes as asocial learning, and (2) made selective by the same broadly attentional processes that make asocial learning selective. Four lines of evidence support the first of these hypotheses (Heyes 1994; 2012c):

1. Social and asocial learning ability covary. Among birds and primates, species and individuals that perform well in tests of social learning tend also to perform well in tests of asocial learning (Boogert et al. 2008; Bouchard et al. 2007; Reader et al. 2011).
2. Solitary animals are capable of social learning. In laboratory tests, animals such as red-footed tortoises (Wilkinson et al. 2010), which lead solitary lives in the wild, prove themselves adept at learning from social cues.
3. Social learning and asocial learning each come in the same three basic varieties: learning about single stimuli, about relationships among stimuli, and about relationships between stimuli and responses, or actions and outcomes (Heyes 1994; 2011). Each type of social and asocial learning has been found in a wide range of species, including humans (Dawson et al. 2013; Leadbeater et al. 2015).
4. Social learning bears the footprints of associative learning. For example, studies of human decision-making combining mathematical modelling with functional brain imaging have found that the same computations, based on the calculation of prediction error, are involved in processing information from social partners (social learning) and personal experiences of reward (asocial learning) (Behrens et al. 2008; Garvert et al. 2015; Hill et al. 2016).

The second hypothesis suggests that, in most cases, social learning is selective by virtue of domain-general attentional processing, rather than domain-specific strategic processing. For example, when exposed to two potential models, observers attend more to one model than the other, and therefore learn more from one model than the other; they do not learn equally from both models and then, in a second stage of cognitive processing, decide which of the models they should trust to guide their own behaviour. Evidence consistent with this view comes from studies of selective social learning in children, adults, and nonhuman animals (Heyes 2016a; 2016d; Heyes & Pearce 2015). However – and here's the crucial part of my answer to the cognition question – in adults and children older than four or five years, there is evidence that some selective social learning is truly strategic; the observer chooses to trust one model rather than another by applying an explicit, metacognitive rule, such as *copy the boat builder with the biggest fleet* or *copy digital natives* (Fleming et al. 2012). In one such study, people used information from another agent – advice about which of two options to choose – to the extent that they believed the advisor to be motivated to help rather than to mislead them (Diaconescu et al. 2014). These beliefs were explicitly stated, and the basic effect – covariation between the advisors' incentives and the participants' use of their advice – disappeared when participants were told that the advisors did not know which option they were recommending. Therefore, these results indicate that the participants used an explicitly metacognitive strategy such as *copy when the model intends to help*.

Thus, my answer to the cognition question is: The selective social learning mechanisms that are specialised for cultural inheritance, that constitute cultural learning, differ from other selective social learning mechanisms in being explicitly metacognitive; they represent *who knows* in the form of conscious, reportable, domain-specific rules. If this is correct, then research on the development of metacognitive rules showing that they are learned through social interaction (Bahrami et al. 2012; Güss & Wiley 2007; Heine et al. 2001; Hurks 2012; Li 2003; Mahmoodi et al. 2013; Mayer & Träuble 2013) provides an answer to the specialisation question; it suggests that the selective social learning mechanisms that constitute cultural learning have been specialised *by* cultural evolution *for* cultural evolution. Consistent with this answer, there is a growing body of evidence of cross-cultural variation in the metacognitive social learning strategies used by adults (Efferson et al. 2007; Eriksson 2012; Henrich & Broesch 2011; Mesoudi et al. 2015; Toelch et al. 2014). For example, in contrast with Westerners, Fijians are less likely to seek advice from people with more formal education (Henrich & Broesch 2011). Compared to Britons, people from mainland China engage in more social learning, and their social learning is less dependent on uncertainty (Mesoudi et al. 2015).

Finally, my answer to the contribution question comes in three steps:

1. Metacognitive social learning strategies are able to focus social learning on knowledgeable agents with greater accuracy and precision because these strategies have been honed by cultural selection.
2. When knowledgeable agents can be identified accurately, individuals and social groups can afford to invest in the development of cognitive mechanisms enabling high-fidelity cultural inheritance of skills.
3. High-fidelity inheritance promotes cultural adaptation by reducing the number of models contributing to each new token of a cultural trait and the degree to which the model's influence is contaminated by asocial learning (Godfrey-Smith 2012).

6. Imitation

Imitation is the longest-serving category of cultural learning. Scientists have been claiming for more than a century that imitation involves complex computations specialised by genetic evolution for high-fidelity cultural inheritance, and that this cognitive instinct plays a crucial role in allowing humans to make and use tools (Washburn 1908). Chapter 6 embraces the idea that imitation is special but argues that it is made possible by a culturally inherited mechanism. The selling point of chapter 6 is that it addresses head-on the question of how a new cognitive mechanism could be assembled in the course of ontogeny through social interaction.

Imitation occurs when observation of a model causes the observer to perform topographically similar behaviour, that is, behaviour in which parts of the observer's body move in the same way, relative to one another, as parts of the model's body. Thus, the boy in Figure 5 is imitating the men, not because he is wearing similar clothes and heading in the same direction, but because parts of the boy's body, his arms and torso, are configured – spatially related to one another – in the same way as those of the men. Imitation has been assumed to involve complex, dedicated computations because in many cases, like that in Figure 5, it solves a thorny correspondence problem. When the boy puts his hands behind his back, he doesn't see (or hear or feel) anything resembling what he sees (or hears or feels) when he looks at the men putting their hands behind their backs, and

Figure 5. An example of imitation.

yet somehow the boy's cognitive system has produced an action that looks the same, that corresponds, from a third-party perspective.

In the late 1970s, it was reported that newborn human babies can imitate a range of facial expressions and hand movements (Meltzoff & Moore 1977). The reliability and validity of these findings have been questioned repeatedly (Anisfeld 1979; 2005; Jacobson & Kagan 1979; Jones 2006; 2007; 2009; Koepke et al. 1983; Masters 1979; McKenzie & Over 1983; Meltzoff & Moore 1979). However, replicated and extended in some laboratories, they have led to widespread acceptance of a theory suggesting that the correspondence problem is solved by a black box delivered by the genes. This cognitive instinct theory suggests that humans have an innate device that detects "equivalences between observed and executed acts," both encoded "supramodally" as "organ relations," but does not propose computations that would allow organ relations to be derived from observed body movements or cashed out as executed actions (Meltzoff & Moore 1997). Thus, the cognitive instinct theory of imitation says there is a genetically inherited thing that solves the correspondence problem, but it does not say how the thing works. Identifying the thing with mirror neurons (Lepage & Theoret 2007) creates another black box. The question "How do people imitate?" becomes the question "How do mirror neurons imitate?"

The alternative, "Associative Sequence Learning" or cognitive gadget, theory of imitation suggests that the correspondence problem is solved by "matching vertical associations" – bidirectional excitatory links between sensory and motor representations of the same action, forged by associative learning during self-observation and specified types of sociocultural interactions (see Fig. 6). This theory offers a mechanistic explanation for the imitation of both familiar actions (sometimes called mimicry) and novel actions (sometimes called true imitation or observational learning). In the latter case, it proposes that, via associative learning, matching vertical associations create a new cognitive mechanism by connecting two domain-general processes that normally operate independently. Matching vertical associations gear perceptual sequence learning, processes that encode the serial order of external stimuli, to motor sequence learning, processes that normally operate only when the agent is learning a new skill, such as riding a bike, through practice (Catmur et al. 2009; Heyes & Ray 2000).

The cognitive instinct theory was recently undermined by a large-scale, longitudinal study of imitation in newborns, which reported negative results for all 11 gestures tested (Oostenbroek et al. 2016). In contrast, the gadget theory is supported by evidence of two kinds (for reviews, see Catmur et al. 2009; 2016; Cook et al. 2014): Training studies involving adults, infants, and nonhuman animals show that imitation – measured behaviourally and via mirror responses in the brain – can be enhanced, abolished, and reversed by novel sensorimotor experience. For example, adults usually do not imitate the actions of inanimate systems, such as robots, but after a brief period of training in which robotic movements are paired with topographically similar body movements performed by the observer, people imitate robots as much as they imitate other people (Press et al. 2005). The second kind of evidence indicates that imitation, although flexible and adaptive, has the signature limits (Butterfill & Apperly 2013) one would expect if it is controlled by matching vertical associations. For example, imitation learning is effector-dependent; it does not readily generalise across parts of the body. People who have observed a complex sequence of key-pressing movements can reproduce the sequence when their fingers are in the same keyboard positions as the fingers of the model, but they cannot imitate the sequence when their hands are crossed on the keyboard (right hand operates left keys, and vice versa), or when they are asked to use their thumbs rather than their fingers to press the keys (Bird & Heyes 2005; Leighton & Heyes 2010).

The final section of chapter 6 addresses five objections to the cognitive gadget theory of imitation, emphasising the following points.

1. *Intervention versus development.* Like most scientific evidence, the results of training studies – and related studies of expertise (e.g., Calvo-Merino et al. 2006) – support inference to the best explanation, not deduction (Lipton 2003). They favour the gadget theory over the instinct theory because they are exactly what the gadget theory predicts but difficult for the instinct theory to accommodate.
2. *Homo imitans.* Humans are more skilled and prodigious imitators than other animals, not primarily because they have better resources "on the inside" (e.g., higher capacity mechanisms of associative learning), but because they have superior resources "on the outside," cultural artefacts and practices that support the acquisition of matching vertical associations.
3. *Intentionality.* A matching vertical association for an action, x, makes it possible, not obligatory, to imitate x.

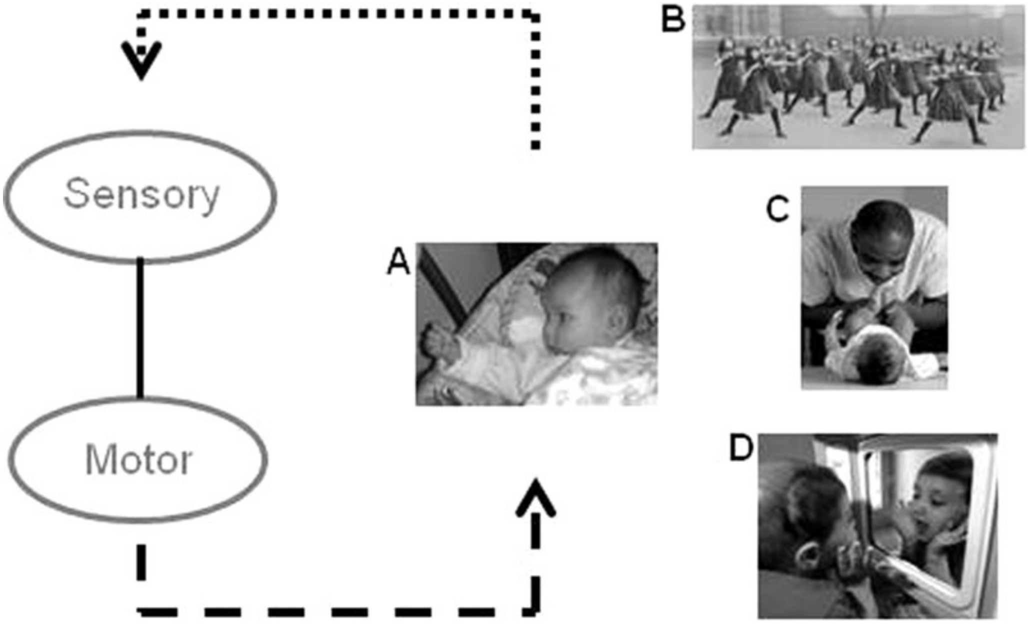

Figure 6. Matching vertical associations are acquired through sensorimotor learning. In the simplest case, self-observation (A), activation of a motor representation contributes to performance of an action (e.g., grasping; dotted arrow), and observation of the performed action produces correlated activation of a corresponding visual representation (dashed arrow). Correlated activation strengthens the excitatory link between the sensory and motor representations, establishing a matching vertical association (solid vertical line). Synchronous activities (B), being imitated by others (C), and optical mirrors (D) provide correlated sensorimotor experience for perceptually opaque actions, such as facial gestures and whole-body movements.

4. *Overimitation.* Children's propensity to imitate instrumentally superfluous features of action (Lyons et al. 2007) raises questions about the motivation, rather than ability, to imitate. Although the gadget theory is concerned with ability rather than motivation, it is consistent with evidence that overimitation is due to reinforcement learning (Baer & Sherman 1964; Garcia et al. 1971; Grusec & Abramovitch 1982; Young et al. 1994).
5. *What's the use?* The gadget model raises the possibility that evolutionists have overlooked the most important function of imitation: high-fidelity cultural inheritance, not of object-directed actions, but of communicative and gestural skills (Heyes 2013).

7. Mindreading

Mindreading, the ascription of mental states, is classed as a form of cultural learning because it is likely to be the special ingredient of human teaching. Effective teaching involves many other cognitive and motivational ingredients, including social tolerance and attentiveness, but mindreading stands out as the most likely candidate for a human-specific cognitive adaptation for teaching.

The idea that mindreading is a genetic adaptation, a cognitive instinct, begins to be less compelling when one compares mindreading with print reading (literacy), a distinctively human cognitive mechanism that is known to be a product of cultural evolution (Heyes & Frith 2014; see Sect. 1). For example, studies of neural specialization (Van Overwalle 2009), cultural variation (Shahaeian et al. 2011), and genetically heritable developmental disorders (autism; Frith 2001), have all been treated as evidence that mindreading is a cognitive instinct, and yet print reading shows comparable degrees of neural specialisation (Dehaene & Cohen 2011) and cultural variation (Changizi et al. 2006), and is associated with genetically heritable developmental disorders of its own (dyslexias; Paracchini et al. 2007).

At 5 years of age, monozygotic twins are no more alike than dizygotic twins in their mindreading ability (Hughes et al. 2005). This suggests negligible genetic influence and a powerful role for learning in the development of individual differences in mindreading, but it does not tell us what kind of learning is important. In principle, it could be the kind of introspection-based learning emphasised by simulation theory; the science-like learning postulated by theory-theory, in which the child tests her self-generated hypotheses against a database of observed behaviour; or, as gadget theory suggests, a form of cultural inheritance in which mindreading experts – parents and others – instruct children about the mind, in conversation and by structuring developmental environments. In chapter 7 of *Cognitive Gadgets*, I argue that evidence from natural experiments (Mayer & Träuble 2013; Pyers & Senghas 2009), observational studies (Meins 2012; Meristo et al. 2012; O'Brien et al. 2011; Slaughter & Peterson 2012; Taumoepeau & Ruffman 2006; 2008), and traditional experiments (de Villiers & de Villiers 2012; Lohmann & Tomasello 2003) favours the third of their possibilities. For example, in a natural experiment, deaf people who had been deprived of conversation about the mind because they learned Nicaraguan Sign Language (NSL) when it included very few mental-state terms were less likely to pass a false-belief test than a second cohort who had learned NSL later, when it contained a wider range of mental-state terms (Pyers & Senghas 2009). The first cohort was 10 years older than the second cohort; they had had 10 more years in which to introspect and test hypotheses. Therefore, if introspection or science-like learning, rather than conversation, were crucial for the development of mindreading, one would expect the first cohort to be better, not worse, at ascribing false belief.

Studies of implicit mindreading using eye-movement indices of behaviour prediction imply that nonhuman apes (Krupenye et al. 2016) and prelinguistic infants (Kovács et al. 2010; Onishi & Baillargeon 2005) are capable of ascribing false beliefs. According to the continuity interpretation, implicit mindreading is mediated by the same, specialized cognitive mechanisms that mediate explicit mindreading in deliberating adults (Baillargeon et al. 2010). If the continuity interpretation is correct, mindreading could not be a cognitive gadget because it develops without (apes) and before (infants) conversation about the mind. Two other interpretations of implicit mindreading are compatible with the cognitive gadget theory, however. According to the "two-systems" (Apperly 2010; Perner 2010) and "submentalizing" (Heyes 2014a; 2014b; 2015; 2017b) interpretations, implicit and explicit mindreading depend on different cognitive mechanisms. The two-systems view proposes that the mechanisms mediating implicit mindreading are specialised for fast and efficient representation of mental states, while the submentalizing view suggests that they are domain-general mechanisms, representing relatively low-level features of action stimuli – such as colour, shape, and movement – rather than mental states. Evidence that concurrent demands on executive function interfere with explicit mindreading (Bull et al. 2008), but not with implicit mindreading (Qureshi et al. 2010), and that people with autism can engage in explicit mindreading despite impairments in implicit mindreading favour the two-systems and submentalizing hypotheses over the continuity hypothesis (Senju et al. 2009).

The cognitive gadget theory implies that children learn to read minds through language and therefore appears to be in direct opposition to the Gricean view that ascription of mental states is a precondition for linguistic communication (Bloom 2000; Sperber & Wilson 1995; Tomasello 1999). For two reasons, however, I suspect that the cognitive gadget theory and the Gricean view of language are reconcilable. First, Grice offered a rational reconstruction, rather than a psychologically realistic account, of what is happening when people talk to one another (Sperber 2000). Second, Moore (2016; 2017) has argued persuasively that Gricean communication can get off the ground – in evolutionary and developmental time – with minimal mindreading; all that is needed is "a basic understanding of others' purposive activities and desires [which I would characterise as knowledge of action-outcome relationships], operating in conjunction with some tracking what others had or had not seen [or viewed]" (p. 19).

Thus, advancing an alternative to simulation theory and theory-theory, chapter 7 argues that mindreading is culturally inherited – a cognitive gadget. Expert mindreaders communicate mental state concepts, and ways of representing those concepts, to novices. As the present generation of novices become expert, they pass on the knowledge and skill of mindreading to the next cultural generation.

8. Language

I have been thinking about social learning, imitation, and mindreading for a long time, but I write about language as an outsider. While developing the ideas in *Cognitive Gadgets,* I immersed myself for the first time in research on the origins of language, expecting to find clear evidence that language is a cognitive instinct – one on which gadgets are built. Instead, I found a wealth of evidence that language is itself a gadget and a divide between genetic and cultural evolutionists that no longer appears to be resolvable by empirical means.

Chapter 8 begins by contrasting a gradualist genetic theory of language evolution (Culicover & Jackendoff 2005; Pinker 1994; Pinker & Bloom 1990) with a cultural theory of language evolution (Christiansen & Chater 2016), and then discusses evidence that should, or is widely thought to, support one of these theories over the other. The evidence relates to linguistic universals, critical periods, neural localisation, domain-general sequence learning, and social shaping.

8.1. Linguistic universals

There are few, if any, non-definitional features that all languages have in common (Evans & Levinson 2009; Everett 2005; Jelinek 1995). However, this is compatible with the genetic theory when linguistic universals are construed not as features that all or many languages have in common, but as components of Universal Grammar, or a genetically inherited language of thought (Berwick & Chomsky 2015). A "universal" in this sense need not be present in all or even most natural languages, and a feature that was found to be present in all languages would not necessarily be a universal (Boeckx 2006; Chomsky 1965; Pinker & Jackendoff 2005)

8.2 Critical periods

Research with migrant populations and native speakers indicates that second-language proficiency depends on number of years of exposure to the second language, rather than on whether learning began before or after puberty (Birdsong & Molis 2001; Flege et al. 1999; Hakuta et al. 2003), and that, with the exception of phonology (Werker & Hensch 2015), first- and second-language learners may obtain similar levels of proficiency (Dabrowska 2012). These findings suggest that, contrary to the claims of some genetic theorists (Lenneberg 1967; Pinker 1994), grammar learning is not a critical-period phenomenon; however, the critical-period claim is not an original or essential part of the genetic account of the evolution of language.

8.3 Neural localisation

Language enlists a more widely distributed set of brain areas than any other major psychological function (Anderson 2008), and Broca's area is more often active during non-linguistic than linguistic tasks (Poldrack 2006). These data certainly tell against the idea that there is a "language centre," but it is not clear why it was ever supposed that genetically inherited information is more likely than culturally inherited information to be found in a narrowly localised area of the brain (Cowie 2016; Lenneberg 1967; Pinker 1994).

8.4. Domain-general sequence learning

Computer simulation indicates that sequence learning, without inbuilt language-specific constraints, enables a system to process complex grammatical constructions in a human-like way (Christiansen & MacDonald 2009). Experiments examining individual differences in typically developing adults and children suggest that they use the same sequence learning processes to learn artificial and "real," linguistic grammars (Kidd 2012; Kidd & Arciuli 2016; Misyak & Christiansen 2012). Studies of people with specific language impairment indicate that their impairment is not, in fact, specific to language (Hsu & Bishop 2014; Hsu et al. 2014; Tomblin et al. 2007). Likewise, research with nonhuman animals confirms that domain-general sequence learning capacity has increased in the hominin line (Wilson et al. 2013) and provides a plausible model of how this change has been implemented in the primate brain (Bornkessel-Schlesewsky et al. 2015; Ivanova et al. 2016). It also supports evidence from humans that mutations of FOXP2 interfere with language by interfering with sequence learning more generally and that FOXP2 is not a "language gene" (Reimers-Kipping et al. 2011; Schreiweis et al. 2014).

8.5. Social shaping

Research on social shaping suggests that infants and children are frequently corrected by adults when they make grammatical errors (Bohannon et al. 1990; Demetras et al. 1986; Moerk 1991), and that this negative input is put to use in language learning (Street & Dabrowska 2010; Taumoepeau 2016). These findings, like those on sequence learning, confirm novel predictions of the cultural theory, and, in the case of social shaping, challenge Chomsky's "poverty of the stimulus argument," a foundation of the genetic account.

The genetic theory is proving remarkably resilient in the face of what appear to be empirical defeats (linguistic universals, critical periods, neural specialisation), and a tide of positive evidence supporting the cultural theory (sequence learning, social shaping). Some of this resilience may be due to the motility of the genetic theory. Chomsky's view has changed radically since the 1950s, but each of his successive approaches is represented in the current literature (Boeckx 2006; Crain et al. 2006; Culicover & Jackendoff 2005; Pinker & Jackendoff 2005). The genetic theory is also insulated by the competence-performance distinction (Chomsky 1965). This enables its proponents to argue that, for example, research on sequence learning and social shaping bears on the externalisation of language (performance), but not on whether there is a genetically inherited language of thought (competence). Some of the resilience may even come from historically deep convictions about the significance of language; the genetic theory more fully preserves the idea that language is a Rubicon separating humanity from the beasts. As an outsider, I can only conclude that, although the genetic theory of language evolution is appealing for a variety of reasons (some of them extra-scientific), the cultural theory – once a poor relation – is now clearly specified and rich in empirical support.

9. Cultural evolutionary psychology

The final chapter of *Cognitive Gadgets* returns to some of the evolutionary questions in chapter 2, now with concrete examples from the case studies, and discusses the prospects for a cultural evolutionary psychology.

9.1. Cultural group selection

Attempting to make the cognitive gadgets hypothesis as clear as possible, I try to spell out who benefits from the cultural selection of cognitive mechanisms and the nature of the benefit. This analysis allows two types of multilevel selection (CGS 1 and CGS 2; Damuth & Heisler 1988; Okasha 2005) and uses imitation as an example (see Fig. 7): Imagine a human population divided into two social groups, X and Y, defined geographically or culturally, not by genes. Each person has an imitation mechanism, gearing motor sequence learning to perceptual sequence learning via matching vertical associations (Ch. 6). There are two versions of this mechanism: M and M′; M′ is less common in X than Y. The M′ version has a richer repertoire of matching vertical associations for whole-body movements than the M version, enabling people with M′ more accurately to imitate actions involved in ritual (e.g., dance), hunting (e.g., stalking), and combat (e.g., spear throwing). As a consequence, bearers of M′ are better able than bearers of M to cooperate in a range of tasks (Heyes 2013; Tarr et al. 2015; Tunçgenç & Cohen 2016), and to sustain the cultural inheritance of techniques that enhance success in hunting and intergroup combat. These advantages lead groups in which the M′ mechanism predominates to acquire greater numbers of new members (CGS 1 in Fig. 7), or to produce more descendent groups (CGS 2 in Fig. 7), than groups in which M predominates.

9.2. Inheritance

The cultural inheritance of cognitive mechanisms involves social processes such as conversation, storytelling, turn-taking, collective reminiscing, teaching, demonstrating, and engaging in synchronous drills. For example, through conversation, teaching, and demonstration, children learn to deploy metacognitive social learning strategies in the same way as the people around them (Ch. 5). Through taking turns in face-to-face interaction and engaging in synchronous drills, children acquire a particular repertoire of matching vertical associations; they become able to imitate the same range of actions as their cultural parents (Ch. 6).

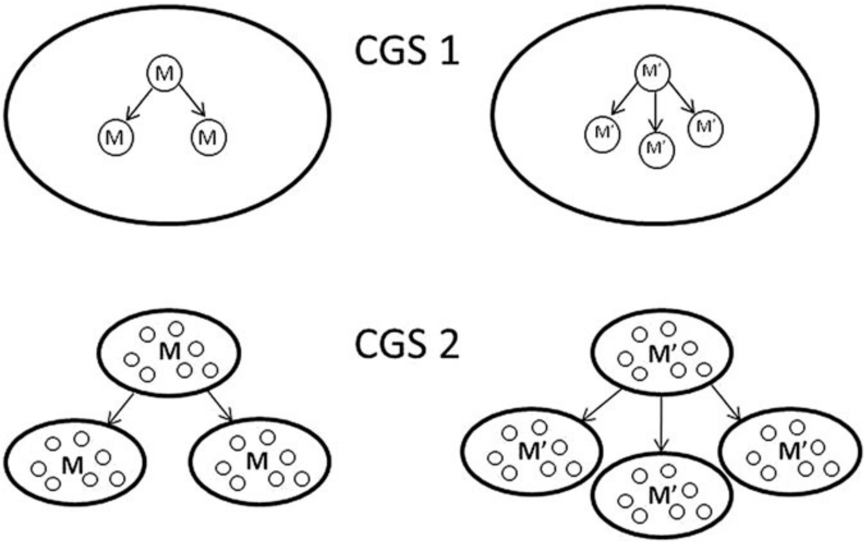

Figure 7. Two types of fitness in cultural group selection.

Through conversation, storytelling, and collective reminiscing, children become able to represent mental states and accumulate a stock of generalisations about the way mental states relate to one another, to behaviour, and to the world (Ch. 7; Nile & Van Bergen 2015; Salmon & Reese 2016). Dedicated research of a radically new kind is needed to measure the robustness of these inheritance mechanisms. In advance of such research, three considerations suggest that they are robust enough to support cultural group selection of cognitive processes:

1. High-fidelity replication is not a requirement for Darwinian selection (Godfrey-Smith 2012).
2. Redundancy is built into distributed inheritance (e.g., mindreading via vertical, horizontal *and* oblique routes).
3. Each social process of inheritance occurs repetitively, delivering multiple learning trials. Children are told a particular story not once but many times. Different stories contain the same themes, morals, and tropes. Adults imitate the same facial gestures over and over again in face-to-face interaction with infants. Collective reminiscence returns repeatedly to the same episodes.

9.3. Genetic assimilation

In principle, it is possible that new cognitive mechanisms start out as cognitive gadgets, constructed in the course of development through social interaction, but then selection progressively favours genetic mutations that reduce the experience-dependence of the gadgets' development, converting them into cognitive instincts (Henrich 2015). In practice, I have looked for, and failed to find, empirical evidence that this kind of genetic assimilation has occurred – for example, evidence that learning is faster in natural than unnatural conditions. Cognitive gadgets may resist genetic assimilation because distinctively human cognitive mechanisms need to be nimble. Their job is to track specific, labile features of the environment, which move too fast for genetic evolution. For example, social learning strategies track "who knows" in a particular social group, something that changes with shifting patterns in the division of labour and therefore of expertise. Imitation tracks communicative gestures, ritual movements, and manual skills that change as groups find new group markers, bonding rituals, and technologies. And mindreading, like language, must track not only externally driven change in the phenomena it seeks to describe, but also self-generated change: alterations in the way the mind works caused by shifts in the regulative properties of theory of mind (McGeer 2007).

9.4. A little history

The cognitive gadgets hypothesis is a force theory rather than an historical theory; it is concerned with the processes involved, rather than the history of events, in human evolution. The ideal theory would be high on both the force and historical dimensions. Therefore, connecting the cognitive gadgets theory to key events in human evolution, using the archaeological record, is a priority for future research. Making a start down that road and building on the "collective intelligence" hypothesis (Henrich 2004b; 2015; Kline & Boyd 2010; Muthukrishna & Henrich 2016; Richerson & Boyd 2013; Sterelny 2018), I suggest that climate-driven demographic changes around 250,000 years ago launched not only the cultural evolution of knowledge and skills, but also the cultural evolution of distinctively human cognitive mechanisms. The Small Ordinary components of the genetic starter kit were already in place (chap. 3) and had been supporting cooperation and simple stone technologies for millions of years. Demographic changes allowed the Small Ordinary components to begin to be elaborated by cultural group selection into the Big Special mechanisms that we now identify as, for example, causal understanding, episodic memory, imitation, theory of mind, and full-blown language.

9.5. Human nature

Cultural evolutionary psychology is consistent with an evolutionary causal essentialist conception of human nature: a hybrid of the nomological account (Machery 2008; 2018) and causal essentialist theories (Samuels 2012). On this view, human nature is the set of mechanisms that underlie the manifestation of species-typical cognitive and behavioural regularities that humans tend to possess as a result of the evolution of their species; crucially, evolution encompasses all selection-based evolutionary processes – genetic, epigenetic, and cultural. The primary implication of evolutionary causal essentialism is that human nature is labile; it changes over historical rather than geological time. The first signs of literacy date from about 6,000 years ago, and now, the cognitive gadgets that enable people to read, being present in more than 80%–90% of the global population, are part of human nature. On a broader scale, cultural evolutionary psychology implies that human minds are more agile, but also more fragile, than previously thought. We are not stuck in the Pleistocene past with Stone Age minds, and new technologies – social media, robotics, virtual reality – provide the stimulus for further cultural evolution of the human mind. However, we have more to lose. Wars and epidemics can wipe out not just know-how, but also the means to acquire that know-how. The capacity for cultural evolution, as well as the products of cultural evolution, could be lost.

9.6. Cultural evolutionary psychology

The idea at the core of *Cognitive Gadgets* – that cultural evolution shapes distinctively human cognitive mechanisms – is a bold, testable hypothesis. Of the mechanisms examined in the case studies, selective social learning provides the freshest opportunity for research by cognitive scientists. Beyond the case studies, there are many other mechanisms to be explored, including causal understanding and episodic memory. Moral reasoning is a priority because it is a form of cultural learning, and, being so intimately connected with emotion, has the potential to cast light on the co-evolution of cognitive and emotional gadgets (Barrett 2017).

One of the strengths of cultural evolutionary psychology is that it brings into sharp focus questions about how a new cognitive mechanism is put together over time, and makes them tractable. Evolutionary psychologists tend to assume that, if something is a cognitive instinct, it is the responsibility of some other discipline (perhaps genetics or paleo-archaeology), not cognitive science, to explain how it was constructed (Samuels 2004). In contrast, cultural evolutionary psychology encourages cognitive scientists and others to develop and test theories about gadget construction. Furthermore, because cultural evolution is faster than genetic evolution, and much of the construction process occurs within lifetimes, the cognitive gadgets theory makes questions about construction empirically tractable. They can be addressed, in collaboration with anthropologists and historians, by research involving contemporary and historical populations, as well as those for which we have only archaeological evidence. We don't have to guess how cognitive mechanisms were put together by genetic evolution in the Pleistocene past; through laboratory experiments and field studies, we can watch them being built in people alive today.

Cognitive Gadgets opens up a third way. It suggests that distinctively human cognitive mechanisms are adaptive because they are shaped primarily not by nature or nurture but by culture. I tried in the book to make this hypothesis clear and plausible, but I have no illusions that the case is already conclusive. A great deal more work is needed to test the cognitive gadgets theory, and, through the lens of cultural evolutionary psychology, to develop a deeper understanding of the origins and operating characteristics of human minds.

Open Peer Commentary

How is mindreading really like reading?

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Abstract

I suggest an alternative basis for Heyes' analogy between cultural learning of mindreading and text reading. Unlike text reading, mindreading does not entail decoding of observable stimuli. Like text reading, mindreading requires relevant inferences. Identification of relevant inferences is a deeply challenging problem, and the most important contribution of cultural learning to mindreading may be an apprenticeship in thinking like a mindreader.

How is mindreading really like reading? An important pillar of Heyes' (2018) argument is that mindreading mediates cultural learning and that mindreading is itself culturally learned. She makes this case by drawing an analogy between mindreading and text reading. Understanding where this analogy fails and where it succeeds casts light on how culture contributes to mindreading.

Mindreading is unlike reading because mindreading does not essentially involve decoding

First, Heyes argues that, just as print reading depends on decoding word sounds from written symbols, mindreading depends on decoding mental states from signs such as facial expressions, body movements, and utterances. This analogy fails, however, because mindreading readily occurs without such signs to decode: I can reason about the mental states of people who are absent, dead, or imaginary.

Second, whereas reading involves parsing grammatical relations among words, nothing analogous is true for mindreading. Despite the claims of "theory theories" (e.g., Davies & Stone 1995), the field has made little progress beyond "common sense platitudes" (e.g., Lewis 1970) when articulating rules or principles governing the relations among mental states or between mental states and behaviour. Approaches that formalise aspects of mindreading as Bayesian inverse inferences (e.g., Jara-Ettinger et al. 2016) are promising for scenarios that artificially limit the set of possible mental states that could be ascribed, but are unlikely to be extensible to more realistic scenarios (Stuhlmüller & Goodman 2014). There are good grounds for thinking "theory theories" have made limited progress because the rules or principles governing relations among mental states are uncodifiable (e.g., Davidson 1990).

It might have been compelling to think that cultural learning helped children acquire the "code" for mindreading, just as it helps them acquire the code for reading. However, this is of limited explanatory value because mindreading does not consist in the decoding of signs, nor even a codifiable set of principles.

Mindreading is like reading because it depends upon effortful inferences that go beyond the given information

Heyes may be right to argue that mindreading concepts are culturally learned. But whether they are learned or innate, it is clear that acquiring mindreading concepts is just the first step towards being a skilled mindreader. As there is no *code* for mindreading, how can we conceptualise skilled mindreading? Reading – and discourse processing more generally – provides a valuable model (Apperly 2010).

Although decoding is essential to reading, there is much more to skilled reading than decoding print into words. Comprehension of written or oral material involves the construction of a "situation model" with inferences that go far beyond the words themselves. These inferences rely upon comprehenders' processing capacity and motivation (McKoon & Ratcliff 1998; Sanford & Garrod 1998; Zwaan & Radvansky 1998), and critically depend on identifying relevant background information. Identification of relevant information is a classic problem in cognitive science (e.g., Fodor 2000), and although solutions may not be agreed upon, it is widely agreed that deep experience in the topic at hand will be critical.

Mapping this analogy to mindreading, what we should expect is that much of the challenge of mindreading will lie with making inferences that go beyond the information available from observable signs or prior knowledge about the target. Such inferences will involve effort and motivation (e.g., Apperly 2012), are only partially constrained by principles (there is no code, remember), and will draw upon a potentially unbounded variety of background knowledge about the target and the context (Apperly 2010). Identifying relevant information in these circumstances is surely challenging, and will require deep experience with the social world and the ways in which people think and act within it. Rather than the cultural transmission of mindreading codes or abstract mindreading concepts, the most important cultural contribution to mindreading is likely to be a long social apprenticeship in how to think like a mindreader (Nelson 1996).

Tinkering with cognitive gadgets: Cultural evolutionary psychology meets active inference

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Abstract

Cognitive Gadgets offers a new, convincing perspective on the origins of our distinctive cognitive faculties, coupled with a clear, innovative research program. Although we broadly endorse Heyes' ideas, we raise some concerns about her characterisation of evolutionary psychology and the relationship between biology and culture, before discussing the potential fruits of examining cognitive gadgets through the lens of active inference.

Heyes' (2018) *Cognitive Gadgets* presents a compelling and erudite case for the influence of cultural evolution on the emergence of the distinctive cognitive gadgets unique to humans. Her argument is a convincing one – she offers a lucid treatment of four empirically supported examples to substantiate her claims and highlights a number of viable research avenues to open her theory to scientific scrutiny. *Cognitive Gadgets* no doubt stands to make a meaningful contribution to current thinking about the evolutionary roots of human cognition. Admittedly, our opinion is also biased – *cultural evolutionary psychology* resonates with our own work, and we hope to see its widespread adoption as a research program.

There are, however, a number of points worth raising about Heyes' misleading characterisation of evolutionary psychology. First, the decidedly gene-centric view she attributes to members of the "High Church" of evolutionary psychology is somewhat specious – to understand and model gene-environment interactions and the ways in which social and physical ecologies impact the development of human cognitive specialisations is a core commitment of the field (Geary & Bjorklund 2000; Krebs 2003; Ploeger et al. 2008). Heyes also overlooks the heterogeneity of evolutionary psychology, broadly construed. For example, consistent with her own *teleosemantic* perspective, proponents of an "evolutionary systems" approach adopt an expanded view of inheritance, which extends beyond the gene to incorporate other forms of intergenerational information transmission, including epigenetic effects and the inheritance of cultural artefacts and patterned cultural practices (Badcock 2012; Caporael 2001; Hendriks-Jansen 1996; Laland 2017; Lickliter & Honeycutt 2003; Ramstead et al. 2016; Roepstorff et al. 2010).

By emphasising Chomsky's (1965) "poverty of stimulus" criterion and our innate cognitive "starter kit," Heyes also creates the impression that evolved, biological traits that help us adapt to the social milieu should largely be relegated to early biases, which are then refined by nurture and culture. However, there are clearly many adaptive traits that show a strong biological basis and profoundly affect social cognition and behaviour throughout the lifespan. Obvious examples include the gross morphology and physiological properties of the brain (Friston 2010); hormonal and neuromodulatory systems (Katz & Harris-Warrick 1999; McGlothlin & Ketterson 2008); reward, mood, and affective systems (Gray 1994; Nettle & Bateson 2012); personality traits (Bouchard & Loehlin 2001; Nettle 2006); and sensitive periods of development (e.g., puberty) that fine-tune our adaptation to different socio-environmental contexts across the life course (Frankenhuis & Fraley 2017; Geary & Bjorklund 2000).

More critically, *Cognitive Gadgets* tends to neglect the fundamental role of biology in shaping our cultural worlds. Dynamical simulation studies have provided proof of principle that individual differences in adaptive decision rules (e.g., mating or social learning strategies) create marked changes in the self-organisation of social norms and cultural dynamics (Kenrick et al. 2003; Molleman et al. 2014). More substantively, evolutionary psychologists have accumulated a wealth of evidence to suggest that cognitive traits favoured by natural selection exert a powerful influence on the sorts of cultural expectations, norms, and practices that are likely to evolve – including those surrounding communal sharing and morality (Kameda et al. 2005; Krebs 2008), in-group versus out-group behaviours (Brewer 2007), and behaviours involving social exchange (Wischniewski et al. 2009). Such work reminds us that culture shouldn't be individuated from the evolved biobehavioural dynamics of the individuals that comprise it (Kenrick et al. 2003; Lehman et al. 2004). The idea that we gain remarkable cognitive capacities via cultural learning almost goes without saying – but this should not detract from a dialectical view that sees biological and cultural inheritance as mutually constitutive.

As such, our main reservation with *Cognitive Gadgets* is that it promotes a sharp distinction between nature, nurture, and culture. As evidenced by our own work in this area (Constant et al. 2018; Kirmayer & Ramstead 2017; Ramstead et al. 2016; 2019), we certainly agree that cultural influences play an essential role in both the inheritance and development of our adaptive cognitive specialisations. However, we do not think that these three sources can be pried apart so easily – our interest lies more in the ways they *interact* to produce human phenotypes. Human biology is also a cultural biology; and human culture is realised by interacting biological systems within a shared material niche (Kirmayer & Ramstead 2017). Indeed, for more than 200,000 years, the main selection pressure on human survival has been the capacity to access and leverage accumulated sociocultural information (Henrich 2015; Hrdy 2009; Tomasello 2014). Heyes wouldn't deny this – she proposes that humans begin with a genetically specified "starter kit" that is geared towards navigating the sociocultural world, which allows more sophisticated forms of social cognition, like literacy and mindreading, to develop. Arguably, such "innate" propensities only ever emerged because of the increasing importance of sociocultural information for human survival.

Accordingly, we think that one of the most interesting questions raised by *Cognitive Gadgets* relates to the mechanisms that explain *how* biological, social, and cultural dynamics interact. This appeals to an *evolutionary systems* perspective that is able to capture both the ways in which biological and cultural evolution shape individual minds and the ways in which individual minds shape culture and biology (Badcock 2012; Caporael 2001; Kenrick 2001). Of course, such multilevel dynamics are challenging to understand, let alone study.

Fortunately, a promising approach has emerged from neuroscience and theoretical biology that has the potential to provide such a multiscale modelling strategy, called *active inference*. A descendent of *predictive coding* schemes of the brain (see Clark 2013), active inference is a mathematical formulation that describes how living systems are able to maintain themselves within a limited range of phenotypic states, that is, within the set of states in which they expect to find themselves, on average and over time. It explains how biological systems appear to resist the natural tendency to dissipate into their environment by fulfilling biologically instantiated (Bayesian) *prior beliefs* or expectations about the way the world unfolds (Friston 2010; Friston et al. 2009). In short, organisms are driven by the biological imperative to maintain homeostasis via action-perception loops that actively minimise "surprise." This framework has recently been extended to explain the evolution, development, and multiscale dynamics of living systems in general (Friston 2013; Kirchhoff et al. 2018; Ramstead et al. 2018). Here, we concentrate on two of our own complementary approaches derived from active inference, which we believe are particularly relevant to Heyes' proposal.

On the one hand, Heyes' appeal to our unique cognitive specialisations connects with a new theory of the human brain, cognition, and behaviour called the *hierarchically mechanistic mind* (HMM); see Badcock et al. (2019a; 2019b). This model rests on two fundamental claims. The first follows active inference by suggesting that the brain is a complex adaptive system comprising hierarchically organised neurocognitive mechanisms that function to reduce the dispersion or decay of our sensory and physical states by producing action-perception cycles that seek to minimise surprise (Badcock et al. 2019a). The second claim follows Tinbergen's (1963) four questions in ethology (i.e., adaptation, phylogeny, ontogeny, and mechanism) by suggesting that neural form and function can only be understood in terms of the broader evolutionary, intergenerational, developmental, and real-time processes that act on human phenotypes, which are differentially illuminated by major paradigms in psychology (i.e., evolutionary psychology, evo-devo, developmental psychology, and psychology's subdisciplines, respectively; Badcock et al. 2019b). Thus, to understand a phenotypic trait, researchers need to develop multiscale hypotheses that synthesise findings from diverse fields of psychological inquiry to explain both *why* that trait is adaptive and *how* it emerges from evolutionary, intergenerational, developmental, and real-time processes (for an application to depression, see Badcock et al. 2017). The HMM situates Heyes' work within a broader meta-theory of psychological inquiry that sees cultural evolutionary psychology as but one viable approach to understanding the evolution of human traits – a paradigm, like evo-devo, that concentrates on the group-level, *intergenerational* dynamics that bridge human evolution and development, thereby driving phylogenetic change. This *complements* insights from other evolutionary paradigms; it certainly doesn't *contradict* them.

To borrow Heyes' own term, active inference also supplies a plausible "force theory" of the nested socio-environmental dynamics responsible for the evolution and development of cognitive gadgets at the level of the individual. This brings us to our second complementary approach, called the *variational approach to niche construction* (VANC) (Constant et al. 2018).

The VANC considers niche construction, that is, implicit and explicit modifications of the environment, as a corollary of active inference, whereby embrained expectations guiding adaptive action-perception loops come to be encoded in the material layout of human niches. Take, for instance, desire paths. As they cut through a grassy field on their daily commute, people implicitly leave traces that inform other pedestrians of the possible intentions of those who crossed the path before; for example, "I want to reach the eastern exit of the park." By engaging the well-worn path, a novice agent can zero in on the optimal route without having any knowledge of the park's design. Our approach here is consistent with Heyes' – all this agent would require is the propensity to let herself be guided by the path. This disposition is made possible, presumably, by a minimal *starter kit* that includes basic *cooperative sensory and motor dispositions*, as well as some expectations regarding what she herself desires to do; for example, "I expect that my action will lead me to the eastern exit." By engaging the desire path, the agent will further wear down the trail, thereby increasing its reliability for others. Of course, another example of niche construction, which relates directly to Heyes' treatment of language, is written text.

The point here is that, through niche construction, humans produce culturally specific behavioural patterns encoded in the constructed artefacts that populate their niche, which they can then recruit to support the performance of various tasks. In so doing, they often implicitly and automatically converge on statistically recurrent behaviours, which, following active inference, are the least surprising ones (i.e., those that characterise the local cultural phenotype) (Constant et al. 2019). Over evolutionary time, cultural evolution scaffolds and finesses progressively complex "nurtural" networks of externally realised expectations (in patterned cultural practices and constructed niches), thereby guiding and transmitting increasingly sophisticated cultural behaviour (Constant et al. 2018; Ramstead et al. 2016; Veissière et al. 2019).

Under both the HMM and VANC, cognitive gadgets can be described as heritable *adaptive priors* that underlie (neuronally encoded) expectations about the dynamics of the social world and guide our action-perception cycles towards unsurprising states (see Badcock et al. 2019b). According to this perspective, such priors have emerged from the reciprocal interplay of biological, sociocultural, and ecological dynamics over evolutionary time because they have afforded a reliable means to reduce socio-environmental uncertainty. In other words, cognitive gadgets can be thought to entail hierarchical architectures of adaptive prior expectations encoded at multiple levels and sites, spanning neural systems, human phenotypes, social interactions, culturally specified motor patterns, and ecological structures.

Arguably, this notion adds to Heyes' proposal in two important ways. First, it avoids the questionable claim that our distinctive cognitive faculties are chiefly cultural products by suggesting that nature, nurture, and culture operate synergistically to optimise our phenotypes and eco-niches over evolutionary, intergenerational, and developmental timescales. Shedding light on such faculties requires recourse to research that spans the full breadth of evolutionary psychology (cultural or otherwise), not to mention allied disciplines like anthropology, biology, and ecology. Second, by subsuming active inference, the HMM and VANC afford a single, common language that allows us to describe both biological and cultural influences on human phenotypes mathematically, to model their interactions computationally, to test these models via simulation studies, and then to compare the outcomes of such *in silico* research with real-world experiments and observations (Badcock et al. 2019a; Ramstead et al. 2018).

In sum, our approach to human cognition builds on that of Heyes, but blurs the lines between nature, nurture, and culture – proposing instead a single, generic information theoretic mechanism (i.e., active inference) that expresses itself in different, complementary ways across all three. With this in mind, we suggest that active inference would make a powerful addition to the explanatory toolbox of cultural evolutionary psychology.

Culture in the world shapes culture in the head (and vice versa)

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Abstract

We agree with Heyes that an explanation of human uniqueness must appeal to cultural evolution, and not just genes. Her account, though, focuses narrowly on internal cognitive mechanisms. This causes her to mischaracterize human behavior and to overlook the role of material culture. A more powerful account would view cognitive gadgets as spanning organisms and their (shared) environments.

We are pleased for the opportunity to engage with such an interesting and well-presented account of the historical origins and physical bases of distinctly human cognitive capacities. We especially applaud Heyes' willingness to challenge deep intuitions about the role of genetic inheritance. It has too often been assumed that an explanation of our uniqueness must ultimately be cashed out in terms of genes. But, as Heyes (2018) repeatedly shows, there is scant evidence that genetic adaptations alone can account for uniquely human behaviors such as social imitation or language. We agree that cultural learning is an important force shaping these aspects of human cognition. Where we disagree is with the methodological assumption that good cognitive science focuses exclusively on the internal (neural) processes that shape behavior. In fact, cognition relies on extensive and mutual interactions between organism and environment. The environment should not be left out of the explanation. In what follows, we will try to show how a core distinction that drives Heyes' account, between grist and mills, potentially blinds her to the importance of environmental contributions to cognition, culture, and learning. We believe that giving up on a strict distinction between grist and mill can lead to a theory of the origins and bases of human cognition largely consistent with the cognitive gadgets hypothesis, but with broader theoretical and explanatory reach.

Early in *Cognitive Gadgets*, Heyes (2018) writes: "The cognitive gadgets answer [to what makes humans distinct] is concerned not with the grist of the mind – what we do and make – but with its mills, the way the mind works" (p. 14). In an earlier paper, Heyes illustrated this distinction by appealing to reading – her paradigm case of a cognitive gadget (Heyes 2012a). In reading, the "ideas and values coded" in the text are grist, whereas the neurocognitive pathways that have developed in a literate human, and that enable her to understand the text, are mills. On the face of it, this seems like a neat distinction. It is certainly a reasonable one to make if your goal is to challenge the nativist assumption that distinctively human traits must be explained in terms of a genetic endowment. The distinction allows Heyes to make a clear negative argument against this assumption. Her argument is roughly: Culture partly shapes cognitive mills; therefore, genes alone are insufficient to explain human uniqueness.

It is clear, however, that the gadget theory is intended to be more than just a negative challenge to the instinct theory. It also aims to be a positive framework for future evolutionary thinking about cognition (Heyes 2018, p. 77). From this point of view, we suggest that the strict distinction between grist and mills is problematic. It overlooks the ways that grist – the things we do and make – can also play a role in cognitive processes. Leaving grist out of the equation leads to an unnecessarily narrow, and individualistic, account of what human intelligence is. The point here is *not* that Heyes' book is too narrow in scope and therefore fails to offer a complete account of "the cultural evolution of thinking." Who could possibly do that? It is rather that by being too narrow in scope it distorts the nature of the cognitive mechanisms she hopes to describe.

It has long been a staple of cognitive science that some actions are special. They are not just the *product* of thinking, but they produce and enhance thinking. Simple epistemic actions such as rotating a jigsaw puzzle piece to better perceive fit (Kirsh & Maglio 1994), writing down the intermediate steps in a long-division problem to reduce memory load (Clark & Chalmers 1998), and gesturing over written equations or in conversation (Goldin-Meadow 2005) are not just the *product* of thinking but part of the cognitive processing. Similarly, some tools are so integral to behavior that we experience them as part of our body. The blind man does not feel with his hand the movements of the cane; he feels the world at the end of the cane (Merleau-Ponty 2013). And it has long been known – and has recently become big business in office design! – that the nature of one's physical environs changes how one thinks, behaves, and interacts (Kirsh 2005). These claims are not wholly uncontroversial, but the examples could be multiplied manyfold (Arendash et al. 2004; Barth & Funke 2010; Belland et al. 2013; Clark 1998; Flick 2000), and each seems to represent a (possible) counterexample to a strict grist–mill distinction. Grist is sometimes mill, or an important component in a cognitive mill, and ignoring this distorts the nature of human cognitive gadgets. Not incidentally, Heyes herself insists that cognitive mills are themselves the product of human behavior – social/cultural learning in particular – so it's also the case that mills are grist. The distinction, compelling at first glance, seems to fall apart under close scrutiny.

Why does it matter that the distinction is blurrier than it might initially seem? Because her commitment to the distinction causes Heyes to miss important points that we suspect she actually agrees with. Specifically, it leads her to overlook the ways that we reshape the world itself in ways that facilitate, constrain, and structure the cognitive work that we do. This idea is key to modern biological thinking. At the root of the extended evolutionary synthesis (Laland et al. 2015) is the notion of organism-environment mutuality and, in particular, the concept of niche construction: the idea that animals reshape their environments through their actions, and this in turn structures the selection pressures exerted on current and future generations (Laland et al. 2000; Lewontin 1983). (Heyes does mention niche construction once in the book, on p. 9, in a list of ideas that she promises to return to later.)

It would not be an exaggeration to say that human evolution does not make sense except in the light of niche construction. Human evolution is characterized by a progressive expansion of the ways in which we have changed our environment, from the use of primitive tools through the reshaping of land and livestock with agriculture to our modern predicament in which we have upset the self-regulating balance of the climate itself. On a broad reading of the word, all of this is cultural. It is the result of our use of and engagement with material culture. *Cognitive Gadgets* uses a more narrow definition of culture. Heyes presents cultural evolution essentially as a process by which ideas are transmitted from one (cultural) generation to the next. Culture is thus thought of as something that is carried around inside the heads of individual actors. But material culture does not fit this model. The architecture of Venice is material culture. It has been there for hundreds of years. But it is not carried around inside the people in Venice. It is persisting, worldly structure. We could claim, metaphorically, that the structure of Venice is "transmitted" from one generation to the next. But this does not capture the fact that Venice is a city that has its own continuing existence as a set of buildings and practices and behavior settings. The place itself structures the behavior of the people in it. Books, paintings, tools, cities – all of these are aspects of culture that do not have to be transmitted, but reside in the shared environment of a community.

The focus on cognitive mills leads Heyes to mischaracterize the role of the environment in a more basic way still. The closest she comes to recognizing the causal role of the environment in action is in a brief discussion of joint actions such as "moving furniture or dancing together" (p. 164). Heyes is, we think rightly, resistant towards mindreading accounts of such actions according to which each party to the action mentally represents the other's beliefs. She points out that the fact that we are able to attend to the same thing in the environment is often sufficient to account for our having the same belief as one another – for example, that "there's a puddle on the floor" (p. 164). This, though, leaves intact the assumption that our actions must be explained with reference to our individual *beliefs*. Now suppose that you and I dance around the edge of the puddle, carefully avoiding getting our shoes wet. Then I jump in the puddle, splashing you. Immature, perhaps. But there was a point to it. The point was to demonstrate that the puddle itself is a component in our action control. The whole sequence of seeing the puddle, avoiding it, jumping in it, is possible because the puddle is actually there, and is meaningful to us because a puddle is the kind of thing our bodies can interact with. We weren't dancing around our *beliefs* about the puddle, and it wasn't your belief about the puddle that caused you to get wet.

As it is with puddles, so it is with highly developed forms of craftsmanship. Acquiring the skills and dexterity to produce traditional stone artifacts such as axe heads would have taken many years of practice. In modern-day populations where such technologies are still produced, it can take 10 years for a learner to master the skill fully, under instruction from a more expert producer (Stout 2002). The point here is that the whole process of learning involves engagement with the stone itself, in a social context; the practice never becomes divorced from the material.

Maintaining the grist–mill distinction distorts Heyes' thinking in some more subtle ways, too. For instance, she characterizes "turnstile learning" as asocial. One confronts a turnstile (or other artifact) and by trial-and-error figures out its operation (p. 86). But that's not quite right. Turnstiles and other artifacts use design conventions to guide perception and behavior, conventions which are themselves reflected in and preserved by the built environment. For humans, there is perhaps very little learning that is truly asocial, even when it doesn't involve synchronic interactions with another human being.

Our final point is about group cognition. Heyes allows that cognitive gadgets are the result of multilevel selection. In the penultimate sentence of the book, she asserts: "Distinctively human cognitive processes are products of cultural group selection" (2018, p. 223). Group selection is anathema to selfish gene theorists. But despite her willingness to adopt this particular heresy, Heyes remains committed to methodological individualism for explanations of cognitive phenomena. We think this is a missed opportunity.

Can there be group gadgets? There are good reasons to explore how the gadget concept might be applied to groups. One of the distinctive features of human societies is the division of labor among members of the population. One could argue that the division of labor is itself a cognitive phenomenon. It expands the possibilities for human thinking because it allows the group to solve problems across an expanding range of activities. Heyes appears to be sympathetic to some version of group intelligence. The specific form of group selection theory that she appeals to is the collective intelligence hypothesis, according to which cumulative culture depends on a population maintaining a minimum group size sufficient to ensure that culturally evolved practices are kept alive (Henrich 2015). A more powerful formulation of the gadget theory would, we suggest, leave open the possibility that an explanation of the mechanisms of cumulative culture needs to appeal not only to processes within the individual, but also to interpersonal processes that structure and constrain how practices are maintained by a population.

If Heyes' goal is only to provide a competitor to the instinct theory, then we think she has succeeded admirably. Allowing that cognitive mills can have their origins partly in culture is an improvement on insisting on an exclusively genetic explanation. The grist–mill distinction, though, places an unnecessary limit on what this new theory can achieve. We think a more powerful approach, and one that will allow the gadget theory to serve more effectively as a framework for future research, is to abandon the distinction in favor of a mutualistic understanding of organisms and their environments. Culture is not just in the head.

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Executive functions are cognitive gadgets

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Abstract

Many psychologists and neuroscientists still see executive functions as independent, domain-general, supervisory functions that are often dissociated from more "low-level" associative learning. Here, we suggest that executive functions very much build on associative learning, and argue that executive functions might be better understood as culture-sensitive cognitive gadgets, rather than as ready-made cognitive instincts.

In her cognitive gadgets theory, Heyes (2018) argues that many of the cognitive mechanisms that make humans special are not produced by genetic evolution, as commonly believed, but by cultural learning. We are largely sympathetic toward this theoretical move, not least because the mechanics of cultural learning are much better understood than the genetics of human cognition. This renders theorizing in terms of cognitive gadgets more transparent and empirically accessible than the common attributions to a mechanistically not-yet-understood, underspecified genetic basis. However, we feel that Heyes underestimates the explanatory power of her own theory when it comes to executive functions – which she considers to be part of a genetically given cognitive starter kit. As we will argue, there is converging evidence that executive functions are not a genetic given but can be considered cognitive gadgets acquired through social and cultural learning.

Executive functions are considered higher-order functions that support goal-directed, flexible behavior, like quickly alternating between offence and defense in sports or stopping to smoke. Executive functions are often distinguished from other, seemingly lower-level processes such as perception, attention, response selection, and learning (Evans & Stanovich 2013; Kahneman 2003). In particular, executive functions and learning have been portrayed as opposite forces (will vs. habit) since the beginnings of experimental investigations on action control (Ach 1910) until today (e.g., in the disguise of model-based/model-free control: Dolan & Dayan 2013). Heyes (2018) uses this same dichotomy to characterize executive functions and associative learning, respectively, as two "cognitive instincts" of genetic origin. However, there are reasons to consider this an unnecessary choice that only complicates her otherwise straightforward gadget approach.

First, the distinction between smart executive functions and dumb associative mechanisms implies a higher (to-be-paid-back) "loan of intelligence" (Dennett 1978) than necessary. Although the mechanics of associative mechanisms are reasonably well understood, assuming an opposing force that apparently operates in an independent, unspecified way runs straight into the homunculus problem, leaving it open as to how executive functions work and what is regulating them.

Second, executive functions have been shown to be as malleable as imitation, for which Heyes takes malleability as a strong indicator of its cultural origin. In particular, Heyes (2018) argues that imitation is a cognitive gadget because it can be enhanced or even reversed in functionality by means of novel sensorimotor experience or training. Interestingly, the same holds for executive functions. For example, people tend to repeat rather than switch between tasks, possibly because the latter is cognitively more demanding (Arrington & Logan 2004). However, this tendency can be considerably diminished or even abolished by reinforcing or simply increasing the frequency of task alternations (Braem 2017; Fröber & Dreisbach 2017).

Third, executive functions share another characteristic with imitation – contextual dependency, which Heyes takes as a strong argument to consider it a cognitive gadget. Just like imitation, which has been shown to be very effector and task specific, executive functions have also been demonstrated to be specific to effector and context (e.g., Crump et al. 2006). For example, Braem et al. (2011) demonstrated how the ability to adjust task focus following cognitive conflict is constrained by the effectors used to perform the previous task (e.g., hand vs. feet; see also, Janczyk & Leuthold 2018). Executive functions are also tightly connected to, and associated with, the stimuli they were operating on (Waszak et al. 2003), and even with irrelevant stimuli that merely covaried with the particular executive function (Spapé & Hommel 2008). In a similar vein, practicing to inhibit a response to a certain stimulus slows down responding to that same stimulus in a subsequent unrelated task (Verbruggen & Logan 2008). Additional evidence for this highly contextualized nature of executive functions also comes from "brain training" studies, which indicate that executive functions can be trained but rarely show transfer (Melby-Lervåg et al. 2016; Simons et al. 2016).

Fourth, latent factor analyses seem to fail in identifying consistent replicable factors indicating independent executive functions (Karr et al. 2018). This makes executive functions "hard to grasp," which already leads some to consider the nature of executive functions elusive (Jurado & Rosselli 2007). In fact, the distinction between inhibitory control, working memory, and cognitive flexibility that Heyes relies on has also been partly challenged by the very authors who originally introduced this distinction (Friedman & Miyake 2017). Therefore, there is increasing evidence that executive functions are highly contextualized and "sticky" (Mayr & Bryck 2005), which we take as a strong hint that they might be grounded in associative learning (Abrahamse et al. 2016; Braem & Egner 2018; Egner 2014). This makes executive functions ideally suited to develop through social communication and transfer to meet contextual and cultural demands (Hommel & Colzato 2017).

Fifth, the idea that executive functions might be grounded in culturally transmitted associative processes is consistent with developmental studies showing that executive functions mature no earlier than around adolescence (e.g., Blakemore & Choudhury 2006) and that parenting plays a considerable role in their development (Hughes & Ensor 2009). Furthermore, executive-control styles have trait-like, sticky characteristics that reflect people's (sub)cultural background, such as religion or sexual orientation (Hommel & Colzato 2017). For example, the impact of response conflict on action control is considerably smaller in Calvinists, and larger in Catholics, than in matched control groups (Hommel et al. 2011), and a similar pattern can be found for the control of temporal attention (Colzato et al. 2010). Along the same lines, measures of cognitive flexibility systematically covary with religious disbelief (Zmigrod et al., 2018). Cultural differences can also be found on a larger scale, with young East Asian children often outperforming Western children on a range of executive function indices (Lan et al. 2011; Oh & Lewis 2008; Sabbagh et al. 2006).

Taken together, executive functions are not well-defined, which holds for both empirical bottom-up and theoretical top-down approaches, and there is increasing evidence that they show characteristics that are typical for culture-related associative processes: malleability, context-dependency, lack of transfer, and cultural dependency. Heyes' key argument for classifying executive functions as cognitive instincts rather than cognitive gadgets seems to be heritability: if executive functions were a product of culture rather than genes, why have they been shown to be heritable, observable in other animals, too, and to be enhanced in humans? Interestingly, a closer look reveals that these signs of heritability are not inconsistent with a cultural basis of executive functions either.

First, executive functions indeed seem to be heritable, at least to some degree (Friedman et al. 2016). Notably, however, more targeted studies on this genetic contribution suggest they rely on a complex interplay of different neurotransmitter functions (Logue & Gould 2014), with a particularly important role of dopamine (Cools & D'Esposito 2010). Given that the efficiency of the frontal and striatal dopaminergic pathways is heritable to some degree (Colzato et al. 2011), there are at least two ways that executive functions might be heritable even if they rely on associative processes. For one, various forms of associative learning rely on monoaminergic processes (Schultz 2013; Tully & Bolshakov 2010), so what looks like the heritability of executive functions might actually reflect the heritability of the domain-general associative learning mechanisms they rely on. For another, the online operations of executive functions have been shown to rely on dopaminergic efficiency (Cools & D'Esposito 2010), suggesting that frontal and striatal control pathways rely on the dopaminergic fuel provided by the ventral tegmental area and the substantia nigra. If so, what might be heritable might not be the engine being driven (i.e., executive functions proper) but the (amount, availability, and/or quality of the) fuel driving it. In any case, it is important to consider that signs of heritability do not determine whether it is the function of interest that is heritable, or just the infrastructural factors it needs to operate on. As an example, although the ability to acquire language is heritable (Byrne et al. 2007; Kovas et al. 2007), this is not in and of itself a reason to conclude that language itself must be genetically coded (Deacon 1997; Heyes 2018).

Second, Heyes (2018) further pointed towards observations that executive functions can also be observed in nonhuman animals, which would suggest they have a longer genetic history. Still, the fact that executive functions can be observed in animals does not invalidate executive functions as cognitive gadgets (as also argued for imitation processes, Heyes 2018). Instead, it merely suggests that in animals too, (rudimentary forms of) these processes can develop. Interestingly, in reviewing recent evidence comparing human and nonhuman primates, researchers have concluded that similarities in executive functions often reflect similarities in domain-general reinforcement learning mechanisms (e.g., as during reward learning), and that certain basic control processes may actually rely on different brain regions across species (Eisenreich et al. 2017; Heilbronner & Hayden 2016; Mansouri et al. 2017). Therefore, similar to how language might have latched itself onto the brain as a parasite to its host (cf. Deacon 1997), certain culture-specific executive functions could have developed onto partially different brain networks in different species.

Third, not only do executive functions seem to be heritable and observable in other animals, but also there are reasons to believe they have evolved into more superior or enhanced functions in humans. However, this enhancement could be culture-driven, or rely on other genetic benefits (e.g., enhanced associative learning or the ability to develop symbolic representations). This aside, the superior nature of these functions has also been questioned altogether. For example, Heyes (2018) cites evidence that self-control – the ability to inhibit one's impulses – might be enhanced in humans. However, others have argued that this ability is still rather poor in humans, and its seemingly enhanced nature could be partially due to procedural differences in measuring self-control across species (Hayden 2018). As for working memory capacity, some have argued this ability to be comparable (Carruthers 2013), or even inferior to some of our closest ancestors (Inoue & Matsuzawa 2007). In fact, Lotem et al. (2017) have suggested that while having a larger working-memory buffer in humans could be possible, having a smaller working-memory capacity might be more adaptive. Last, it is true that humans show a remarkably higher proficiency in switching between different tasks, and thus enhanced cognitive flexibility. However, this difference has been attributed to differences in language proficiency, rather than switching abilities per se (e.g., Hermer-Vazquez et al. 2001). In fact, a set of recent studies using a nonverbal computer task showed that baboons and children, as well as semi-nomadic adults from north Namibia, were better at switching away from a certain strategy to select more optimal strategies than were adults from North America (Pope et al. 2015; 2019).

Heyes (2018) emphasizes that no mental process is likely to be the product of nature, nurture, or culture alone, and she admits that "learning and cultural inheritance play major roles in the development of human executive function" (p. 74). We suggest taking these roles somewhat more seriously and consider executive functions not as cognitive instincts but as cognitive gadgets. Ultimately, this question will depend on one's exact definition of executive functions, one's level of analysis, and the specific executive function of interest, but we suggest that executive functions can be considered an emergent property arising from a complex interplay of different basic reinforcement learning processes, working at the level of more distributed or abstract representations (e.g., Abrahamse et al. 2016; Eisenreich et al. 2017). Such a perspective could further promote the study of how executive functions emerge through development, how they can be acquired and become conditioned and bound to context, and how this can lead to substantial inter-individual and cultural differences in the development of these particularly interesting "cognitive gadgets."

Cognitive gadgets: A provocative but flawed manifesto

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Abstract

The argument against innatism at the heart of *Cognitive Gadgets* is provocative but premature, and is vitiated by dichotomous thinking, interpretive double standards, and evidence cherry-picking. I illustrate my criticism by addressing the heritability of imitation and mindreading, the relevance of twin studies, and the meaning of cross-cultural differences in theory of mind development. Reaching an integrative understanding of genetic inheritance, plasticity, and learning is a formidable task that demands a more nuanced evolutionary approach.

The provocative thesis of *Cognitive Gadgets* (Heyes 2018) is that human abilities such as imitation, mindreading, and language – the traits that allow our species' extensive cultural transmission – are not adaptations produced by biological evolution or, as repeated throughout the book, "in our genes." Instead, these abilities are themselves "gadgets" that have been created and refined by cultural group selection. Although they give the illusion of innateness, they are taught to children through social practices, and learned with the support of enhanced domain-general mechanisms such as attention, social motivation, working memory, and – most importantly – associative learning. Except for potentiating these general-purpose cognitive tools, genetic evolution has had virtually no role in shaping the distinctive traits that define human nature.

Why evolution should have followed this route in our species is a mystery, and Heyes does not offer any rationale or theoretical model to make sense of it. In fact, she stresses that genetic evolution *could* have played a role – the evidence from cognitive science just happens to say otherwise. The first question, then, is whether the book makes a compelling empirical case for its almost-blank-slate argument. *Cognitive Gadgets* presents a wealth of interesting findings and useful criticism of previous research; but as a refutation of innatism I found it surprisingly weak. Consider Heyes' treatment of genetic assimilation. In a nutshell, genetic assimilation occurs when traits that initially develop through learning (or other types of plasticity) get increasingly under genetic control, as selection favors variants that make the learning process faster and more reliable. In principle, assimilation can proceed so far that the trait develops entirely under genetic guidance, with no environmental input.

Heyes claims that she found no evidence of genetic assimilation for abilities like imitation and mindreading. Granting the premise for now, Heyes assumes that the heritability of a trait estimated from twin studies is an indicator of whether the trait develops with minimal environmental input ("poverty of the stimulus," high heritability) or with considerable input from the social environment ("wealth of the stimulus," low heritability). For imitation, the book cites one study of 2-year-olds by McEwen et al. (2007) as showing that "identical twins are no more alike in their imitative ability than fraternal twins" (p. 208). But this is not what the study found. The correlation was significantly higher in identical twins, and the authors estimated the heritability of imitation at 30%. This figure is well within expectations: The heritability of cognitive traits is small in infancy, but increases to about 30%–40% in childhood and reaches 50%–60% by late adolescence (Briley & Tucker-Drob 2017). Heyes fails to cite another study of imitation in 2-year-olds (Fenstermacher & Saudino 2007), which also found a higher correlation in identical twins and estimated heritability at 45%. For mindreading, Heyes cites one study by Hughes et al. (2005), which found the same correlation between identical and fraternal twins, indicating negligible genetic influences on individual differences in children's theory of mind. She omits to mention that, although the authors found no specific genetic contributions to theory of mind, there was a significant influence of nonspecific genetic factors shared with verbal ability (accounting for about 15% of variance). Other twin studies of theory of mind in children and adults have found heritabilities in the 15%–35% range (McEwen et al. 2007; Ronald et al. 2006; Warrier et al. 2018). Thus, contrary to Heyes' claim, both imitation and mindreading skills show a nontrivial proportion of genetic variance. Moreover, the apparent heritability of mindreading is most likely deflated by the rather noisy measures employed in these studies.

A deeper question is whether twin correlations and heritabilities are germane to the book's argument. In contrast with Heyes' assumptions, the proportion of genetic versus environmental variance says very little about the nature of environmental inputs and the trait's history of genetic assimilation. Consider a genetically assimilated trait that has become fixed in a population, and shows little or no genetic variation among individuals. By necessity, most of the variance of such a trait would be environmental. Or consider a hypothetical developmental process in which an environmental variable triggers the expression of alternative, genetically specified behaviors that are the same for all the individuals in a species. The resulting trait would show low heritability and high environmental variance; but the role of the "stimulus" would be limited to selecting from a menu of pre-specified alternatives. To further complicate things, nonshared environmental variance in a trait may reflect random events and insults (e.g., infections) rather than learning or organized plasticity; and genetic variance may capture the effects of deleterious mutations besides those of functional alleles. In general, the factors that drive the development of a trait may not be the same factors that produce individual differences in that trait. Moreover, a particular skill can be both evolutionarily novel and socially learned, but depend for its acquisition on traits that show substantial genetic variation. To illustrate: playing chess is a cultural "gadget" if there ever was one, and yet interest and aptitude for chess are about 40–50% heritable (de Moor et al. 2013; Olson et al. 2001; Vinkhuyzen et al. 2009). By Heyes' criteria, one should conclude that playing chess is more likely to be a "cognitive instinct" than imitation or mindreading. In sum, the book's argument for rejecting genetic assimilation is conceptually flawed and supported with cherry-picked data.

To remain on the topic of mindreading, Heyes cites interesting cross-cultural evidence that the stages of theory-of-mind acquisition differ between individualistic countries like the United States and Australia and collectivistic countries like China and Iran. But these findings are damning only if one holds an inflexible model in which the various components of mindreading (Schaafsma et al. 2015) can interact only in one pre-specified way, with no meaningful input from the social environment. Of note, the observed sequence changes typically involve two particular tasks out of five ("diverse beliefs" and "knowledge access"; see Duh et al. 2016; Kuntoro et al. 2017; Shahaeian et al. 2011; 2014; for a puzzling exception, see Dixson et al. 2018). The overall picture, then, is one of patterned variation on a background of stability. Heyes also cites evidence that theory of mind development is markedly delayed in Samoan children (Mayer & Träuble 2013). However, this literature contains several inconsistent findings that cannot be explained by cultural differences (see Liu et al. 2008; Mayer & Träuble 2015). Some apparent delays may reflect culture-specific issues with task demands, as Mayer and Träuble (2015) noted in their follow-up to the original Samoan study.

At the same time, theory-of-mind skills are not independent from other cognitive traits, and are significantly associated with IQ (e.g., Baker et al. 2014; Rajkumar et al. 2008). It may be impossible to fully make sense of the cross-cultural data on developmental trajectories without addressing the thorny issue of national differences in cognitive ability (e.g., Rindermann 2018).

These examples serve to illustrate a double standard that is applied throughout the book: whenever the data do not support a rigidly "preformist" view of development, they are implicitly or explicitly counted as positive evidence for an associative account. But in several of the examples discussed in *Cognitive Gadgets*, associative learning is little more than a hypothetical mechanism (or a plausible contributing factor), and it is unclear if the models proposed by Heyes are able to explain the totality of the evidence. Moreover, the apparent simplicity of associative accounts often hides a lot of complexity (and inefficiency), which is revealed only by careful unpacking (e.g., Dickinson 2012; Hanus 2016). For all these reasons, Heyes' rejection of innateness in favor of almost-blank-slate associationism seems highly premature.

I will not discuss the book's case for cultural group selection in any detail, except to note that the argument is fully – and admittedly – speculative. To be clear, I see nothing wrong with bold speculation; but there is some irony in the sudden shift away from the hard-nosed empiricism of the rest of the book, precisely at the point where Heyes needs to explain *how* all the distinctive content of human nature can be outsourced to culture-mediated learning. For example, it is unclear if the selection process envisioned in the book could provide enough robustness and reliability to enable adaptive evolution; if it could work on a realistic timescale, given the long "life cycle" of groups compared with that of individuals; how it would respond to conflicts of interests between different social actors, and between group and individual fitness; and how it would prevent genetic adaptation from catching up with cultural transmission.

Even though my review of *Cognitive Gadgets* is critical, I strongly recommend the book to other evolutionary-developmental psychologists. It will stimulate them, challenge them to think more deeply about their assumptions, and prompt the field to open the developmental "black box" and become more explicit about computational processes. I see a clear parallel with much recent work in artificial intelligence (including neural networks), which shares the book's empiricist attitude and faith in the power of domain-general learning (Marcus 2018; see also Lake et al. 2017). This new wave of research is a fantastic opportunity for evolutionary-developmental psychology. Understanding how learning is instantiated in the mind/brain, guided by evolved developmental programs, and integrated with innate information is a daunting task, which has been made even harder by a scarcity of explicit models (Frankenhuis & Tiokhin 2018). Computational tools like reinforcement learning can help understand what (and how much) pre-existing information is needed to perform efficiently and reliably in the real world (Frankenhuis et al. 2018), and how evolved developmental programs may respond to novelties in the environment, from optical mirrors to online interactions.

These questions can be approached in a spirit of synergy and integration (e.g., Frankenhuis et al. 2018; Lake et al. 2017; Versace et al. 2018), or – less productively – as a zero-sum competition between genetic inheritance and learning. Back to *Cognitive Gadgets*, it is unfortunate that Heyes sets up her main argument as a dichotomy between two extremes. Psychological mechanisms are either genetically encoded, domain-specific "instincts" that develop with minimal environmental input; or culturally transmitted "gadgets" that are learned through domain-general processes, with minimal or no contribution from genetic factors. The only middle-ground option entertained in the book – and quickly dismissed – is genetic assimilation (see above). This black-and-white contrast leaves out a world of more plausible possibilities. For example, psychological mechanisms may reliably develop a basic level of functionality with minimal input, but depend on learning (often directed and canalized) in order to reach full competence. Although basic preferences for sweet versus bitter flavors are present at birth, food preferences are expanded and fine-tuned through years of intensive but nonrandom learning, which yields cultural similarities as well as differences (Rozin 1990a; 1990b). Furthermore, even established preferences for or against certain foods can be adaptively overturned by conditions such as pregnancy and nutrient deficiency (Berthoud 2011; Flaxman & Sherman 2000; Rozin 1990a).

By tuning their operating parameters, general processes such as associative sensory-motor learning can be canalized to reliably yield specific, adaptive outcomes.

My colleagues and I have proposed such a canalization hypothesis for the development of mirror neurons (Del Giudice et al. 2009). Also, distinct mechanisms specialized for different tasks may reuse some basic information-processing algorithms – for example, reinforcement learning – while adapting them to the particular nature of each task. Modularity, functional specialization, and the difficulty of distinguishing between domain-general and domain-specific processes have been addressed in considerable depth in the work by Clark Barrett et al. (e.g., Barrett 2012; 2015; 2017; Barrett et al. 2016), which reconciles the notion of specialized adaptations with a sophisticated view of learning and plasticity. A powerful idea stemming from this approach is that cognitive mechanisms may develop hierarchically, through "module spawning" and progressive specialization induced by different categories of inputs (Barrett 2012; 2015). Heyes never considers these possibilities, which have been discussed for years in mainstream evolutionary psychology (e.g., Buss 2015). It remains to be seen whether *Cognitive Gadgets* will herald a genuine paradigm change, or succeed mainly as a timely provocation.

Language is not a gadget

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Abstract

Heyes does well to argue that some of the apparently innate human capabilities for cultural learning can be considered in terms of more general-purpose mechanisms. In the application of this to language, she overlooks some of its most interesting properties. I review three, and then illustrate how mindreading can come from general-purpose mechanism via language.

Although I agree with Heyes' main stance that emphasizes the power of general-purpose mechanisms in contributing to higher cognitive function, I think that she has taken a particular construal that obscures a potentially more interesting situation. Characterizing language as one of multiple mechanisms (selective social learning, imitation, mindreading, and language) resulting from cultural evolution is misleading, as it obscures its role as a principal vehicle of cultural learning and evolution.

It is likely that there are strong interactions between the four mechanisms. By laying out the structure of the book as an enumeration of how each could have come about, the potentially more interesting aspect of their interrelations, and dynamics, is significantly downplayed. This contributes to a false impression that they are independent.

This false impression is particularly the case for language. The cultural structuring role of language has been eloquently elaborated by many including Bruner, Lakoff, Riceour, and Polkingborn. Yet, from the outset the role of language is underplayed: "I argue in this book that it is the information we get from others, handled by general purpose mechanisms, that builds distinctively human ways of thinking" (Heyes 2018, p. 2). Where does this information come from? The problem with Heyes' characterization is that it hides the notion that the information that we get from others via language may have a special status, so that language is not a mechanism of the same caliber as the other gadgets. Setting language alongside the other cognitive gadgets downplays the importance of language in cultural evolution, as she states "and linguistic communication is far from the only significant channel of cultural inheritance" (p. 169), yet at the same time she notes that "language comes first" (p. 166) with respect to mindreading, and that "through language children learn to read minds" (p. 166).

I will develop three characteristics and arguments for elevating language to a special status in cultural learning. I will then focus on one of these, illustrating how – based on general cognitive mechanisms – language creates a capability for analogical mapping that contributes to theory of mind.

The first special characteristic of language that makes it quite distinct from the other three elements is that language is structured around the event-based organization of human experience (Goldberg 1995), and thus provides a very high density vehicle for the transfer of information that is central to construction of the distinctively human ways of thinking. Through the structure-defining dimensions of language including time, mode, and aspect, the speaker can communicate very precise spatial, temporal, causal, and other relations between an agent's actions and outcomes. Importantly, in addition to re-describing the already visible aspects of events, language allows for the enrichment of descriptions, by explaining in more detail aspects of events that are not visible to the untrained observer (Bruner 1991; Nelson & Fivush 2004), in a process referred to as narrative enrichment (Mealier et al. 2017). Of particular interest here is how language can be used to specify how unseen mental states may have causal roles in the actions of others. This provides a vehicle for structuring and organizing "the information we get from others" that renders language in a different class from the other proposed cognitive gadgets. This is crucial for the transmission of complex knowledge – instructions – of how to make and build complex cultural artifacts (Stout & Chaminade 2012). Reciprocally, the structure of language prefigures how human experience is perceived (Ricoeur 1984). Ricoeur developed a framework for narrative that involves the encoding of experience, the emplotment of that experience, and then the reception and comprehension of the resulting narrative by the listener. Interestingly, already in the perception phase, language has pre-shaped our perception so as to construe things in a narrative-compatible manner. This is even more apparent in the process of emplotment whereby we construe experience into a form that is consistent with normative structures. Thus, by modeling the event structure of life, language has two unique roles – it allows the precise communication about this structure, and at the same time it filters the perception of the world so that it is consistent with this structure.

The second characteristic of language that makes it the significant channel of cultural inheritance is related to its unique role in making meaning (Bruner 1990), through its creative and normative dimensions. In the technical realm, the creation and labeling of notions like right angle, hypotenuse, and square root allow for the further specification and discovery of properties in a typical example of meaning making. That is, by allowing the creation of expressive forms for new realms of meaning, language is a workhorse of cultural evolution. Likewise, in the social domain, the development of normative schemas of human behavior by the same kind of labeling and enrichment provides the vehicle for the specification of cultural artifacts like creation myths and social norms that are central to the human condition.

Like Bruner, Polkinghorne (1988) considered narrative as the primary form by which human experience is made meaningful. He considered that having narrative as one of our fundamental structures of comprehension shapes the character of our existence in a particular way, similar to the effects of Ricoeur's emplotment (Ricoeur 1984). The realm of meaning is an open system in which new forms of organization can emerge and new meaning systems can develop. Polkinghorne (1988, p. 31) summarizes the position of Merleau-Ponty that "language takes up the contingencies of existence, and the perceptual openness of life to the natural and intersubjective worlds, and molds them into a meaningfulness that is greater than the meaningfulness they originally hold." In this context, a crucial aspect of narrative is its capacity for the disclosure or creation of possible worlds (Bruner 2009). Riceour noted that the adequate self-understanding of man is dependent on this dimension of language as a disclosure of possibility. "It is by an understanding of the worlds, actual and possible, opened up by language that we may arrive at a better understanding of ourselves" (Ricoeur & Kearney 1978, p. 118).

It is worth noting that this notion of meaning, and language's role in creating and porting meaning, is essentially not addressed in Heyes' analysis, although the notion of information is highly present. Perhaps language becomes more like the other gadgets when it is considered independent of its role of making meaning in Bruner's sense. From an historical perspective on the status of meaning, Bruner (1990) noted that the initial goal of the cognitive sciences was to understand meaning and the symbolic activities humans employ to make sense of the world and themselves. Then, for various reasons (greatly related to the rise of theoretical computer science and information theory), cognitive science became a science of information processing. In Bruner's words, critics argued that cognitive science may have "gained its technical successes at the price of dehumanizing the very concept of mind it had sought to re-establish" (p. 1). This trend in cognitive science – away from meaning towards information processing – is partially reflected here in the analysis of cultural tools, wherein the notion of meaning in Bruner's sense is largely left unaddressed.

The third (related) characteristic of language is its mechanism for building up new structures from existing structures, and labeling these so that they can in turn be composed into ever more structured representations. Goucha et al. (2017) postulated that the uniquely human language capability relies on something like the syntactic merge operator, and crucially, the ability to label the results of the merge, and to reuse these new labeled structures in future merge operations. This recursive capability is the foundation for the building of complex hierarchical structure that is crucial to cultural evolution, and is not present in the other cultural learning components that Heyes analyses.

If language is so different, how can it be built up from existing cognitive mechanisms? The answer might be found in the construction grammar framework, which characterizes language as a structured inventory of form-to-meaning mappings. Part of the beauty of this characterization is that the mechanism that learns and generalizes over these mappings between form (words, sentences) and meanings (e.g., event representations) can indeed be from a more general-purpose toolbox. The cue competition hypothesis (Bates & MacWhinney 1987; Bates et al. 1991, Li & Macwhinney 2013) holds that across languages, cues including word order, grammatical marking, and intonation are used to code thematic roles and other dimensions of meaning. Using this hypothesis, we re-used a well-characterized model of the primate cortico-striatal sensorimotor sequence learning system (Dominey 1995) in order to learn grammatical constructions (Dominey 2013; Dominey et al. 2003; Dominey et al. 2009; Hinaut & Dominey 2013). Cues including word order and grammatical marking are used by the model to appropriately map sentence form to predicate-argument meaning. Thus, grammatical function words indicate the relations between open class words in the sentence. We then extended this notion to the narrative level, where narrative function words (such as because, before, after) indicate relations between elements of events in a narrative (Mealier et al. 2017). This introduces the concept of narrative construction, which extends the notion of grammatical construction as a form-to-meaning mapping at the sentence level to the narrative level, consistent with the construction framework, where there is a continuum between lexical elements and constructions.

Part of the novelty of this system is that it easily allows a form of narrative enrichment, whereby new narrative relations, such as causal relations between a mental state and action can be created. For example, I want to grasp a glass but it is out of reach, so I ask you to give it to me. In your subsequent narration, you say “I gave you the glass because you wanted it,” and establish a causal link with an unseen mental state (Mealier et al. 2017). Once the construction was learned, it could then be instantiated with different arguments in a form of analogical mapping, thus allowing expression of a narrative where I am trying to learn math but I don’t get it, so I ask you to teach it to me, and you teach me, because I wanted you to. The use of such patterns can provide a basis for powerful mechanisms for enrichment including metaphor (Lakoff & Johnson 2008).

It can also provide a simple but powerful tool in the development of theory of mind. In this context, Gallagher and Hutto (2008) and Hutto (2007) have developed a narrative practice theory of folk psychology. They noted that humans appear to have powerful mechanisms for intersubjectivity, like the detection of intentions in expressive movement and eye direction, and from an early age we are actively involved in dyadic relations with others. These interactions form the meaning component of a form to meaning mapping in our narrative construction model. Gallagher and Hutto (2008) then held that in addition, narrative patterns accompany this intersubjective behavior. In our narrative construction model, these narrative patterns contribute to the form component of the form-to-meaning mapping. Then, children understand why people act as they do by being exposed to psychological narratives of intersubjective relations. Through narrative practice they come to understand the norms of behavior in their society, as the narrative forms a structure in which the behavior can be interpreted, from experience (practice). Thus, as similarly noted by Heyes, in the development of theory of mind, language comes first.

In summary, although I applaud Heyes’ analysis which argues for the use of generalized cognitive mechanisms in the development of higher cognitive functions, here in the service of cultural evolution, I fear that the status of language as a unique mechanism for making meaning has been ignored, which gives a (perhaps unintentional) misconstrual. Characterizing language as one of multiple mechanisms resulting from cultural evolution is misleading, as it obscures its role as a principal vehicle of cultural learning and evolution.

Cultural evolutionary psychology is still evolutionary psychology[1]

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Abstract

The cognitive gadgets theory proposes to reform evolutionary psychology by replacing the standard nativist and internalist approach to modularity with a cultural constructivist one. However, the resulting “cultural evolutionary psychology” still maintains some controversial aspects of the original neo-Darwinian paradigm. These assumptions are unnecessary to the cognitive gadgets theory and can be eliminated without significant conceptual loss.

Heyes’ (2018) cognitive gadgets theory (henceforth CGT) constitutes a significant advancement over the standard neo-Darwinian account in evolutionary psychology. According to the latter, the mind is a collection of innately specified domain-specific units, which operate through inner representations and algorithms and are shaped by natural selection because of their causal contribution in adapting the organism to critical issues in the environment (e.g., Barkow et al. 1992; Buss 2012; Cosmides & Tooby 2013). Culture, in turn, is the physical derivative of such modules and stands as instrumental to the solution of these adaptive problems. The CGT argues that the standard view “does not line up with the evidence from cognitive science” (p. 15). In contrast, it aims to replace the standard view with a “cultural evolutionary psychology” (p. 16), according to which cultural practices create cognitive functions by building upon internal and biologically selected domain-general mechanisms. The CGT thus conceives the mind not as a collection of cognitive modules but rather of culturally constructed "cognitive gadgets."

Although we praise the constructivist lean assumed by the author, we intend to argue that the CGT does not completely free itself from a variety of problematic neo-Darwinian assumptions. Despite the fact that many accounts in social anthropology (Ingold 2007), cognitive archaeology (Iliopoulos & Garofoli 2016; Knappett 2005; Malafouris 2013), postphenomenology (Ihde 1990; Ihde & Malafouris 2018; Verbeek 2005), and enactive cognition (Fenici & Garofoli 2017; Hutto 2008; Hutto & Myin 2013) have extensively opposed these assumptions over time, the author has not considered such criticisms in the current formulation of the CGT. Within this commentary, we intend to bring to the fore (and suggest) possible solutions to these critical issues that also affect the CGT. In particular, we will discuss and criticize its assumptions concerning (1) the computational and semantic-information theory of mind and culture, (2) the adaptionist view in cognitive evolution, (3) the completeness of cognitive functions as units of selection, and (4) the fixed link between brain regions and cognitive functions.

To start, the CGT shares with the standard neo-Darwinian view a computational and representational conception of mind and culture. Indeed, like modules, domain-general systems remain in any case representational components of a computational architecture. Their content is determined by teleosemantics (Heyes, 2018, pp. 27–30; see Millikan 2004), and natural selection alters their representational capacities by acting on the minimal constituents of their physical vehicles – that is, their genetic bases. At the same time, although the author states that "a cognitive mechanism certainly is not a pellet of information that can be copied inside your head, sent through the air, and planted wholesale in my head" (p. 44), she keeps adopting a model typical of cultural evolution theory, according to which culture is semantic information, traveling across human minds through social learning (e.g., Mesoudi 2011; Richerson & Boyd 2005). The novelty of the current model thus lies in the proposal that different codes inhabiting respectively the biological and the cultural channels are now integrated, thereby generating the cognitive gadgets through "wide computations" (cf. Wilson 1994). However, these representational and computational foundations remain highly controversial at present. Representationalism has indeed been considered metaphysically inconceivable (Hutto & Myin 2013; 2017), the information-semantic view of culture utterly disembodied (Malafouris 2016; Walls 2019), and the great success of these views primarily associated with biases in computer-based societies rather than empirical validation (Penny 2017).

The CGT exploits these conceptual bases also to maintain a hard adaptationist stance in cognitive evolution – although modified in order to accommodate its constructivist amendments – according to which "cultural evolution has the potential to explain the adaptedness of distinctively human cognitive mechanisms" (Heyes 2018, p. 37). The core point is that "genetic and cultural evolution are based on the same, fundamental heuristic – variation-and-selective-retention" (p. 36). Thus, wide computations appear as elements of a broader code that are generated, modified, replicated, and transmitted downstream along the dual-inheritance system just described. This implies that we can analyze cognitive gadgets with the tools of the neo-Darwinian theory – although presented in the form of a "'Campbellian' selectionist approach" (p. 36). The modern human mind, allegedly shared by all human populations, therefore appears as a collection of adaptive gadgets that survived selection, in line with the idea that evolutionary principles ultimately justify why the mind has the shape we observe in the present.

In response to such a neo-Darwinian take on cognition and culture, we note that over time many critics from different domains have repeatedly challenged these assumptions. During the 1980s in archaeological theory, the post-processual movement strongly reacted to the idea from the New Archaeology and its heirs that human behavior and cognition are determined by adaptive laws, which could be assembled in the present through ethnographic studies and deductively applied to the study of the past (Bednarik 2013, p. 21; Hodder & Hutson 2003, chap. 2; Shanks & Tilley 1987; Trigger 1998). Post-processual critics argued that human culture is created and maintained within a psychological and ideological dimension, which can overcome strict adaptive reasons. Similarly, critics in social anthropology have contended that human life is a shared narration and an embodied way of being in the world. Thus, they have rejected metaphors depicting humans as computational machines, and culture as the outcome of transmission and selection processes (Ingold 2004; 2007; Ingold & Palsson 2013; Tallis 2011). If these criticisms are correct, the human mind cannot be reduced to the evolutionary selection of wide computations acting on the cognitive level, as the author suggests, but rather cognitive gadgets are likewise embedded within a social narration. Thus, they can actively be formed and maintained because of what humans believe, think, desire, and emotionally experience independently from supposed adaptive reasons.

The previous discussion hints against a third important neo-Darwinian aspect of the CGT, namely, the idea that gadgets are distinct units of selection provided with specific adaptive values. Following the principles of material engagement theory (Iliopoulos & Garofoli 2016; Malafouris 2013; Renfrew 2004), we argue that gadgets are not only integrated with a broad gamut of conceptual and affective states but are also materially extended through their hybridization with artifacts and features of the external world. Furthermore, they are constitutively related to one another, and the boundaries between them are hard to identify. For instance, similarly to Heyes, Everett (2012) has proposed that language is a cultural construct that capitalizes on domain-general systems capturing perceptual regularities, thereby appearing as a cognitive gadget. However, language is not an isolated cognitive function, because it is constitutive of and simultaneously constituted by other cognitive gadgets. To mention one, many scholars defending a constructivist perspective believe that meta-representational mindreading is realized through linguistic practices (Fenici 2017; Fenici & Garofoli 2017; Gallagher & Hutto 2008; Hutto 2008). Mindreading in turn allows language to bend on itself, and bootstrap meta-linguistic awareness: namely, the ability to understand the abstract regularities behind the organization of language (Taylor 2012). Thus, language and mindreading coexist with one another.

The difficulties in isolating units of selection also speaks against the possibility of ascribing decontextualized adaptive values to gadgets, which could be modified and enhanced independently from the rest of the mind/world complex. In contrast, any variation within a gadget can cause cascade effects in a series of intermeshed and materially extended cognitive functions so that the adaptive value of a gadget is given from how it alters the whole cognitive world it lies within. Overall, the massive interconnection and coexistence of factors suggests that selection-based approaches cannot be applied to gadgets in a reductionist fashion and raises the possibility that neo-Darwinian methods are incommensurable with the domain of cognition and culture.

Finally, we argue that the CGT maintains a conservative idea of the relation between brain regions and functions – though milder than the standard evolutionary psychology account – because it contends that brain regions are selected by culture *for* mediating particular cognitive functions. However, following the theory of neural reuse (Anderson 2014; Raja 2017), brain regions are deployed and redeployed in multiple cognitive tasks, depending on their internal constraints and relations to bodily and material structures. By acting on such physical constraints, natural selection makes some neural networks more or less suitable to hosting particular functions, but these networks have no original functional exclusivity of any sort. Thus, brain regions are evolved by culture *without being for anything* in particular, including domain-general processes.

The criticisms of the neo-Darwinian view that we have expressed shape a radically different conception of the mind in relation to the brain, the body, and culture. Rather than a computational device constructed through cultural selection, this view depicts the human mind through the metaphor of a “brainwave” that invades reality and resonates with external structures (Gibson 1966, p. 5; Raja 2017 and references therein; Robbins 2006). Cognition in this sense stands as a dynamic system incurring between particular structural patterns in the world and neural territories showing appropriate conditions for resonance but does not involve a brainbound computational architecture. Furthermore, material structures are non-neutral, because they incite the mind, foster the creation of new patterns of resonance, and therefore continuously reshape cognition (Ihde 1990; 2009; Ihde & Malafouris 2018; Knappett 2005; Verbeek 2005). Consequently, culture cannot be conceived as a disembodied code of operations and algorithms; rather, it implies the socially negotiated alteration of such structures, and the creation of new affordances for cognitive transformation that are inherited by the new generations (see the concept of a “landscape of affordances” in Rietveld & Kuverstein 2014 and in Rietveld et al. 2018). Within this view, cognitive evolution is intended as a metaplastic trajectory, whereby the mind emerges only at the nexus of neural and cultural plasticity, and does not identify an autonomous level for natural selection (Aston 2019; Iliopoulos & Garofoli 2016; Malafouris 2010; Roberts 2016; Woodward 2019).

This conception remains friendly with the constructivist inclination of the CGT, and yet renounces the idea that some cognitive constructs (i.e., the gadgets) are fixed units of adaption and selection, and with this avoids the serious reductionist pitfalls of the neo-Darwinian theory. In contrast, cognitive functions are one and many, intermingled with motivational and emotional aspects, and deeply embedded within materiality (cf. Spivey 2007). They are prone to developmental change and inherently incomplete (Malafouris 2016), so that any transformation in one of them potentially affects the whole structure of the mind as well as the relational entanglement of agents and the world (Garofoli 2019). Such resulting conception predicating the coalescence of cognitive properties, the radical interconnection of beings, and the fluid transformation and “rebirth” of the mind and the world seems closer to a form of naturalized Buddhism rather than a neo-Darwinian theory of cognitive evolution (Varela et al. 2017; Vogd 2013). We hope to have convincingly shown that this conception allows the CGT to maintain its constructivist foundations while renouncing unnecessary and controversial assumptions.

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Note

1. In compliance with specifications of the Italian Ministry of Education, Universities and Research, we clarify that Marco Fenici has written the first four (and the last) paragraphs and that Duilio Garofoli has written the remaining five paragraphs.

Cognitive gadgets and cognitive priors

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Abstract

Some of the foundations of Heyes’ radical reasoning seem to be based on a fractional selection of available evidence. Using an ethological perspective, we argue against Heyes’ rapid dismissal of innate cognitive instincts. Heyes’ use of fMRI studies of literacy to claim that culture assembles pieces of mental technology seems an example of incorrect reverse inferences and overlap theories pervasive in cognitive neuroscience.

In the book *Cognitive Gadgets: The Cultural Evolution of Thinking* (2018), Cecilia Heyes takes a strong stance against the established idea that natural selection of genetic variants is the force that has selected and shaped human cognitive capacities. Heyes negates the existence of innate cognitive instincts. She suggests instead a fascinating and radical alternative: that cultural evolution occurring through social interactions in childhood has “built” and “assembled” the pieces of mental technology that underlie some unique human cognitive capacities. Heyes does not negate the natural selection of variants; however, she believes that these variants are not genetic but cultural.

The attempt to provide a neurobiological, mechanistic explanation of theories of cultural psychology and social anthropology (Shweder & Sullivan 1993) is admirable. As would any radical position, Heyes’ theory of uniquely human cognitive gadgets being assembled in the brain by cultural evolution requires a careful scrutiny. We note that some of the foundations on which Heyes builds her reasoning are based on a fractional selection of the available empirical evidence.

A first tenet of Heyes’ theory is the denial that cognitive mechanisms such as social attentional biases and the ability to imitate are genetically inherited. As a consequence of this negation, Heyes proposes that these cognitive capacities are physically assembled in the brain only after birth, through social interactions in childhood. Although Heyes considers these capacities as uniquely human (more on this later), an ethological perspective is fruitful in order to examine the solidity of this assumption.

An interesting example is associated with newborns' responses to face-like stimuli, which Heyes considers at length in her book (2018; pp. 60–63). She argues that "domain-general processes of associative learning are sufficient to explain why, in the first year of life, a simple preference for inverted triangles of blobs becomes a highly robust and selective preference for fellow humans 'looking at me'" (p. 62). Quite in contrast, it seems to us that in the absence of such a "simple preference," domain-general processes would simply have no time and opportunity to build up complete face representations on the sole basis of the exposure to real-world exemplars of human faces.

We believe that organisms are equipped with dedicated orienting and learning mechanisms that work as *adaptive priors*, engrained in cortical architectures that have been shaped by natural selection to deal appropriately with environmental stimuli. This approach may provide a different view of why, as also stressed by Heyes, face preference at birth is not only human-specific but also widespread among vertebrates (p. 62). Research on comparative cognition may prove useful in this regard. As stated recently by Versace et al. (2018):

> (Cognitive) priors imply some assumptions about the external world that guide learning, but can, and must, allow errors (…). Research has shown that (e.g.) early preferences of chicks are not strictly species-specific but apply equally to hen face-like or polecat face-like features, or to the biological-motion appearance of either a hen or a cat. This is due to the fact that the orienting mechanisms cannot be too specific for the individual features of the mother hen, which are to some extent unpredictable from the genetic repertoire. A level of non-specificity is functional in avoiding excessive false negatives in the form of failed recognition caused by variability between adults within a species, and by changes in the appearance of even a single individual. (p. 963)

A noticeable example related to our species is provided by recent results suggesting that a cortical route specialized for face processing is already functional at birth. Buiatti et al. (2019) used electroencephalography to record neural activity in one- to four-day-old newborns who were exposed to schematic patterns of upright and inverted face-like stimuli. Compared to inverted faces, upright faces elicited stronger responses in a partially right-lateralized network including lateral occipitotemporal and medial parietal areas that largely overlap with the adult face-processing circuit (Rossion & Jacques 2011). Most interestingly, a negative correlation between age and the face-like pattern response was observed, in striking contrast with the idea that the face-specific cortical response increases as a function of exposure to faces. This can be explained as follows: The highly simplified face-like geometrical patterns (the inverted triangles of blobs to which Heyes 2018 alludes, p. 61) act for newborns as, using ethological terms, key or supernormal stimuli. The immature visual system of the newborn in the very first hours of life is genetically tuned to optimally detect such key stimuli, and exposure to real-world complex and variable faces may refine the face-like circuitry such that it rapidly gets more attuned to the real-world features and gradually loses sensitivity to artificial face-like geometrical patterns. This view is profoundly different from that proposed by Heyes because it posits that the unfolding of a genetically inherited face processing mechanism is indeed at work here, and that its lack of specificity is expected as part of such an adaptive prior to account for "variability between adults within a species, and by changes in the appearance of even a single individual" (Versace & Vallortigara 2015, p. 963). Another glaring omission to this discourse is the robust evidence that newborn humans can imitate (e.g., Meltzoff et al. 2018).

These cognitive capacities, whose neural bases have become to be understood (Lorenzi et al. 2017; Mayer et al. 2017; Versace & Vallortigara 2015), are, in our view, innate mechanisms. Thus, the presence at birth of the specific cognitive capacities that Heyes postulates to be exclusively "acquired through sociocultural experience" (p. 5) makes this first foundation of the cognitive gadget theory unwarranted.

A second tenet of Heyes' cognitive gadgets theory is that cognitive mechanisms such as causal understanding, imitation, and mindreading are not only acquired through sociocultural experience, but are also "distinctively human" (p. 1). However, all these cognitive mechanisms are observed in several other species, although in different grades. For example, birds display causal understanding (e.g., Jelbert et al. 2019), and mindreading is present in a number of nonhuman animals. Thus, the current debate pertains only to the degree by which animal mindreading differs from that of other animals (Lurz 2011). Throughout her discussion of the issue, Heyes affirms that what is commonly considered to be mindreading is not actual mindreading, and she specifies that the cognitive gadget theories refer to the special case of "explicit" mindreading. This construct drift towards less tractable definitions is a consequence of the use of open concepts typical of some psychological discourse: Definitions are construed theoretically rather than being naturally defined by their inherent compositional nature or causal structure. Paul Meehl ascribed the lack of cumulative progress of psychological theories to the use of these open concepts, evoking General McArthur's description of old generals: "They never die, they just slowly fade away" (Meehl 1978, p. 807).

A third, and most fascinating, idea of *Cognitive Gadgets* is that "human cognitive mechanisms have been built by cultural evolution" (p. 22), and that these new "pieces of mental technology are not merely tuning but assembled in the course of childhood" (p. 22). The evidence that Heyes brings in support of this idea comes from functional magnetic resonance imaging (fMRI) in humans: In response to viewing written sentences, literate individuals produce stronger responses than illiterates in several areas of the brain, including the left mid-fusiform region (the so-called "visual word form area," VWFA; Dehaene et al. 2010). Heyes considers this finding a proof of principle for the cognitive gadgets theory: A cultural product (literacy) builds a new specific piece of brain machinery ("If one did not know that reading is culturally inherited, it would be easy to mistake the […] precise localization of VWFA for signs that the capacity to read depends on a cognitive instinct"; p. 20). There are, however, two main problems in this reasoning. First, several forms of simple noncultural learning enhance fMRI activations in a large set of cortical areas (e.g., Buchel et al. 1998): such changes in brain activity should not (and are not) considered as testimony that "new pieces of mental technology are […] assembled" (p. 22). Second, matters of specificity and sensitivity of fMRI responses, and the ensuing difficulties of unequivocally identifying a certain cognitive state on the basis of an fMRI response (Poldrack 2006), are not considered. Indeed, the mid-fusiform gyrus (i.e., the VWFA) responds to a wide number of sensory stimuli, including visual stimuli that do not entail words and have no linguistic implications (Price & Devlin 2003; van Turennout et al. 2000). Thus, given that this brain region is also activated when no linguistic stimuli are presented, it is an incorrect reverse inference to conclude that its activation indicates that any language response has occurred, and should therefore not be labeled VWFA (Price & Devlin 2003). Unwarranted conclusions based on reverse inferences and overlap theories of fMRI results are pervasive in human cognitive neuroscience (Iannetti et al. 2013). Some of Heyes' propositions are not immune from this issue.

We wish to conclude by recalling the message that Valentino Braitenberg offers in his "Vehicles – Experiments in Synthetic Psychology" (1984): The use of mentalistic terms to describe the behavior of artificial machines with an internal structure inspired by the nervous system reduces our chances to understand properly the mechanisms determining their behavior. These mechanisms are instead more easily understood by creating the structure that gives rise to the behavior. In contrast to Braitenberg's famous "law of uphill analysis and downhill invention," Heyes states that "relationships between the brain, behavior and the world cannot be understood without describing those relationships at an abstract, mental level" (p. 9). A critical assessment of these diametrically opposed viewpoints has the potential of being revealing.

Cognitive gadgets and genetic accommodation

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Abstract

Heyes argues that human metacognitive strategies (cognitive gadgets) evolved through cultural rather than genetic evolution. Although we agree that increased plasticity is the hallmark of human metacognition, we suggest cognitive malleability required the genetic accommodation of gadget-specific processes that enhanced the overall cognitive flexibility of humans.

In her book, Cecilia Heyes (2018) puts forward a bold hypothesis: The foundational and unique meta-cognitive capacities underlying the human mind – social learning, imitation, theory of mind and language – are not genetically-based "instincts." They are culturally evolved "gadgets." Constructed in the social domain, they are transmitted through cultural inheritance, and acquired through cultural learning. What this means is that virtually nothing was required at the brain level during human evolution apart from a dramatic increase in the overall capacity of the brain for plasticity. Heyes acknowledges some additional biases in the ontogenetic "starter kit": slightly greater social tolerance and social motivation; some slight perceptual visual and auditory biases; and greater executive control based on our disproportionately larger frontal lobes. But apart from these, Heyes claims that our cognitive uniqueness lies in the simple fact that our brains are much larger. Because our large brains evolved for increased general plasticity, there is no reason to expect the gadgets to be supported by genetically given, gadget-specific brain structures and cognitive biases.

We agree with Heyes that increased plasticity is the hallmark of human metacognition, and we think that Heyes has done an admirable job showing how associative learning can account for what seems like inborn biases. We believe, however, that Heyes' overall conclusion – although theoretically possible – is implausible. To see why, we have to look more closely at the phylogenetic dynamics.

Incontestable signs of cultural, social, and cognitive uniqueness began to appear in hominin communities around 2 million years ago. From then on, these communities gradually transformed themselves into increasingly efficient, gadget-based collaborative enterprises, which required an entire array of new capacities – exactly those that we don't share with our ape relatives. Individuals thus began to be selected for their capacity to participate in the collaborative efforts. Increased plasticity was rewarded, and so were the biases that Heyes acknowledges. But beyond this, every variation that allowed individuals to extend and put less effort into their learning – whatever its nature – was probably selected, as long as it did not jeopardize other learning capacities too much. Different culturally learned adaptations were gradually genetically accommodated, forming biases for the gadgets. It was this accommodation that allowed the extension of plasticity in specific domains, and the invention of new and more elaborate gadgets, which increased the pressure on individuals, and so on.

As West-Eberhard (2003) and others have shown, the process of genetic accommodation (as opposed to the narrower process of genetic assimilation) encompasses the evolution of plasticity and the evolution of canalization, which includes the evolution of *canalization for plasticity*. Consider, for example, the human hand. The hand is an exquisitely evolved "tool of tools," as Aristotle put it, with specific morphology, sensitivity, innervation, and musculature. It evolved in the context of tool use and social communication in small, highly collaborative hominin groups. Its hyperplastic affordances are based on the canalization of its accommodated structure. Human hyperplastic culturally molded cognition evolved in the very same social and ecological context and involved multiple interacting, selection pressures that resulted in patterns of plasticity-enhancing canalization: organized systems that extended humans' affordances. Heyes claims that our brains, our "cognitive hands," are shaped almost exclusively *during ontogeny*. The alternative is that, just like the hand, the human brain was gradually shaped *during phylogeny* for specific types of plasticity and enhanced affordances, required for specific types of social behavior.

Heyes doesn't mention genetic accommodation in her book, and her arguments against the role of genetic assimilation are based on problematic assumptions. First, genetic assimilation need not be complete; it is almost always partial, leading to quicker and more efficient context-sensitive responses, so plasticity need not be compromised. Second, the genetic assimilation of one part of a behavioral sequence can facilitate learning that refines and lengthens this behavioral sequence (Avital & Jablonka 2000). Third, and most relevant to our argument, genetic assimilation of specific plasticity-promoting strategies increases, rather than decreases, the more general aspects of plasticity (Dor & Jablonka 2010). Culturally learned strategies can drive the evolution of the enhanced plasticity that extends the scope and ease of learning of this strategy, leading to its genetic accommodation. In the case of imitation, for example, an enhanced, initially laboriously learned plastic ability to imitate unfamiliar contents is likely to become genetically accommodated in changing environments requiring context and content flexible imitation.

Our interpretation of the observations that fraternal and identical human twins are alike in some of their metacognitive capacities (e.g., mindreading), and that both familiar and unfamiliar tasks can be learned with the same facility, is different from that of Heyes. Whereas she infers from that similarity that no genetic assimilation for these metacognitive capacities was involved in their evolution, we propose that the similarity is the result of strong positive *selection for plasticity and canalization* in the relevant cognitive domains (e.g., imitation, mindreading, control of social emotions, imagination, additional levels of representation). Selection for plasticity and canalization renders genetic variation cryptic and selectively neutral and expands responsiveness to environmental cues, which is exactly what these studies show.

Heyes argues that genetic assimilation did not occur because the cultural world changes too rapidly. Thus, for example, specific linguistic structures change too quickly to be accommodated. This is correct, and this is indeed why Chomsky's universal grammar project – the flagship of the "instincts" approach – resulted in failure. But the functions of language-specific structures that enhance the overall communicative capacity of all languages are much more stable, much more fundamental: Language requires the capacity for auditory phonetics, which cannot be reduced to general hearing; it requires the capacity for semantic categorization, which cannot be reduced to the ways we and other animals categorize our worlds of experiences; it requires new levels of representation, of words and communicative norms, and an entirely new relationship between episodic memory and the capacity for imagination (Dor 2015). It goes without saying that every aspect of our language-related physiology – the innervation and musculature around the mouth, the larynx, and the vocal cords; the unique function of the expanding muscles around the lungs; and so on – has been genetically accommodated. There is no reason to believe that the cognitive system, responsible for the activation and control of this physiology, somehow managed to remain unbiased towards it.

We thus agree (and have argued repeatedly) that the language capacity started, like literacy, as a cultural adaptation (Jablonka & Lamb 2005; Jablonka & Rechav 1996). But language, unlike literacy, probably began to emerge, in a rudimentary form, as early as half a million years ago; and again, unlike literacy, it became an obligatory component of human life. Genetic variations contributing to the stabilization, fine-tuning, and enhancing the flexible capacity to culturally acquire a language must have been selected for. As we see it, the dynamic relationship between the evolution of the brain and the evolution of language was reciprocal: Language adapted itself to the brain, as Heyes emphasizes, but the brain also adapted itself to language, and the two came to be entangled in a co-evolutionary spiral. Language, in other words, culturally, and then genetically, molded the brain.

All this means that we should expect to find additional biases and changes in brain organization that are related to the human-specific, gadget-based social environment. At the emotional level, we see it in the capacity to internalize the "social gaze" and thus feel the uniquely human social emotions of shame and guilt, embarrassment and pride. These emotions express themselves, as Darwin (1872) noted, in the uniquely human *blush*. The blush and its emotional and cognitive foundations seem to be a part of the human innate starter-kit (Crozier 2006). A second bias, also related to the evolution of social emotions, is the increased executive control of emotions, their social (and sometimes voluntary) regulation, and their linkage with episodic memory and social communication. We see this increased social-communicative emotional control as a specific evolved facet of a more domain-general executive control, which was a precondition for the evolution of the language capacity, and has further increased following language evolution (Jablonka et al. 2012).

Genetic and morphological evidence show variations that lead to both the increase in general aspects of brain plasticity and in specific features of the human brain and presumably human cognition. Examples of the more general features are variations linked to the overall increase in the size of the human neocortex (Florio et al. 2015; Gómez-Roblesa et al. 2015) and to the disproportionately larger human frontal lobes (Berto & Nowick 2018). One notable variation that seems to enhance particular aspects of human brain plasticity is the increased depth of the superior temporal sulcus in the right hemisphere that is probably related to social communication (Leroy et al. 2015). Many other variations that are associated with *specific* aspects in the human brain are reviewed by Sousa et al. (2017) and include alterations of the arcuate fasciculus that is involved in audition-based language production; the organization of the superior longitudinal fasciculus (the primary white matter tract connecting lateral frontal with lateral parietal neocortical areas), which is implicated in social learning and tool use; great expansion of two lateralized human frontoparietal networks in the cortical regions; and structural and functional reorganization of corticofugal projection neurons (connecting the neocortex and the subcortical regions) that may be important for motor control and digital dexterity. Together, the distinctive functional attributes of these connections build up the domain-general metacognition of humans.

Genetic accommodation of developmental dispositions and strategies brought about selection for altering the threshold, range, and sensitivity of developmentally acquired and learned responses is ubiquitous. As West-Eberhard (2003) has shown, processes of genetic accommodation can explain the evolution of general and specific flexible aspects of animal morphology, behavior, and cognition. The key to human evolution is the fact that we constructed the cultural niche collectively, phenotypically accommodated to it individually, and eventually became, through genetic accommodation, even better niche constructors and phenotypic accommodators. As Heyes argues, the ontogenetic tool kit does not include "instincts." It seems, however, to include a set of interconnected, partial biases and specific structural and functional reorganizations for different cultural gadgets. This set of biases is not the a priori foundation of the gadgets, as the "instincts" approach would have it: It is the a posteriori outcome of the huge and enduring significance of the gadgets in our social lives.

Keeping *cultural* in cultural evolutionary psychology: Culture shapes indigenous psychologies in specific ecologies

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Abstract

In *Cognitive Gadgets*, Heyes seeks to unite evolutionary psychology with cultural evolutionary theory. Although we applaud this unifying effort, we find it falls short of considering how culture itself evolves to produce indigenous psychologies fitted to particular environments. We focus on mentalizing and autobiographical memory as examples of how socialization practices embedded within culture build cognitive adaptations.

In *Cognitive Gadgets*, Heyes (2018) proposes "cultural evolutionary psychology" to unite the long-opposed "High Church" evolutionary psychology (especially Cosmides & Tooby 1996; Tooby & Cosmides 1992) with cultural evolutionary approaches (especially the California School: Henrich 2015; Richerson & Boyd 2005). This effort promises to invite further engagement across disciplinary boundaries, with important points made about adding clarity to aspects of cultural evolutionary theory that have been as yet underspecified. Heyes highlights the disciplinary baggage that cultural evolutionary theory carries from its roots in anthropology and biology, leading to a tendency to black-box the brain and leading also to conceptual ambiguity about how social and cultural learning differs. Adding a more explicitly cognitive science perspective to these theories may encourage engagement from more cognitively oriented researchers. Although we applaud this unifying effort, we still find it to be limited by its own cognitive science disciplinary baggage by being strikingly thin on *cultural* psychology.

The argument in chapter 2 in favour of isolating effects of nature, nurture, and culture exemplifies this culturally narrow view. Heyes focuses many of her arguments on trying to prove the point that cognitive mechanisms involved in mentalizing and social learning are domain-general. However, we find the discussion to be so focused on debating the nativists that it misses the opportunity to examine how teaching and learning environments vary across cultures to provide children with context-specific opportunities to develop the cognitive abilities needed to thrive as adults. Doing so implies (1) there is a single set of distinctively human cognitive mechanisms and that (2) existing cognitive research is the "core" of this set, with all variation being deviations around this core (perpetuating West vs. the Rest thinking, see: Henrich et al. 2010; Kim & Park 2006; Kline et al. 2018). Worse still, it misses perhaps the most powerful element of cultural evolutionary theory: that culture itself evolves to produce these adaptations, leading to a diverse range of specific, indigenous psychologies that are fit to particular environments by culture. These culturally adapted, culturally produced learning environments provide the connection point between culture and cognition that builds locally adapted brains to particular environments. We focus our discussion on mindreading and autobiographical memory – both shaped by culturally specific, indigenous practices – as examples of how evolutionary cultural psychology might better examine cognitive adaptations that arise through adaptive socialization practices embedded within culture.

We largely agree with Heyes' account of early-developing mentalizing developing from Bayesian, domain-general learning mechanisms and later-developing, more effortful mentalizing developing from input of culturally evolved practices. However, the print reading metaphor may be more confusing than it is illuminating. Perhaps the strongest evidence against the mentalizing-as-print-reading comparison comes from societies where mental state discussion is prohibited. In these societies with norms that treat the mind as an opaque container (a set of norms called the opacity doctrine or opacity of mind: Danziger & Rumsey 2013; Duranti 2015; Robbins & Rumsey 2008) verbal instances of mental state reasoning are far fewer than in more mind-focused societies. Were the parallel to print reading as solid as Heyes claims, one would expect mentalizing to be fully absent in these societies, just as one would expect print reading to be fully absent in individuals never exposed to explicit training in print reading. The data do not, however, bear this out. Rather, though early childhood false belief tests hit an average "pass" rate at a later age in these societies than in more mind-focused groups (Barrett et al. 2013; Callaghan et al. 2005; Mayer & Träuble 2013; Slaughter & Zapata 2014), children do acquire this skill. Further, adults in these societies do use mental state information in their assessments of actions (i.e., moral right and punishment), but include outcome more than other more mind-focused (even collectivistic) groups (Barrett et al. 2016; McNamara et al. 2019).

The solution to unpacking this, we suggest, lies in focusing on variation and process as these mentalizing and other social cognitive abilities develop. If we step out to consider the adaptive dynamics presented by various social-ecological contexts, we find different sets of adaptive pressures and challenges that inform different social cognitive solutions across societies. These social cognitive solutions are accompanied by unique, context-specific cultural learning environments that help foster those abilities to build locally adaptive indigenous psychologies.

Ecological conditions inform the social structures societies might adopt, which in turn influence the extent to which individual desires, beliefs, and preferences versus group norms (or shared expectations about correct actions in various contexts) guide behaviour. In unstable, resource-poor, and otherwise risky conditions, group structures are typically more central to daily survival and deviations from norms are less tolerated – making norms more informative predictors of behaviour (Fincher & Thornhill 2012; Gelfand et al. 2011; Hruschka et al. 2014; Van de Vliert 2011). Hierarchically structured social systems also require stronger social norms, which are common in more traditional, less industrialized societies (Hofstede 1986; Inglehart 1997). In more stable, abundant environments and when institutional buffers against life's slings and arrows are reliably strong, individuals typically have more autonomy and norm deviation is more tolerated (Norris & Inglehart 2004; Van de Vliert 2008).

Cultural variation in folk understanding of minds and behaviours (variable theories or models of mind: Lillard 1998; Luhrmann 2011) may parallel how the aforementioned cultural dimensions and population dynamics modulate the behavioural predictive value of individual mental states versus group norms. If we consider these adaptive dynamics across contexts, we might approach mentalizing as a cognitive ability that modulates to fit the behavioural prediction needs of these social landscapes. In societies where norms are well known, relatively strict, and when social groups are highly stable due to low relational mobility, mentalizing may be simply less informative about behaviour. This, in turn, might foster a different set of social cognitive strategies that emphasize reference to norms or other social information rather than minds when predicting and interpreting behaviour (McNamara et al. 2019). This may partly explain cultural differences in the fundamental attribution error versus situation attribution (Choi et al. 1999; Norenzayan et al. 1999) and why intent focus in moral judgments varies across societies (Barrett et al. 2016; McNamara et al. 2019).

Building from the socio-ecological dynamics that inform cognitive strategies in different contexts, we can then look for how cultural practices and institutions foster the cognition that suits these varied social environments. Heyes cites work on parental mind-mindedness and its correlates with mentalizing development (Taumoepeau & Ruffman 2008), but she does not expand to look at how these parenting practices play out in a wider context of socialization across societies. Mind-mindedness, or the tendency for caregivers to imbue young children with mind by referring to them and (importantly) speaking to them using mentalistic words, is associated with better mentalizing performance across early childhood in WEIRD (Western educated industrialized rich democratic) societies (Carr et al. 2018). In these contexts, mind-mindedness is a mark of responsive parenting in an environment where mindreading is an important skill (Taumoepeau & Ruffman 2016). It provides children opportunities to tune their domain-general learning cognition to pick up on the statistical regularities of behaviour that are associated with the mentalistic terms caregivers use, enforcing and transmitting the mind-focused folk theory of mind common in more individualistic societies. Mind-mindedness, therefore, could be seen as a cultural adaptation to enable this mind-imbued social world to propagate across generations. The terms used to discuss mental states may also be cultural innovations to enable mentalizing: Introducing mental state terms predicts better mentalizing performance – even in the same participants (Pyers & Senghas 2009).

We temper this with the caveat that mentalizing is operationalized and measured in ways designed by and for mind-focused WEIRD societies. We cannot use these approaches alone to examine whether and how these abilities are developed and deployed in less mind-focused societies. Though mind-mindedness explains some cross-cultural variation in early mentalizing (Hughes et al. 2017), the more collaborative, authoritative parenting style associated with mind-mindedness in places like the United States does not consistently correlate with mentalizing performance; in some instances, children from more collectivistic, less mind-focused contexts perform better (Vinden 2001). Further, even if mentalizing needs to be taught to children via mind-minded parenting in some societies, that does not mean it must be taught in others. Though explicit teaching is prominent in Western parenting, formal, explicit teaching is comparatively rare in smaller-scale, tightly knit traditional societies (Hewlett 2016; Kline et al. 2013; Lancy & Grove 2010). Children in these traditional-society learning environments tend to perform better on observational learning by directing their own attention, whereas children in societies with more emphasis on formal teaching tend to rely more on adults to direct their attention (Clegg & Legare 2016).

By looking to the wider context of socialization within particular socio-ecological settings, we may further find socialization practices that foster cognition outside the typical focus of mainstream cognitive science. We focus on the example of autobiographical memory transmitted via dyadic reminiscing styles in Māori families. Reminiscing styles typically follow two forms: (1) Elaborative reminiscing builds on existing information using open-ended "wh" questions elicited by adults when recalling the past event (Fivush et al. 2006), and (2) repetition reminiscing focuses on repeating one or two informational aspects of a past situation. In New Zealand Māori families, repetition reminiscing is used more heavily for past events that are highly relevant to Māori identity (Reese & Neha 2015; repetition reminiscing appears to have a similar function in Haitian families: Okpewho 1992). As children grow, reminiscing about past events can become an even more collaborative and an adaptive undertaking with family iterations of discussing different subjective perspectives of an event alongside the facts of the event (Fivush 2001). This practice of shared, co-constructed recall with children in Māori families builds shared cultural identity and is especially prominent in transmitting social behavioural expectations in discussion of children's past transgressions (Reese et al. 2014). Existing theories of social transmission (i.e., Godfrey-Smith 2012) emphasize individual-level learning and neurobehavioural monitoring. However, the Māori parent-child reminiscing example illustrates how a child's later transgression may require revisiting discussion around a past event, socially building on the shared memory of these events within the family environment. The result is a behavioural monitoring and autobiographical memory system that is jointly produced by individual neural systems and the sociocultural space built by ongoing conversations between child and parent and within the wider whānau Māori (family/community) context.

In addition to building social identity, the reminiscing styles common in Māori families may provide an advantage for recall of early childhood experiences that challenges assumptions about childhood amnesia. Most early childhood recall studies show adults recall their earliest memories around 3–4 years of age (Fivush & Nelson 2004). This is not merely a product of garden variety forgetting; when forgetting curves are fitted to adults' early childhood recollections, there are significantly fewer memories below age 7 than would be expected, there are almost no memories before age 3 (Labov 1972), and the earliest coherent memories often take another year to emerge at around age 4½ (Fivush & Nelson 2004). However, Māori adults' earliest recollections average around 2½ years, whereas New Zealand European and Asian adults average around two years later (MacDonald et al. 2000). These earlier recollections for Māori adults may be due in part to the cultural relevance of past experience (Pere 1982; Rewi 2013). Traditionally, Māori communities relied on oral transmission; past recollections have long been steeped throughout oral dissemination that spread and maintained cultural identity and knowledge. Cognitive techniques like mnemonics (e.g., whaikairo, tā moko) and devices (e.g., rākau, tokotoko) to prompt remembering ancestral lineage was paramount for cultural, social, and ecological survival. These cognitive abilities may therefore be seen as specific adaptations to the social learning environment that Māori communities navigate. This provides another example of how a seemingly hard constraint on the human neural system is modulated by cultural socialization practices, leading to context-specific indigenous psychologies that might be completely missed when speaking of nature, nurture, and culture as anything but inextricably bound, building brains to particular environments through cultural adaptation.

Imitation: Neither instinct nor gadget, but a cultural starting point?

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Abstract

Heyes asks whether cultural learning mechanisms are cognitive instincts or cognitive gadgets. I argue that imitation does not fall into either category. Instead, its acquisition is promoted by its value in social interactions, which is evident across phylogeny and ontogeny and does not depend on the role of imitation in cultural learning.

In her book, Heyes (2018) sets up a dichotomy between two potential sources for mechanisms of distinctly human cultural learning: biological specification and inheritance via genetic programs versus acquisition of these mechanisms via their own cultural learning processes. Referring to these two possibilities in shorthand, she asks if the processes that support cultural learning are cognitive instincts or cognitive gadgets.

If there are only two possibilities, then eliminating Option 1 allows for settling on Option 2 by default. Much of Heyes' case for cognitive gadgets relies upon this strategy, as she focuses on ruling out the possibility that the mechanisms she investigates are cognitive instincts. She presents less conclusive evidence, however, that the process of acquiring these mechanisms involves cultural learning, defined as "social learning involving cognitive processes that are specialized for cultural evolution" (Heyes 2018, p. 86).

Heyes does not fully consider a plausible third option: that small, quantitative changes in genetic predispositions for social tolerance, motivation, and attention (i.e., the changes laid out in her "starter kit") could collectively create the opportunity for developing humans to acquire novel social cognitive processes in the absence of any cultural transmission process or selection for cultural evolution and accumulation. To express this idea in another set of Heyes' terms, she lays out how the genetic inheritance of the human starter kit may promote the social learning of "grist," including social behaviors such as infant gaze following. I suggest that this genetic starter kit could also support the social acquisition of novel "mills" (i.e., cognitive processes that support learning), including one featured among Heyes' case studies: imitation.

Heyes makes a convincing case that human imitation should not be considered a cognitive instinct. Setting aside the debate regarding the possibility of some neonatal imitation based on innate perceptual-motor mapping of a limited range of facial movements (Meltzoff et al. 2018; Oostenbroek et al. 2016), she presents strong evidence that many "vertical" links between perceptual and motor representations of specific actions are acquired (and can be altered) through associative learning, and that we learn the ability to execute perceived sequences of actions motorically. Our comparative expertise at topographically matching others' movements is thus not the product of a genetically specified mechanism, but is rather an acquired cognitive skill.

But is the acquisition of the ability to imitate an example of cultural learning, or does it fall in the space of noncultural social learning? Heyes defines cultural learning not by the presence of particular transmission mechanisms (e.g., teaching) or outcomes (e.g., selective learning), but by the selection of the learning mechanism for its role in promoting cultural evolution. Thus, to answer this question we need to ask if imitation is learned because it promotes the faithful transmission of and selection over cultural variants. Are the necessary experiences of correlated action execution and perception (e.g., parents' imitation of their infants), and reward for imitating (e.g., social partners' positive responses to being imitated), specialized for the transmission and evolution of a cultural learning strategy? Or is the prevalence of these elements in human social interaction the product of the incremental increases in the human genetic predisposition for social motivation and attention?

Research on the nature and role of imitation in social interaction suggests the latter. Human interaction partners imitate many aspects of one another's behavior regardless of the potential for social or cultural learning (Chartrand & Lakin 2013). As in the studies on synchrony and social bonding cited by Heyes (e.g., Tunçgenç & Cohen 2016), experiments find that imitative interactions elicit liking and rapport (Chartrand & Bargh 1999; van Baaren et al. 2004). Moreover, the deployment of imitation in social interaction is sensitive to the need for social inclusion and the imitated social partner's ability to perceive that she is being imitated, indicating that users understand its role in creating rapport (e.g., Bavelas et al. 1986; Lakin et al. 2008; Over & Carpenter 2009). A preference for imitators also precedes the robust use of imitation for cultural learning (or any other purpose) both phylogenetically and ontogenetically (e.g., Agnetta & Rochat 2004; Carpenter et al. 2013; Paukner et al. 2009; Powell & Spelke 2018b).

The preference for being imitated and for those who imitate their social partners cannot be explained by reward learning following one's own imitative behavior, nor can it be explained by a preference for contingency, which is typically equated for in control conditions. It is also not well explained by approval of the imitator's capacity for cultural learning, as might be the case for positive responses to a learner's skill at reading printed text, as it extends to the imitation of useless behaviors and to infant observers who do not yet imitate for cultural learning purposes themselves. Instead, preferences for imitation likely stem from what imitation indicates about the imitator's disposition as an attentive and affiliative social partner (Meltzoff 1990; Powell & Spelke 2018a; 2018b).

This social value of imitation explains why young human learners receive both the experience necessary to solve the correspondence problem and the rewarding feedback that reinforces imitative behavior, without the need for cultural learning processes that have been selected based on the role of imitation in cultural evolution. Parents and other caregivers may imitate their infants (Kokkinaki & Kugiumutzakis 2000; Pawlby 1977), providing correlated perceptual and motor experience, simply because that is a regular component of their interaction with valued social partners. Meanwhile, infants and young children may be rewarded for their early imitative behaviors as a result of the same social motivations that reinforce imitative interactions among adults. Finally, the relative prevalence of these factors in human social experience, compared to that of other primates, can be explained by the incremental shifts in motivation for social affiliation and attention described in Heyes' starter kit. (This is not to say that, once acquired, the capacity for high-fidelity topographic imitation is not used for effective cultural learning, just that the forces that promote its acquisition do not depend on this use.)

What is at stake in the distinction between imitation as a culturally learned cognitive gadget versus merely a socially learned capacity? There are at least three implications. The first involves the necessary relationship between the imitative capacities that promote cultural learning and those that are acquired by learners via social interaction. As Heyes notes, for imitation to be shaped by cultural selection as a cognitive gadget, the imitative mechanism would need to be transmitted from model to learner with relatively high fidelity. In contrast, if imitation is learned due to its socially rewarding nature, along with the increased prevalence of social attention and engagement, then these forces can continue to shape imitation in similar ways across generations of learners without the need for strict fidelity across individuals.

Second, the distinction changes predictions about the impact of cultural disruption. Heyes notes that, like all cultural knowledge and skills, cognitive gadgets could be lost when cultures are disturbed by conflict or natural catastrophe. If, however, imitation is the product of the human starter kit, then it should recur regardless of the maintenance of a preexisting cultural repertoire.

This leads to the final implication, which is that the acquisition of imitative capacities via social, but not cultural, learning could serve as the starting point for the accumulation of culture, including true cognitive gadgets. The strength of selection for cultural learning mechanisms should depend on the size of the pool of cultural knowledge and skill that such mechanisms could potentially tap. When little cultural knowledge exists, accumulation may depend on mechanisms, like imitation, that could be acquired without the benefit of shaping via cultural selection. With the growth of information stored within a culture's traditions, dedicated cultural learning mechanisms will become more valuable, leading up to our current state of affairs, in which the information that can be accessed by cultural learning is now so vast that it is considered beneficial for virtually any human to engage in the immensely effortful, years-long process of learning to read. Thus, taking one item off her list of cognitive gadgets and assigning it to a third category may ultimately provide necessary support to Heyes' innovative theory of cultural learning.

Mending wall

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Abstract

Heyes suggests that selective social learning comes in two varieties. One is common, domain general, and associative. The other is rare, domain specific, and metacognitive. We argue that this binary distinction cannot quite do the work she assigns it and sketch a framework in which additional strategies for selective social learning might be accommodated.

Robert Frost's (1914) poem uncovers the costs and benefits of crisp boundaries. It is true both that sometimes "good fences make good neighbors" and that fences can stand in the way of understanding. In her insightful account of how genetic evolution and cultural evolution working together could have produced our modern human minds, Cecilia Heyes (2018) introduces and vividly names some valuable distinctions – most importantly between cognitive instincts and cognitive gadgets, between "Big Special" and "Small Ordinary" cognitive gifts, between mills and grist, and between metacognitive rules and other useful dispositions. But "something there is that doesn't like a wall," as Frost said, and that something is nature: the gradual effects of variation, differential reproduction, decay, and inauspicious birth. Heyes' distinctions are fine contributions to the task of explaining the evolutionary trajectory from animal to human cognition, but they are not all as crisp as she suggests. Acknowledging this can save her account from a variant of the well-worn chicken-and-egg problem. Which came first: cultural evolution or metacognition? To see why this looks like a problematic question for Heyes, note that her account provides support for each of the following four claims.

1. Cultural evolution requires transmission fidelity. (p. 112)
2. Transmission fidelity requires focused selectivity in social learning. (p. 111)
3. Focused selectivity in social learning requires metacognition. (p. 111)
4. Metacognition is a product of cultural evolution. (p. 107)

The apparent circularity implied by these claims stems from the fact that metacognition is described both as a product of cultural evolution and as one of its drivers. Of course, Darwin showed that chicken-and-egg problems like this are not nearly as perplexing as they first appear. The hint of paradox disappears as soon as we consider the role of intermediate forms. Metacognition must have emerged gradually – perhaps by means of a cultural evolutionary process that was noisier than the higher-fidelity process it subsequently made possible. And if metacognition did evolve gradually, there must be (or must have been) some intermediate cognitive form(s).

> I suggest that the crucial, culture-relevant difference between selective social learning in humans and other animals is that some human social learning is made selective by explicit metacognition (Shea et al. 2014): by conscious, reportable, domain-specific rules …. (Heyes 2018, pp. 105–106)

You can't follow an explicit rule that you don't understand, so comprehension is crucial in *some* human social learning, but what about the rest of it? Couldn't there be "rules" – don't there have to be "rules" – that are inexplicit, semi-understood free-floating rationales (Dennett 1983; 2017) that modulate and control many of the competent behaviors that provided the evolutionary stepping stones to our current cognitive powers? Competence without comprehension must precede competence with comprehension.

Heyes does recognize one form of competence without comprehension in the domain of selective social learning. She discusses social learning strategies found in non-human apes (in addition to humans), and refers to them as *planetary*, cleverly reminding us of the fact that, just as planets follow Isaac Newton's rules without comprehending them, nonhuman apes can follow learning rules without any ability to reflect on them. For example, monkeys can learn to arrange a series of photos so that it matches the order provided by a human experimenter (Subiaul et al. 2004). Nothing in this behavior demands a metacognitive explanation. Domain-general associative learning would suffice for the monkey to learn that copying *that particular human* leads to a food reward. For Heyes, this sort of planetary social learning has little in common with the more sophisticated metacognitive variety that supports human cultural transmission.

Heyes refers to uniquely human social learning strategies as *cook-like*, evoking the domain-specific and self-aware kind of social learning familiar to anyone who has tried to cook by following a written recipe.

If Heyes' goal is to remind us of the fact that not all learning requires consciousness and episodic memory, the distinction between planetary and cook-like learning strategies is helpful. However, if her goal is to understand the evolution of metacognition, then, regardless of whether that evolution is genetic or cultural, this binary distinction threatens to blind us to the messy middle ground between planetary and cook-like learning. As is often the case in thinking about evolutionary change, it may help to imagine a multidimensional space of possible learning strategies (cf. Dennett 2017; Godfrey-Smith 2009). The planetary and cook-like varieties represent only two extremities in that space. Moreover, it is unlikely that evolution has managed to avoid visiting large subspaces in the interior. In Heyes' own view, the adaptations that mark our trajectory through that space have been "Small and Ordinary" (p. 53), which rules out large saltation-like leaps.

In our view, Heyes' already excellent treatment of selective social learning could be enriched by acknowledging and then exploiting the inner regions of this space. The attraction of this expansion can be seen clearly when we compare Heyes' treatment of *status-based* selective learning with her treatment of *age-based* selective learning. Heyes describes a study by McGuigan (2013), in which 5-year-old children can get help solving a puzzle-box problem from different classes of adults. It turns out that 5-year-olds can rank the social status of adults, and then tune their social learning strategy to ensure that only high-status models get copied. Although this looks like a case of children regulating their social learning in just the way cultural evolutionary theory requires, Heyes offers this study as an example of domain general, associative, and *non*-metacognitive learning. Contrast this with her most prominent example of genuine metacognition, the rule that instructs us to *copy digital natives*. Metacognition is defined as thinking about thinking. So what makes this rule metacognitive? Can't we construe it as a rule about what to do, rather than a rule about what to think? One might say to oneself: "If, in the future, you happen to be thinking about which app to download, copy digital natives." If one were to subvocalize that sentence, it would be a clear case of metacognition in Heyes' sense. But we see no reason that a rule with this content must be acquired by such metacognitive means.

In these two cases, we have an exemplar of purportedly non-metacognitive learning that looks meta, and an exemplar of purportedly metacognitive learning that doesn't look quite so meta after all. One might interpret this as evidence that Heyes' distinction between genuine metacognition and merely planetary social learning is not as mutually exclusive as she makes it out to be. Instead, our suggestion is that these two styles of social learning are not jointly exhaustive. They simply leave out many of the more complex kinds of learning rules that don't fit either category neatly.

The benefits of embracing the messy middle are not exhausted by the opportunity to improve the conceptual framework we use to characterize human social learning. Consider the literature on so-called *rational imitation* in chimpanzees. Chimpanzees raised in captivity will imitate a human who turns on a light switch with her forehead more often when the human seems to choose that method freely, compared to a condition in which it appears there is no choice, because the experimenter's hands were full (Buttelmann et al. 2007) This suggests a kind of social learning selectivity that isn't purely planetary, since it displays some sensitivity to the possibility of there being a rationale behind the forehead technique. Or, think of the second-order confidence "judgments" of monkeys (Middlebrooks & Sommer 2012). Monkeys will place large bets on judgments they are highly likely to get right, and smaller bets on judgments they are less likely to get right. These decisions might accurately be described as only *sorta* (Dennett 2013) metacognitive, and none the worse for that.

Our suggestion is not that these partial cases might, appearances to the contrary, suffice for cultural evolution. Rather, our suggestion is that phenomena like these provide clues about the kind of learning strategies that occupy the messy middle ground between planetary and cook-like learning. In fact, Heyes' wonderful term, "gadget," is ideally suited to play the role of a semi-understood, semi-appreciated found object that an agent might put to good use without fully understanding why.

Mills made of grist, and other interesting ideas in need of clarification

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Abstract

Heyes' book is an important contribution that rightly integrates cognitive development and cultural evolution. However, understanding the cultural evolution of cognitive gadgets requires a deeper appreciation of complexity, feedback, and self-organization than her book exhibits.

Heyes is right to bring cultural evolution to the forefront of cognitive development. As the cognitive and developmental sciences have been slowly drifting away from extreme nativist claims, the glaring question is now, "Where do constraints on social learning come from?" As it happens, cultural and language evolution experts have been working on aspects of this question for some time now. Heyes (2018) gives the reader a number of useful landmarks from those fields, but the real story of how cognitive development and cultural evolution interact is somewhat more complex than she implies. We unpack the book's central evolutionary arguments, noting some important perspectives that are omitted and highlighting the need for involvement by experts in complex systems. We will also identify problems with her central grist-and-mills metaphor. Though our tone is one of critique, we want to make it clear that we think Heyes' book is an important contribution to the literatures on both cognitive development and cultural evolution, and we fully endorse her thesis that a deeper synergy between these often disconnected research areas is paramount.

There are two principal components of Heyes' argument. The first is that cognitive mechanisms are not innate but are shaped during development by social forces – we might call this "gadgetization." The second component is that the structure of these social forces is the product of cultural evolutionary processes. We address each of these in turn.

The gadgetization that Heyes writes about is an important and underappreciated idea, with thick roots in the cognitive science of the 1990s. Heyes provides compelling demonstrations of why imitation, mindreading, and language should each be seen not as innately-given cognitive instincts but as learned cognitive gadgets. In general, calling these neural mechanisms "cognitive gadgets" will be a catchy and helpful remedy for cognitive developmentalists who have been tempted to accept the notion of "cognitive instincts." But others may want a bit more detail regarding how these gadgets are actually constructed. For example, many non-nativist cognitive developmentalists will recognize cognitive gadgets as resulting from something like the learning-based *modularization* process described by Karmiloff-Smith (1994). Such processes are likely to have substantial innate *architectural constraints* based on gross neuroanatomy, but fewer *representational constraints*, because representations are based on more plastic fine-grained neuronal connectivity (Elman et al. 1996). There is already a large literature on how individuals' environments, including the social and cultural environments, shape fundamental aspects of their cognitive machinery (e.g., Henrich et al. 2010; Karmiloff-Smith 1994; Nisbett et al. 2001; Nisbett & Miyamoto 2005), and so we hope the additional evidence Heyes provides signals the end of overly simplistic nativist approaches to cognitive development. Beyond this statement, however, Heyes provides somewhat scant details regarding how gadgetization occurs. One of the few detailed examples given is the rather outdated dual-route model of literacy. Readers interested in a model that actually learns the way children do might be better served by Seidenberg's (2017) neural networks.

Savvy readers will also want to know more about how cultural evolution shapes the social learning environment that imposes this gadgetization. The most interesting part of Heyes' argument, in our view, is that the social environments that facilitate the development of culturally important cognitive mechanisms also evolve. This is an important point that has, to date, received too little attention. However, Heyes' presentation of how the relevant evolutionary dynamics occur is somewhat thin, and glosses over both the staggering complexity of those dynamics and the considerable progress that has already been made in describing that complexity.

Heyes characterizes members of the California school as being vague and inconsistent in their descriptions of evolutionary dynamics. Let us first note that "the California school" is an unfortunate term for many reasons, not least because it enables the author to ascribe to a collective a set of viewpoints without naming any individual sources, which would require attribution and subsequently allow scrutiny of those claims. Many of those associated with the referenced "school" have gone to great lengths to individuate their own research programs and clarify exactly the sorts of transmission, inheritance, and population-level dynamics they believe to have occurred in human cultural evolution, including using computational models, archaeology, cross-cultural fieldwork, and laboratory experiments.

In contrast, the evolutionary dynamics Heyes proposes are themselves vague. Let us consider her discussion of cultural group selection, which draws little from more established discussions (e.g., Boyd & Richerson 2002; Henrich 2004a; Richerson et al. 2016; Smaldino 2014; Wilson 2002; Zefferman & Mathew 2015). The key point about multilevel selection or group selection is that selection on a social trait can strongly depend on the social environment, and so the contributions of each level of selection must be taken into account to analyze the overall population dynamics (Okasha 2009). Altruists can be exploited by free riders within their group (individual-level selection against altruism) but still increase the *overall* fitness of their group relative to other groups (group-level selection for altruism). Additionally, prosocial norms often require coordination among social actors to provide marginal benefits, and therefore face difficulties in propagating in new communities (Bicchieri 2006; Boyd & Richerson 2002; Richerson et al. 2016). Understanding how such social traits spread is a key research area throughout the social sciences, encompassing not only the selection-based work in cultural evolution, but also the epidemiology of beliefs pervasive in other areas of the social sciences (e.g., Centola 2018; Sperber 1996). Heyes' evolutionary model (pp. 199–201) pays lip service to group selection, but closer inspection shows that her model is completely unaffected by group structure. In her model, trait M′ always has higher fitness than trait M, so that it will spread regardless of group structure. There is no selection at the group level that is any different from selection at the individual level. This is a mistake, of course. The traits Heyes is talking about *are* social and will likely have different fitness gradients at different levels of selection; it's just that there is no mention of what the different gradients might look like. Heyes does briefly mention the potential importance of social complexity, but hardly enough. The consideration of emergent social structures that are important in cultural evolution is explored at length in Smaldino (2014). There is still a lot of important work to be done on understanding these evolutionary dynamics, and we agree with Heyes that the inheritance mechanisms for social structures is an important target for future research.

What makes understanding the cultural evolution of social organization so challenging? We suspect that the missing piece from Heyes' discussion is the complex feedback between extant traits and selection pressures and principles of organization (cf. Kauffman 1993; Thompson 1942) that shape those traits. In terms of the cognitive gadgets discussed in Heyes' book, some of the clearest perspectives on this front can be found in the work of Kirby and Smith (Kirby 2017; Smith & Kirby 2008). They have proposed that once humans had genetically evolved sufficient capacities for sociality, imitation, and cooperation, cultural evolution was sufficient to shape early communication systems towards easier understanding, production, and flexibility. Most importantly, they have provided dynamic models of how such a process might occur. Tomasello et al. have suggested more generally that social cooperation was a likely driver of the emergence of many uniquely human cognitive features (Moll & Tomasello 2007; Tomasello et al. 2012; Tomasello & Gonzalez-Cabrera 2017), which is consistent with, but not a direct consequence of, Heyes' central arguments.

In general, the processes of feedback across multiple organizational and temporal scales needed to explain the evolution of complex systems (Caporael 2003; Caporael et al. 2013; Smaldino 2014; Wimsatt 1974) are missing from Heyes' story, though their importance is hinted at in her final chapter. Implicit in this discussion of feedback is that, at some point in our evolutionary past, humans lived in social environments that were not well adapted to facilitate the development of many cognitive gadgets in the forms we now know (relatedly, it is likely that other gadgets, adaptive in past environments, have since been lost). Over time, humans constructed environments which promoted the development of new cognitive gadgets, which in turn facilitated the development of new environments, and on and on. Co-evolutionary dynamics like this have, in fact, been increasingly studied under the banner of *cultural niche construction* (Kendal 2011; Laland & O'Brien 2011). This body of work explicitly targets the evolutionary feedback processes by which humans modify their environments (e.g., by producing new social institutions like writing), which in turn creates new selection pressures (e.g., by encouraging literacy), which in turn creates new opportunities for modifying the social environment (e.g., by producing new divisions of labor in which some individuals are express stewards of written knowledge), and so on.

All this creates problems for Heyes' central metaphor of grist and mills. There is a reason that the social skills essential to human cultural learning are reasonably well described as being handled by cognitive "gadgets," in the sense that the word usually refers to cobbled-together thingamajigs. The reason is that the environments that led to the evolution of those skills were socially constructed ones – a set of social niches constructed by the same species that was itself developing those skills. These gadgets were pieced together over time by a nonlinear unguided process, and, therefore, they are not pristine engineered devices. The grist was not already there to cause the formation of the mill, nor was the mill already there to cause the formation of the grist. As Heyes herself notes on p. 203, "the inheritance mechanisms for mills overlap with the inheritance mechanisms for grist." Thus, the social environments influencing development (e.g., the grist) co-evolved with the cognitive gadgets (e.g., the mills), bringing each other into being in a fashion not unlike autocatalysis (where two chemical reagents cause each other to come into prominence). To understand something like autocatalysis, one needs some facility with the dynamics of complex systems. Treating cultural evolution and cognitive development as though they are linear feed-forward processes that straightforwardly turn selection pressures into human traits just will not cut it. For example, the social mechanisms of language use and the neural mechanisms of language processing may not be well treated as "a grist" and "a mill," respectively, precisely because they overlap so much with one another (e.g., Clark 2008; Kirby et al. 2008; Spivey & Richardson 2009).

Real mills are traditionally made of wood and stone, or whatever modern materials are currently in fashion. In our unpacking of Heyes' analogy, the mill is formed by the grist, which it then processes in such a way that changes the construction of subsequent mills. If grist can change the way the mill works, and vice versa, then perhaps grist-and-mill is not the right metaphor for understanding the cultural evolution of thinking (most mills don't reshape themselves as a result of changes in the grist that they are milling). If a metaphor is needed, a more apt one might be rivers and the water that runs through them. A riverbed channels the water that runs through a geographical area, but it can also get reshaped by that water. And the quality and flows of that water can change over time. If one embraces a river metaphor to illuminate this mutual relationship between cultural evolution and cognitive gadgets, it is easier to see how culture and brain can indeed shape one another. It also becomes clearer that culture and brain are not two separate factors that additively combine to generate mind. They are sufficiently interdependent that they might be best treated as one complex system: a distributed cognition composed of information that is transmitted via both neural fibers and social fibers.

Instincts or gadgets? Not the debate we should be having

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Abstract

I argue, with examples, that most human cognitive skills are neither instincts nor gadgets but mechanisms shaped both by evolved dispositions and by cultural inputs. This shaping can work either through evolved skills fulfilling their function with the help of cultural skills that they contribute to shape, or through cultural skills recruiting evolved skills and adjusting to them.

Cecilia Heyes sharply contrasts two mutually incompatible accounts of the cognitive skills that make humans so special. According to an account she opposes, these skills are biologically evolved cognitive instincts. According to the account she defends, they are culturally acquired "cognitive gadgets" (Heyes 2018). This way of framing the debate is based on a strong presupposition which she barely discusses, namely that there are just two alternatives worth considering: specialised cognitive skills are either instincts or gadgets. Consistent with this presupposition, she treats any argument to the effect that a skill is culturally acquired as showing that it is not biologically evolved, and conversely. Here I want to challenge this presupposition and hence the pertinence of the debate so conceived.

Heyes assumes that the main mechanism through which all animals including humans acquire knowledge and skills is "associative learning," which she views as intrinsically domain-general. Associative learning is complemented by specialised neurocognitive mechanisms. In animal cognition generally, these are cognitive instincts. In the human case, they can also be cognitive gadgets, which are socially learned and culturally evolved. Whatever cognitive instincts humans have, they share with other primates. It is their cognitive gadgets that make humans special. This might sound like a new defence of the nurture side in the old nature-nurture debate, but Heyes herself rejects such simplistic understanding of the issue. "The rich interactive complexity of developmental processes," she notes, "makes it absolutely clear that, in cognition as in other biological systems, there are no pure cases of nature or of nurture; no biological characteristic is caused only by 'the genes' or only by 'the environment'" (Heyes 2018, p. 24).

Still, Heyes has very little to say about the contribution of the environment to the development of instincts: how, for instance, growing up in a given cultural community may contribute to curbing, enhancing, or otherwise shaping human sexual instincts (which are not purely cognitive but have an essential cognitive dimension). Similarly, she has little to say regarding the contribution of the genes to the development of gadgets, which, she maintains, are acquired through associative learning. She views associative learning as a domain-general evolved learning capacity. Associative learning merely enables the acquisition of gadgets but doesn't contribute to shaping their domain- or task-specific characteristic features. There is no place in her account for "learning instincts" (Marler 1991). Gadgets are developmentally disconnected from instincts. Hence her "evo-devo" approach breaks down into an "evo" account of instincts and a "devo" account of gadgets.

Is the partition of cognitive skills into two nonoverlapping clusters – instincts and gadgets – self-evident or at least particularly plausible? I want to suggest that, in fact, the many and varied cognitive skills that make humans special are on a continuum of cases with, at one end, mechanisms the development of which is strongly canalised by biological factors and not much modifiable by environmental factors and, at the other end, mechanisms that are only weakly canalised by biological factors and are particularly susceptible to environmental factors (on canalisation, see Ariew 1996; Waddington 1942). If there is such a continuum of cases and if human cognitive skills stand at various points along the continuum, then the old term "instinct" and the new clever lexical term "gadget" should not be used to partition the whole range but only (if at all) to highlight its end points.

There is a principled reason why, among all biological traits, neurocognitive mechanisms are particularly likely to be scattered along an "innate-acquired" or "instinct-gadget" continuum rather than clustered at one or at both ends. The general function cognition is to adjust the behaviour of the organism to its environment. Sensitivity to the environment is the sine qua non of cognitive mechanisms. When there is selection for one and the same form of behavioural adjustment to the same recurrent local environmental conditions, then the development of the cognitive mechanism involved can be strongly canalised by biological factors. When, on the other hand, the relevant environmental conditions are more varied and complex and hence call for more flexible responses, there are biological-evolutionary grounds to expect weaker canalisation and a greater role of variable environmental factors. This is obviously a matter of degree.

Heyes, on her part, assumes something like this: When a relatively rigid response to recurrent environmental conditions is adequate, selection favours specialised cognitive instincts. When, on the other hand, greater flexibility would be more adaptive, selection favours a radically different alternative: the development and use of a domain-general learning mechanism (such as associative learning). As she points out, "advocates of deep learning, predictive coding, hierarchical reinforcement learning, causal modelling, and Bayesians of almost every stripe" describe these learning procedures as domain-general capabilities (Precis, sect. 1, para. 5). True, but the fact that the formal properties of a learning procedure are best specified without assigning to it any specific domain or goal does not entail that the use of such a procedure in an organism or a machine cannot be tied and adjusted to specific goals.

In defence of her view, Heyes quotes Lake et al. (2017). They however, observed:

> The claim that a mind is a collection of general-purpose neural networks with few initial constraints is rather extreme in contemporary cognitive science. A different picture has emerged that highlights the importance of early inductive biases, including core concepts such as number, space, agency, and objects, as well as powerful learning algorithms that rely on prior knowledge to extract knowledge from small amounts of training data. This knowledge is often richly organized and theory-like in structure, capable of the graded inferences and productive capacities characteristic of human thought." (Lake et al. 2017, p. 5)

In other terms, a Bayesian learning mechanism used for the acquisition and use of information in a given domain can, to good effect, be endowed with priors appropriate to its domain and task making it a specialised mechanism. From an evolutionary point of view, it is quite conceivable that many if not all cognitive adaptations may be specialised Bayesian mechanisms with, among other evolved features, initial priors ready to be readjusted in the course of cognitive development.

Heyes also appeals to general considerations on the course of human evolution. How likely is it that, in the time constraint of human evolution, many new mechanisms should have evolved not just to make culture possible but to shape distinct cultural cognitive skills? This is a reasonable question to which people working on human evolution give different answers. Some, like Joe Henrich (2015), have assumed that a variety of mechanisms targeting specific aspects of culture may well have evolved; others, like Michael Tomasello (1999) or Heyes herself are more sceptical. A consideration that is generally missing in this debate is the fact that cultural skills can be partly shaped not only by an evolved mechanism, the function of which is at least partly fulfilled through these cultural skills; cultural skills can also be shaped by evolved skills that have not evolved to favour any cultural consequence but that are recruited in the process of cultural evolution to make certain skills more learnable.

There are, indeed, two main ways in which biologically evolved dispositions may contribute to shaping a cultural trait. A biological function may be fulfilled through the cultural evolution of an appropriate trait. For instance, humans are omnivorous animals who are biologically disposed to seek a combination of nutrients meeting their biological needs. Cuisines vary from culture to culture and are shaped by cultural histories, social organisation, and local ecologies. They are also, obviously, shaped by evolved food preferences. Hence, the cognitive and practical skills involved in cooking are not appropriately described either as instincts or as gadgets. To take a less trivial example, the biological benefits of "kin altruism" have caused the biological evolution of various forms of cognitive sensitivity to relatedness. Such sensitivity may, in the human case, favour the cultural evolution of relevant cultural skills and practices (Bloch & Sperber 2002).

A second way in which biologically evolved dispositions may contribute to shaping a cultural trait is through cultural evolution taking advantage of biologically evolved dispositions. Heyes, for instance, evokes the work of Dehaene and Cohen (2011) on reading skills. Given the recent history of writing, nobody would argue that reading is shaped by genes that evolved for reading. What Dehaene and Cohen have argued, however, is not that reading is a cultural gadget acquired through associative learning or some other kind of domain-general procedure. Rather, they showed that reading recruits an evolved cognitive capacity implemented in the left lateral occipitotemporal sulcus and the initial function of which is to identify visual patterns relevant to identifying object contours. The cultural evolution of writing and reading has been made possible and has been shaped by this evolved mechanism, taking advantage of its capabilities to create novel visual stimuli.

Sperber and Hirschfeld (2004) have illustrated another way in which biologically evolved dispositions – the function of which is not, or not initially, related to culture – nevertheless provide opportunities for the cultural evolution of cultural skills or practices and contribute to shaping these skills. Consider, for instance, the evolved mental mechanisms that allow humans to recognize individual faces and to interpret facial expressions. The input conditions that a stimulus must meet to trigger the operation of these mechanisms are fulfilled not only by actual faces, but also by face-like items such as pictures of faces, smileys, masks, and so on. Only actual faces are in the "proper domain" of the mechanisms: that is, in the range of items they evolved to process. All items that meet their input conditions, however, whether they fall in the proper domain of the mechanisms or not, fall in their "actual domain" – that is, in the range of items that trigger the operations of the mechanism. Most of these face-like items belonging to the actual domain of face-processing cognitive mechanisms are culturally produced. The production and appreciation of portraits, for instance, is both common and diversified across cultures. Actual faces themselves can be modified (through make-up or hair styling for instance) so as to bias the perception of the face (of its youth, its mood, and so on). There is, in other terms, a range of cultural skills involved in representing and modifying faces and in interpreting these representations and modifications that exploit and extend the actual domain of face recognition. The face recognition mechanisms did not evolve to produce such cultural effects. What happened, rather, is that cultural skills evolved by taking advantage of the biologically evolved face recognition mechanism and populating its actual domain with cultural artefacts.

More generally, human cognitive skills can be shaped by biological evolution, cultural evolution, or both. Some cultural skills are fine-tunings or elaborations of a biological skill, as in the case of cultural food production and appreciation. Such cultural mechanisms typically fulfil biological and cultural functions. Cultural skills may also be exploitations of biologically evolved cognitive skills without serving the biological function of the mechanisms they exploit. Portrait painting or make-up skills are examples in point. Some cultural skills have a more complex relationship with evolved capacities. Such is the case of reading which not only exploits but which also modifies a perception mechanism the initial function of which is to help identify object contours.

So, we are at a stage in the study of the relationship between cognition and culture where, in Heyes' own words, "it remains coherent and important to ask, for any particular characteristic [here, human cognitive skills involved in culture], to what extent and in what ways nature and nurture contribute to its development" (Heyes 2018, p. 25). This, however, does not amount to, or even resemble the task of sorting these skills into instincts and gadgets or of asking whether most of these skills are instincts or are gadgets. This is not the debate we should be having.

Could nonhuman great apes also have cultural evolutionary psychology?

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Abstract

Attempted answers are given to (a) whether nonhuman great apes (apes) also have evolved imitation (answer: no); (b) whether humans can transmit imitation as a gadget to apes (answer: yes, partly); (c) whether human-to-ape transmission can kickstart subsequent and stable ape cultural evolutionary psychology ("CEP"; answer: unlikely); and (d) when CEP evolved in our lineage (answer: relatively late).

Heyes (2018) proposes that cultural evolutionary psychology (henceforth CEP), and with it, *cultural* evolution, underlies many human-specific cognitive mechanisms. To mark their cultural source, Heyes calls these mechanisms "cognitive gadgets." A cultural source is certainly likely for some human phenomena (such as Heyes' example of reading). It may also be correct for other mechanisms traditionally regarded as cognitive instincts. I am not completely convinced of all the aspects of CEP (yet?), but to foster readability, my comment will read as if I were already a full CEP convert.

Heyes discusses four cognitive gadgets that form the "mechanisms of cultural learning": selective social learning, mindreading, language, and imitation. Here, I will focus on imitation (the copying of the form of an action[1]). I fully agree with Heyes that imitation is *logically required* for (large) parts of human culture – specifically for culture *based on actions* (Heyes 2018; Tennie et al. 2012).

Any claim for human-specific cognitive abilities benefits from a "control" comparison with humans' closest living relative – that is, for nonhuman great apes (henceforth apes). Heyes (2018) herself frequently mentions apes, but does not clearly say whether, in her view, apes spontaneously imitate or not[2] and whether ape imitation would (have to) be due to an "imitation gadget."

Finding *spontaneous* ape imitation – that is, without any human interference – would mean one of two things: (a) apes may then have a cognitive *instinct* to imitate[3] or (b) they, too, may have evolved their own variant of CEP – including an imitation gadget. Empirically, *if* apes spontaneously imitate in either of these ways, we should see at least two types of evidence: (1) Wild ape behaviour should show "smoking gun" signs of underlying imitation, and (2) captive apes[4] should not *require* human interference to show imitation. Does the current empirical data demonstrate these two patterns?

Imitation transmits the *form* of actions, automatically creating path-dependent differences over time (e.g., due to unavoidable copying error; Eerkens & Lipo 2005). This allows the detection of "smoking gun" signs of imitation: If wild ape cultures were based on imitation, we should see *action form differences* across time and between populations – for example, as different gesture sets/dialects. However, empirically, we find instead *overwhelming similarity in gestural form* across populations – and this extends even to captive populations (see analysis in Byrne 2016). The picture for ape material culture is more complicated but essentially the same: Although these behaviours are more likely to show *differential frequencies* across populations, the forms of also these behaviours neither require nor indicate imitation (e.g., Tennie et al. 2009; 2017).

What about captive apes? *Unenculturated*, apes consistently *fail* to imitate in controlled settings – where imitation would be the sole key to success (Clay & Tennie 2018; Tennie et al. 2012; Tomasello et al. 1997). *After* human training/enculturation (henceforth enculturation) apes can show clear (albeit often limited) evidence for imitation (Custance et al. 1995; Tomasello et al. 1993b). What explains this pattern is that unenculturated apes lack important brain structures for imitation but that human enculturation produces these structures in their brains (Pope et al. 2018).

In sum, the best matched "control" for humans – apes – lack imitation as *either* an "ape cognitive gadget" and/or as a cognitive instinct. Whenever apes imitate, they do so because of human enculturation ape imitation is a gadget lent to apes by humans. This supports Heyes' "wealth of the stimulus" argument (p. 46) regarding the cultural transmission of imitation.

Given this somewhat successful cross-species cultural transmission of a single (imitation) gadget, could apes also become a "model species" for the cultural evolution of whole CEP? For this, high levels of human enculturation would be necessary. In the past, this was sometimes achieved when studying ape capacity for language. However, high enculturation tends to have negative consequences for apes (Freeman & Ross 2014). And so, although we should therefore not repeat these studies, we can re-examine old data.

After a human "kickstart" enculturation process (the human transmission of one or more gadgets towards apes), the argument whether or not apes could ever sustain the *continuous transmission* of cognitive gadgets across pure ape generations (as a "stable ape CEP"[5]) should depend in part on the fidelity with which cognitive gadgets can be passed *from ape to ape after human influence has been removed*. To examine this fidelity, an experiment would require an initial phase, where a "seed" ape population is enculturated so as to acquire – to the highest possible degree – one or more human cognitive gadgets. Then, after adding unenculturated apes (subjects) to the seed population, human enculturation efforts must cease both to seeds and subjects. Next, subjects need to be observed over extended time periods – even across ape generations, in case of initial success. Would the affected subjects "catch" cognitive gadgets from the seed population – and if so, how many and to what degree? Would these subjects later be able to enculturate additional subjects? There is exactly one long-term study with systematic data collection that came close to this hypothetical setup. This study introduced a single, unenculturated male chimpanzee – 10-month-old Loulis[6] – to a seed population of four sign-language trained conspecifics. During the 63 months that Loulis spent in this experimental setup,[7] he reportedly used 51 different signs. In addition, Loulis was claimed to have learned these signs (mostly) via *ape-to-ape imitation* (Fouts et al. 1989). There are many reasons to doubt these and related claims (Rivas 2003; 2005), but even when taken at face value, a signing usage of 51 different signs after human-to-ape-to-ape transmission would already be substantially *smaller* than the claimed repertoire of the seed group after human-to-ape transmission (e.g., already at 36 months of age, one of the "seeds" (Washoe) was claimed to have mastered 85 different signs; Gardner & Gardner 1971).

What is especially illuminating, of course, are the *long-term* effects of human-to-ape-to-ape transmission – did enculturation effects/gadgets persist in Loulis? When we look at the entire group's (seed plus Loulis) later performances (across four corpora)[8] the difference in persistence between subject and seed becomes highly apparent. In this dataset, the seed chimpanzees "imitated" (= responded to like with like) known signs much more frequently than Loulis did (around four times as often; Rivas 2003). That is, the human-installed ape *imitation gadget* seems to have already lost most of its power within the first generation of ape-to-ape transmission.[9] Equally important, whereas the seed chimpanzees still showed evidence of using between 38 and 55 different signs, Loulis now merely showed evidence for four different signs (Rivas 2003).[10] However, two of these "signs" (GIMME and HURRY) simply resembled species-typical behaviour (Rivas 2003). The third sign (THAT/THERE/YOU) involved "pointing" to various entities by way of extending the entire hand – which *non–language-trained* captive chimpanzees also do (Leavens & Hopkins 1999).

Finally, Loulis's fourth sign (CHASE) involved wrist-hitting actions using both arms[11] – but a related gesture (Rivas 2005) also develops (and in a similar play function) in non–language-trained chimpanzees (wrist hitting another chimpanzee with one arm; Tomasello et al. 1989). Note also that, at the time, Loulis's use of these four signs was studied by Rivas, Loulis had already *additionally* been exposed to several years of human-to-ape transmission (which included signing CHASE to him). And so, none of the "signs" Loulis persisted to use need be attributed to ape-to-ape transmission – and most should probably not even count as signs (except maybe one single sign; and even this sign perhaps only in part).

In sum, in terms of long-term effect of human-to-ape-to-ape transmission, Loulis demonstrated a grand total of zero signs that he clearly learned from the seed population. In addition, he also showed a relative lack of motivation to sign compared to the seed (human-trained) chimpanzees. Even his level of prompted "imitation" of seen gestures/signs was heavily reduced compared to the seed chimpanzees.

Overall then, the "Loulis experiment" – using a suitable methodological design – uncovered that even a short-chained human-to-ape-to-ape transmission of cognitive gadgets did not survive well. Any potential small gadget-residue in Loulis (~one sign plus weak imitation?) would likely fail to pass down to later ape-to-ape transmission steps. Thus, I must disagree with Gardner and Gardner (1989) who concluded that ape "sign language is robust and self-supporting" (p. 25). At least when chimpanzee seeds are human-trained to these levels in only these two cognitive gadget domains (communication and imitation[12]) and when using a small seed/subject population, apes on their own seem unable to stabilise an ape CEP. The leakage of this system proved too large – apes still fall back into their cognitive baseline (i.e., to evolutionary psychology, rather than to CEP). The analogy here is filling an unclosed bathtub with water – that can be done, but the bathtub will empty itself as soon as the water supply stops or even shrinks.

The (theoretical) question remains as to whether humans could ever kickstart a stable ape CEP – and if so, how? In general, we should not forget that the only available "style" in which humans can enculturate themselves and other species could have evolved culturally to fit our and *only our* human biology (as a co-evolved bathtub-plug system). If we had the knowledge to devise enculturation ways specifically suited to ape biology, then perhaps an "artificial ape enculturation bathtub plug" could be transmitted to them, and then a stable ape CEP might succeed.

But, perhaps, we could get apes to evolve ape-specific enculturation styles on their own – via cultural evolution. For this, more and deeper cognitive gadgets important for cultural learning would have to be human-transferred to an ape seed population. It is not altogether clear how this could be done, but if it could, then at least *some* successful survival of gadgets across at least two ape generations could be induced. Once such multiple-generation ape-to-ape transmission happens, ape-specific enculturation styles could theoretically evolve culturally – perhaps even to a level able to stabilise ape CEP.

All the above is water on Heyes' (2018) mills. I also agree with Heyes that we need to engage in historical theory of human CEP. Clearly, in our own lineage, we must have evolved CEP ourselves entirely from scratch (likely in a feed-forward process). But when and why did our lineage evolve CEP? Knowing when *not* to look saves from misattributing factors. Given that imitation plays a crucial role, time periods with an absence of "smoking gun" (see above) evidence for imitation can therefore be dismissed. Using this logic, we recently found that the imitation gadget was likely absent from our lineage prior to ~500,000 years ago (compare Tennie et al. 2016; 2017). In accordance with Heyes (2018, p. 212), we therefore state that imitation evolved late (roughly within the last 500,000 years).

Notes

1. There is more to imitation than action copying alone, but there is no space.
2. Heyes (2018) states instead that humans are better at imitation than apes.
3. Heyes (2018) regards imitative *instincts* as generally unlikely.
4. At least when not socially deprived.
5. Assuming that apes do not already have a CEP on their own.
6. The study still contained human interaction (including some ASL signing) *after* subject integration – though with restrictions for human signing towards the subject. (During the experiment, interacting humans were not supposed to use more than seven predetermined signs with Loulis, although there were about 40 exceptions to this; Fouts et al. 1989).
7. After this point, the experimenters started to use a wider variety of signs/techniques towards all of these apes, including Loulis.
8. And using an appropriate data analysis (Rivas 2003; 2005).
9. And the power of even the seed subjects to learn new gestures by imitation likely never was all that high (Tomasello 2019).
10. Loulis was included in only two of the four corpora datasets. This probably reduced his absolute number of signs. But this does not really help the picture, because the reason (sometimes made explicit) he was excluded was due to his relative lack of willingness to engage in signing (Rivas 2003).
11. Namely hitting his own wrist with a fist or open hand (Rivas, pers. comm.).
12. Note that other domains seem to be less affected by human enculturation (Tomasello 2019).

Sociocultural memory development research drives new directions in gadgetry science

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Abstract

Sociocultural developmental psychology can drive new directions in gadgetry science. We use autobiographical memory, a compound capacity incorporating episodic memory, as a case study. Autobiographical memory emerges late in development, supported by interactions with parents. Intervention research highlights the causal influence of these interactions, whereas cross-cultural research demonstrates culturally determined diversity. Different patterns of inheritance are discussed.

Heyes (2018) claims that social interaction and social learning processes between children and others are mechanisms by which numerous cognitive abilities are inherited. By implication, therefore, many essentially "human" capacities are both learnable and teachable. This claim can be fruitfully extended to make contact with recent work on the development of memory and socio-emotional function. Although Heyes contrasts "a Vygotskian psychology" with real cognitive science (p. 18), we argue that sociocultural developmental psychology can drive new directions in gadgetry science. To extend Heyes' claims and offer guidance in that task, we use memory as a case study.

Heyes lists episodic memory as a possible cognitive gadget, but does not discuss specific pathways of inheritance. This natural and promising line of inquiry will require us to identify the components of its "starter kit," and then the cognitive mechanisms (the "mills") that emerge reliably in development when configured through sociocultural interaction (Sutton 2019). Here, as a first step, we focus on autobiographical memory, which is plausibly a compound cognitive capacity incorporating episodic memory alongside other components.

Autobiographical memory emerges late in development. Western adults typically recall little of their lives before age 3 or 4, a phenomenon known as infantile amnesia (Bauer 2015). Young children themselves can recall events that occurred at age 2 or earlier, but these sparsely detailed memories are not usually retained into adulthood (Bauer 1996; Hayne 2004). Surprisingly, evidence for other forms of memory emerges in infancy (Hayne 2004). Accordingly, the neural wetware for remembering is in place much earlier than autobiographical remembering itself, which has to be learned in a slow, multistage, and variable process essentially involving sociocultural interaction (Nelson 1996; Nelson & Fivush 2004; Sutton 2015). Between ages 2 and 6, Nelson argued, "biology hands over development to the social world" (1996, p. 325).

Across 30 years, sociocultural memory research has shown how children learn to structure and elaborate on their own autobiographical memories in reminiscing with their parents (Fivush et al. 2006; Nelson & Fivush 2004). Parents who use a highly "elaborative" reminiscing style, scaffolding the unfolding narrative using open questions and event details, have children with particularly rich and detailed memories: first for the events being discussed, and later for other, undiscussed events (Fivush et al. 2006). Thus, children appear to learn not just about what to remember, but how to do so (Wareham & Salmon 2006). These claims are further supported by two lines of research.

First, intervention studies show that a high elaborative style causally influences autobiographical memory and other capacities, such as emotion understanding (see Salmon & Reese 2016). A role for culture is clear. In these studies, mothers in the intervention condition are coached to use a high-elaborative style with their children. A control group is either placed on a wait list or, to control for the number of interactions, asked to complete a play-based task together. Children in the intervention condition subsequently display stronger memory than those in the control condition, with evidence of successful change in shared recall after 6 months (Van Bergen et al. 2009) and in independent recall after 12 months (Reese & Newcombe 2007). Given these potential benefits, there have been calls within clinical research for parent-child reminiscing interventions to be used with children who are developmentally at risk (Wareham & Salmon 2006). Such children typically experience infrequent, low-elaborative reminiscing and may show delayed memory development. Replications have been successful with maltreating parents (Valentino et al. 2013) and children with conduct disorder (Salmon et al. 2009; Van Bergen et al. 2018).

Second, cross-cultural studies show corresponding differences in parents reminiscing and children's autobiographical memory (Leichtman et al. 2003; Wang 2013). European American mothers reminisce up to three times as often as Chinese mothers, for example (Mullen & Yi 1995), with a more elaborative style and greater emotion content. Chinese mothers, in contrast, are typically less elaborative and more likely to discuss social expectations (Wang 2018). Consistent with these patterns, European American children show earlier and more detailed memories than Chinese children (Han et al. 1998; Wang 2004). In New Zealand, Māori mothers are particularly elaborative when discussing culturally significant birth stories with their children (Reese & Hayne 2008). Māori children show a particularly early age of first memory: just 2.5 years on average (MacDonald et al. 2000). Wang attributes these cultural differences to variability in memory function, stating that "this need for memory sharing and collaborative remembering of personal experiences is not universal" (2018, p. 297).

Building on these two lines of reasoning, new questions about the interaction of multiple different lines of cultural inheritance may also be useful in driving cognitive gadgetry science forward. To date, most sociocultural memory research has occurred with mother-child (and, occasionally, father-child) dyads. In new work, we show that mothers are more elaborative but less mind-minded than teachers (Andrews, submitted). Yet no research has considered how these and other social partners might interact to support memory. At least two possible patterns of cultural inheritance require testing. One is a compensatory pattern, in which regular reminiscing conversations with at least one teacher, grandparent, sibling, or friend might be sufficient to enable rich and full autobiographical memory development. This is particularly important for children whose parents are absent or neglectful. The second is a cumulative pattern, in which memory scaffolding from all social partners matters incrementally and in which children who are neglected by one key partner may show impoverished memory outcomes. Future studies that disentangle the influence of multiple social partners are crucial.

As demonstrated above, different patterns of cultural inheritance strongly influence everyday development. The social implications of these claims should not be underestimated, particularly when considering the developmental nurturance of children who are at risk of poor cognitive, socio-emotional, and educational outcomes. There are important implications for theory, too. By using autobiographical memory as an exemplar, we show how elements of a sociocultural developmental stance can contribute easily and richly to an expanded cognitive science of gadgets.

Twenty questions about cultural cognitive gadgets

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Abstract

Heyes sets out an intriguing theory but it raises more questions than compelling answers concerning culturally shaped cognition. I set out what I see as the most pressing questions, ranging over the book's early chapters concerning the structure of the theory, to two of Heyes' four exemplar cognitive domains, selective social learning and imitation.

The study of social learning and culture in humans and nonhuman animals has expanded exponentially. The significance of this work for many disciplines covered by *Behavioral and Brain Sciences* has become increasingly apparent, with implications from evolutionary biology at large (Whiten 2017a; Whiten et al. 2011) to human nature (Henrich 2015; Laland 2017). The Précis and Heyes (2018) offer a theory of deeper penetrations of human culture into our minds, shaping, perhaps even creating, major aspects of cognition. This potentially opens up exciting new landscapes for culturally focused interdisciplinary research.

The basic idea, however, appears not as shiny and new as Heyes implies. It's now 20 years since Tomasello's (1999) *The Cultural Origins of Human Cognition* (perhaps tellingly mis-cited as 2009 in Heyes' book and circulated précis), whose title seems perfectly apt for Heyes' argument. Heyes argues that her approach differs from Henrich's (2015) in defining cultural learning "by ostension: by pointing at putative examples" (Heyes 2018, p. 88), but Tomasello et al. (1993a) did this already in proposing three examples, including imitation and instructed learning via mindreading, now echoed by two of Heyes' four examplars. Still, Heyes' overall thesis is stimulating in exploring such ideas much further.

Much in the book begs questions that I hope Heyes may answer in her Response. First, I see no explicit definition of what counts as Heyes' central concept of a cognitive gadget. Can she offer a definition, in a sentence or two? The metaphorical contrast between grist and mills appears clear, but how this maps to cognition is not. Heyes (2018) notes that cultural evolutionary theory covers "large-scale conceptual structures such as fairy tales, systems of religious belief, and scientific theories," but to her these are "cognitive grist" rather than mills (p. 36). Yet the religious beliefs of, say, an ancient Mayan or Egyptian would surely shape "not just what they think but *how* they think it" (Précis, sect. 1, para. 2) in radically different ways to each other and to a contemporary atheist, so what makes these not cognitive gadgets? Saying the latter are "neurocognitive" does not seem to help, for don't we nowadays assume that everything cognitive is instantiated in the brain and hence "neurocognitive"?

A related difficulty in what "counts" as a gadget arises in relation to testing selectionist evolutionary theories. I agree with Heyes that memetics has foundered in trying to unitize and count memes (her example is "heaven" [2018, p. 38]: does this count as one meme? Then what about subsidiaries like angels?). Heyes suggests that by contrast, cognitive mechanisms are "unitized" by cognitive science, making them (as gadgets) more tractable for testing Darwinian selectionist theories of cultural evolution. But don't the same problems arise? Taking the example of language, does a bilingual person have one gadget, or two? Or many? Developmental changes raise further questions paralleling those concerning angels and heaven: For example, when a child adds irregular verbs to their language competence, is that adding a gadget (mini-gadget?) to their larger linguistic skill (macro-gadget?)? If not, why not? Imitation and mindreading also change, bit by bit, throughout development, challenging unitization. None of this is to disparage Darwinian analyses of cultural phenomena, of course. Colleagues and I, noting that Darwin knew nothing of genes, set aside the difficulties of genes' purported equivalent of memes and simply returned to the principles set out by Darwin, revealing their operation in human (Mesoudi et al. 2004) and animal (Whiten 2017a; 2019b) cultural evolution.

Heyes' mission is to identify what creates distinctively human cognition, proposing that cultural learning supplies the answer. But if other animals' lives are shaped by their cultural inheritance (Whitehead & Rendell [2015, p. 6], for example, conclude from their comprehensive survey that "Culture is a major part of what the whales are"; also see Whiten 2017b; Whiten & van de Waal 2018, for primates), then presumably their cultures too are predicted to shape their cognition. Gruber et al. (2009) offered the novel affordance of honey-filled holes in logs to wild chimpanzees from communities that either did (Kanyawara) or did not (Budongo) have stick-tool use in their cultural repertoires, and found that although the Kanyawara apes applied sticks to efficiently extract honey, Budongo individuals applied just their habitual leaf-sponging technology, with less success. The authors' conclusion, encapsulated in their title, was that chimpanzees "rely on their cultural knowledge" to solve such novel problems. If this interpretation is correct, would it translate in Heyes' terms as the Kanyawara chimpanzees having a "cognitive gadget" like imagining modifying stick-tool use appropriate to solving a novel problem – a cultural cognitive gadget the Budongo chimpanzees lack? If not, why not?

This chimpanzee study of Gruber et al., contrasting two populations, is relevant to Heyes' proposals for dissecting the effects on cognitive competences/gadgets of "nature, nurture, culture" (Précis, sect. 2). Developmental ethologists like Hinde (1970) long ago recognized that one cannot easily dissect these at the level of the individual because these factors interact in complex ways from conception to death; yet when it comes to *differences* – between individuals, populations, or species – such causes can be empirically distinguished. Taking Heyes' example of literacy, one can show that culture is crucial to the emergence of literacy because literacy does not appear in societies that lack the requisite cultural background. However, this is different from claiming, as Heyes appears to do, that literacy is a cognitive gadget in human individuals, created by cultural evolution alone, because literacy arose only a few thousand years ago. We know from contemporary hunter-gatherer studies that hunters are impressively skilled in reading, in signs in the dirt, a narrative of recent events ("a kudu with a lame calf travelled north around an hour ago") (Wannenburgh et al. 1979). The signs are not images of kudu; they are abstract signs that have meaning for readers of them, as printed words do for us. Hunting is known to have an ancient ancestry (Whiten & Erdal 2012) during which genetic changes could be associated with such a capacity, so this might well underlie our ability to culturally acquire literacy. A hominin lacking an evolutionary history of hunting and gathering should thus struggle to acquire literacy. This is not practicable to test, of course, but doesn't the possibility mean it is premature to conclude that literacy is any "purely culturally created" competence?

A somewhat pedantic aside: I am puzzled that the term "teleosemantic" has emerged and been adopted by Heyes. It seems to mean "teleonomic," the term introduced by Pittendrigh (1958) to contrast with "teleogical," the latter meaning guided by purpose, the former distinguishing the mere appearance of purpose, for reasons such as evolution by natural selection. We say such biological phenomena have evolved to serve certain fitness-supporting *functions*, rather than to fulfil anyone's purposes. The term teleonomic has been widely used by well-known evolutionary biologists like Mayr and G. C. Williams and philosophers of biology like Nagel and Hull. In the same spirit Lorenz (1966) talked of the ways in which both genome and learning function to "acquire and store information on the environment" (p. 8). If teleosemantic is indeed only a synonym for teleonomic, good scholarship suggests settling on the latter and abandoning the other term.

Relating to such distinctions, Heyes states that "'Cultural learning' is a subset of social learning … specialized for *cultural evolution*" (2018, pp. 86, 89 [my italics]). But surely cultural transmission functions only to benefit either a receiver, like an observational learner, or a transmitter engaged in some form of teaching; its function is not so futuristically oriented as to be about creating cultural *evolution* – except perhaps for vocational inventors. But Heyes is not focused on such inventors. Elsewhere Heyes more correctly says "specialized for cultural *inheritance*" (e.g., Précis, Fig. 4 [my italics]), which avoids the impression that every imitator or mindreader is out to create cultural evolutionary change; should that not always be the terminology used?

Turning to the first of the two of Heyes' four cognitive gadget exemplars I have room to discuss, I agree that social learning biases appear widespread among animals and not only in humans (Kendal et al. 2018; Price et al. 2017). And they can be complex; Bono et al. (2018), for example, showed that interactions between as many as three biases may interact to predict wild vervet monkeys' social learning: the sex of the observer, the sex of the potential model, and the relative payoff gained by the latter. I disagree with Heyes that such effects have "barely appeared on the radar of cognitive scientists" (sect. 5, para. 2). It depends on who counts as a cognitive scientist, of course, but a considerable research literature has now delineated a diversity of biases in nonhuman animals, and in children and adult humans (Kendal et al. 2018; Price et al. 2017).

Heyes proposes that human distinctiveness in this domain is defined by "explicit, metacognitive rules" about the biases in play. But the only examples of such rules offered are verbalizations. If "explicit" translates only as "verbalized," the terms "explicit" and "metacognitive" appear disappointingly redundant. The key question is how explicit metacognitive rules could be recognized in nonhuman animals in order to test hypotheses about their presence or absence in nonlinguistic beings.

Finally, I turn to imitation, which Heyes (2018, p. 116) describes as the "Lamborghini" of social learning. But does the restricted sense of bodily copying that Heyes favours really play a key role in cultural transmission? I agree this is plausible particularly for gestures, including the distinctive human realm of rituals (Whiten 2019a); Clay & Tennie (2018), for example, found that children tended to overimitate causally irrelevant hand gestures made while solving an object manipulation task, while bonobos ignored them. But I suggest that the majority of skills a child acquires through observational copying, such as how to make an unfamiliar tool do its job, do not rely on fidelity of bodily copying, which plays little part in the now more than 50 reports of "overimitation" (Hoehl et al. 2019). Is there any evidence to the contrary? More generally, what is the empirical evidence for the oft-repeated assertion that cumulative culture relies on high-fidelity copying – especially the bodily imitation on which Heyes' model focuses?

In that model, Heyes likewise seems overenthusiastic about the role that adults imitating a toddler can play in building a child's imitative capacity "from scratch" using domain-general associative learning. Caregivers may sometimes imitate infants' facial expressions in face-to-face interactions, but is there any evidence they routinely imitate toddlers' limb and other bodily movements? Is Heyes really suggesting that the boy copying "clasp hands behind back" developed the ability to imitate this because often in the past he did this or similar actions, and his parents copied him? And how could looking in mirrors, or synchronous activities, deliver this example? The same goes for chimpanzees and orangutans, able in "'do-as-I-do" tests to copy novel test items like "touch back of head" (Call 2001; Custance et al. 1995), that they surely have not learned because others copied them doing this? And what of avian imitation of bodily actions, like using foot versus beak (Heyes & Saggerson 2002; Zentall et al. 1996)? As I remarked in a critique following Heyes' initial promotion of the ASL model (Whiten 2005), there is a more general problem here too. Most of what a parent does cannot match what their infant is doing – they are attending to feeding, changing nappies, cooking, and so on – so for the infant to learn about matching, there would have to be some specific signal indicating "now, here is my rare perceptual match to what you just did." I think no such signals are known. Moreover, bodily imitation is not "correlated" in the sense of being synchronous anyway; imitation *follows* a model's acts.

So does the underlying process of imitation, from perception to matching action, remain a black box? Well yes; we remain ignorant of how the brain does it and how it comes to do so. Similarly, a humanoid robot that can achieve the whole process, globally, is yet to be created? It would be illuminating to see if such a robot could build the ability if programmed only with ASL.

Author's Response

Cognition blindness and cognitive gadgets

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Abstract

Responding to commentaries from psychologists, neuroscientists, philosophers, and anthropologists, I clarify a central purpose of *Cognitive Gadgets* – to overcome "cognition blindness" in research on human evolution. I defend this purpose against Brunerian, extended mind, and niche construction critiques of computationalism – that is, views prioritising meaning over information, or asserting that behaviour and objects can be intrinsic parts of a thinking process. I argue that empirical evidence from cognitive science is needed to locate distinctively human cognitive mechanisms on the continuum between gadgets and instincts. Focussing on that requirement, I also address specific challenges, and applaud extensions and refinements, of the evidence surveyed in my book. It has been said that "a writer's idea of sound criticism is ten thousand words of closely reasoned adulation." I cannot disagree with this untraceable wag, but the 30 commentators on *Cognitive Gadgets* provided some 30,000 words of criticism that are of much greater scientific value than adulation. I am grateful to them all. The response that follows is V-shaped. It starts with the broadest conceptual and methodological issues and funnels down to matters arising from specific empirical studies.

R1. Cognition blindness

One of the overarching aims of *Cognitive Gadgets* is to encourage people interested in human evolution to think not only about brains, bodies, behaviour, and beliefs, but also in a computational way about how our minds work. I was trying to overcome "cognition blindness," a tendency among evolutionists to look straight past an important resource – the kind of cognitive science, thriving in labs all over the world since the 1970s, that casts mental processes as software running on the brain (Block 1995). Some commentators revealed, inadvertently, just how tenacious cognition blindness can be. While making otherwise valuable points, these commentators looked straight past the software and wrote about cognitive gadgets as if they are parts of the brain, chunks of behaviour, or airy bridges between brain and behaviour built out of folk psychology and pure maths (e.g., **Badcock, Constant, & Ramstead** [**Badcock et al.**]; **Iannetti & Vallortigara**; **Jablonka, Ginsburg, & Dor** [**Jablonka et al.**]; **Smaldino & Spivey**; **Sperber**; **Tennie**; **Whiten**). The arcuate fasciculus is part of the brain, not of the mind. "Social organisation," "norm," "conformity," and (in frequent usage) "decision rule" refer to behavioural regularities rather than computational processes. And in many models, terms such as "inference" and "belief" are taken from folk psychological stock and applied so promiscuously that they lose all meaning, leaving maths to do the work.

Of course, it is vital to study the brain and behaviour, often with the help of mathematical models and folkweave characterisations of the mind, but *Cognitive Gadgets* recommends a major addition to the evolutionist's armoury. It suggests that we can better understand human evolution if we recognise that the brain interacts with behaviour via cognitive mechanisms; these mechanisms are among the targets of genetic and cultural selection; and folk psychology seldom provides the most precise and empirically grounded descriptions of how these mechanisms work. In many cases – such as the mechanisms involved in object recognition, speech production, and reading – folk psychology is simply silent.

Mathematical models can help fill the silence, but without more abstract, software characterisations of what the mind is doing, these models struggle to make testable predictions (Coltheart 2002; 2012).

Dominey and **Fenici & Garofoli** certainly do not suffer from cognition blindness. They see the computationalism of *Cognitive Gadgets* clearly and challenge it head-on. At the heart of their challenge are a lament and an historical claim. They lament that computationalist cognitive science makes little contact with lived experience and, therefore, with the humanities. It sides with the natural sciences, offering "explanation" rather than "understanding," in the language of "information" rather than of "meaning." The historical claim is that this could easily have been otherwise. If computer technology had not been advancing so rapidly when behaviourism ran out of steam, the cognitive revolution would have produced a more humane, meaning-based cognitive science (Bruner 1990).

I am sympathetic to the lament and I find the historical claim fully plausible. It is deeply regrettable that we are still a long way from knowing how to integrate explanation and understanding, information and meaning, science and the humanities. However, I doubt that the direction of cognitive science can be changed from on high by the kind of metaphysical arguments advanced by critics of computationalism (e.g., **Baggs, Raja, & Anderson (Baggs et al.)**; Clark & Chalmers 1998; Hutto & Myin 2017; Malafouris 2016), and, even if such inorganic change were possible, I am not sure there would be a net gain from switching sides. A cognitive science that jettisoned computationalism for "meaning" would lose most of the insights accumulated over the last 50 years and, although closer to the humanities, would be alienated from the natural sciences. As long as a meaning-based approach continues to dominate social and developmental psychology (e.g., Tomasello 1999; 2014; 2019; **Whiten**), I see no danger that it will be abandoned completely by those who study the mind. Furthermore – and this may be where I differ most from **Dominey** and **Fenici & Garofoli** – I am not disturbed by the historically contingent origins of computationalism. I see both computationalism and folk or "belief-desire" psychology – the "meaning" framework – as products of cultural evolution. They each have strengths and weaknesses, and are eminently revisable. For now, as highlighted by **van Bergen & Sutton**, there are advantages to be gained from using both folk psychology and computationalism to understand the evolution of the human mind.

R2. Grist and mills

In one of my efforts to overcome cognition blindness, to point at what is missing from cultural evolutionary studies, I borrowed an 800-year-old metaphor of the mind from St. Thomas Aquinas. I said that cultural evolution operates not only on the grist of the mind (e.g., beliefs, ideas, behaviours, skills, artefacts) but also on the mills (cognitive mechanisms). Like most metaphors, this one is far from perfect. Mills work on grist and cognitive mechanisms work on beliefs, ideas, behaviours, skills, and artefacts (BIBSA); cognitive mechanisms take these particulars as input and transform them. So far, so good. But whereas mills turn grist into flour, cognitive mechanisms turn BIBSA into more BIBSA. Beliefs, ideas, behaviours, skills, and artefacts – the usual targets of cultural evolutionary analysis – are both inputs and outputs of cognitive processing.

As **Smaldino & Spivey** noticed, the grist-and-mills metaphor would have been even more imperfect if I had used it to capture not the synchronic relationship between cognitive processes and their contents, but the diachronic relationship between social interactions and neural mechanisms. I agree with them that "the social mechanisms of language use and the neural mechanisms of language processing may not be well treated as 'a grist' and 'a mill', respectively." Fortunately, although the mutually formative relationship between social interactions and cognitive (rather than neural) mechanisms was a central theme of *Cognitive Gadgets*, I did not try to capture that relationship with a metaphor of any kind. Instead I characterised it as a relationship in which cognitive mechanisms undergo cultural evolution.

I am pleased to find that I have much in common with **Baggs et al.**, but they are also unhappy about the grist-and-mills metaphor. At first blush it seems that, in their view, this metaphor misled me into thinking that "the things we do and make" are mere products of cognitive processes. On this reading, to cast behaviour and artefacts as grist is to overlook the vital role of the agent's own behaviour in determining the information to which s/he has access, and to underestimate the importance of both artefacts and the behaviour of other agents as carriers of information in their own right. But when the first blush has subsided, this is an implausible reading of the concern expressed by Baggs et al. *Cognitive Gadgets* does not say a lot about artefacts because it focusses on social cognition (language, mindreading, imitation) rather than instrumental cognition (e.g., causal understanding, spatial navigation), but it dwells at great length on the importance of social interaction – what we do with others – in informing and shaping the human mind. Given this emphasis, it is more likely that Baggs et al. are objecting to the metaphysics of the grist-and-mills metaphor. They are challenging the assumption – enshrined in both computationalism and contemporary Western folk psychology – that thinking, acting, and artefacts are three fundamentally different kinds of things. They see value in the idea of "the extended mind" (Clark & Chalmers 1998), the view that behaviour and objects can be intrinsic parts of a thinking process.

There is something exhilarating about philosophical work on the extended mind. Consistent with the cultural evolution of mindreading, it shows that our thinking about thinking could easily have been both coherent and radically different from the way it is now. However (call me old-fashioned), I cannot see what would be gained, in everyday life or in cognitive science, by switching from the view that the mind is "in the head" to the view that the mind is (partly) in the world. The capacity of a puddle to constrain dance movements and inspire mischief can be captured not only by casting the puddle as "a component in our action control" (**Baggs et al.**), but also in the conventional way by casting the puddle as an environmental input to action control – grist to a mill. Similarly, in the diachronic case, when I say that the childhood development of imitation draws on experience with optical mirrors, and of being imitated by others, I struggle to see what would be gained by casting the mirrors and the actions of other agents as component parts of the child's developing mind. It is kind of cool to think of it that way, but would the extended mind perspective suggest different empirical questions, or make existing questions more empirically tractable?

Baggs et al. also chide me (gently) for neglecting niche construction, "the idea that animals reshape their environments through their actions, and this in turn structures the selection pressures exerted on current and future generations." It is not clear whether niche construction is a bold new concept, like the extended mind, or a catchy new term for an important and pervasive phenomenon that has long been recognised by evolutionists (Feldman et al. 2017; Gupta et al. 2017). Without attempting to resolve that issue, which is way above my pay grade, I can only say that I am puzzled when people suggest that niche construction – a ubiquitous phenomenon throughout the animal kingdom – is not just important in humans, but a key to understanding distinctively human characteristics. It is a bit like the problem posed by research on social learning strategies in nonhuman animals (Heyes 2018, ch. 5). If nearly all animals have social learning strategies, we need to find out what it is about human social learning strategies that makes us different. Similarly, if nearly all animals engage in niche construction, we need to find out what it is about human niche construction that makes us different. Most of the explanatory work is done by the difference-maker rather than the base concept – in the case of social learning strategies, by the recognition that, in humans, some social learning strategies are explicitly metacognitive.

R3. Gadgets and instincts

In the movies, Frankenstein screams maniacally "It's alive! It's alive!" as his monster begins to twitch. We have no trouble understanding what Dr. F. is asserting (and denying) even though he is drawing on a distinction, between life and death, that affords many intermediates and ambiguous cases. A creature can be more or less alive, closer or further away from death; there are entities – viruses, zombies, Frankenstein's monster – that resist classification; and, as it says in *The Book of Common Prayer* (2007/1549), "In the midst of life we are in death." The distinction between cognitive gadgets and cognitive instincts, although less profound, is similarly sinuous.

The first thing I should emphasise is that a cognitive gadget is *not* an entity "created by cultural evolution alone" (**Whiten**). As highlighted by **Sperber**, I am convinced that "The rich interactive complexity of developmental processes makes it absolutely clear that, in cognition as in other biological systems, there are no pure cases of nature or of nurture; no biological characteristic is caused only by 'the genes' or only by 'the environment'" (Heyes 2018, p. 24). Rather, a cognitive gadget is a cognitive mechanism with distinctively human characteristics that have been shaped predominantly by selection operating on cultural variants. In contrast, a cognitive instinct is a cognitive mechanism with distinctively human characteristics that have been shaped predominantly by selection operating on genetic variants. The terms cognitive gadget and cognitive instinct mark the ends of a continuum of cases (Sperber), with, I argued in *Cognitive Gadgets*, imitation and mindreading close to the gadget end, and things like associative learning and the inborn face bias (**Iannetti & Vallortigara**) close to the instinct end of the continuum.

There are many evolutionary processes that could, in principle, send a cognitive process from one end of the continuum into a "messy middle ground" (**Rathkopf & Dennett**) between gadgetry and instinctiveness. For example, in principle, genetic assimilation (**Del Giudice**) could increase the role of genetically inherited information in shaping development, and genetic accommodation could amplify the roles of nature, nurture, and/or culture (**Jablonka et al.**). As Del Giudice underlined, this is not a "zero-sum competition." All of these in-principle possibilities I happily embrace. What puzzles me is that those commentators who were critical of the gadget-instinct distinction seem to share my interest in examining how different factors (genetic, cultural, "plasticity," etc.) combine to produce cognitive development, but do not seem to believe that, in order to do this, one must be able to get an empirical handle on what and how each factor is contributing in any given case. It is as if they want to know how different ingredients and oven settings contribute to the texture and flavour of a cake but do not believe that, to find out, one must be able to distinguish their contributions through intervention – for example, by adding more flour – and by examining patterns of covariance – for example, by comparing cakes baked at 180, 190, and 200^{0}C.

Badcock et al., **Jablonka et al.**, and **Sperber** say very little about empirical matters. They distinguish types of interaction between genetic and experiential influences – or genetic and specifically cultural influences – without considering how the types could be distinguished in practice. For example, they do not explain how we would know whether genetic accommodation had or had not occurred (Jablonka et al.), or how we can tell apart cases in which "A biological function [has been] fulfilled through the cultural evolution of an appropriate trait" and in which "cultural evolution [has taken] advantage of biologically evolved dispositions" (Sperber). On the other hand, **Del Giudice,** revisiting our disagreement about mirror neurons (Cook et al. 2014; Del Giudice et al. 2009), concerns himself with empirical matters but offers a counsel of despair. He doubts that twin studies can provide positive evidence of genetically inherited contributions to development, and remarks ominously that "It may be impossible to fully make sense of the cross-cultural data on developmental trajectories without addressing the thorny issue of national differences in cognitive ability." However, Del Giudice does not direct us to empirical methods that are, in his view, better able to trace the contributions of nature, nurture, and culture to cognitive development. It seems that he wants to consign cognitive mechanisms to the middle ground between gadgetry and instinctiveness because he despairs of our ever being able to find positive evidence of genetic, learning, and cultural contributions.

As I acknowledge repeatedly in *Cognitive Gadgets*, both explicitly and by poring over data, it is very difficult indeed to get an empirical handle on the contributions of nature, nurture, and culture to cognitive development. For example, after discussing a range of methods, I note:

> "each of the methods outlined above is highly fallible. When learning opportunity A (for example, talking with a parent about mental states) correlates with cognitive ability B (mindreading), it could be because a hidden factor C (linguistic skill), is influencing both A and B, not because A is causing B. Likewise, twin studies may indicate a relatively large genetic contribution to development simply because the people included in the study happen to have grown up in very similar environments, and, in cross-species comparisons, convergent evolution can be mistaken for a strong influence of learning on development. Given these risks, in this area of science, as in most others, we have to place more trust in research that includes effective control procedures, and to look for convergent evidence – for signs that studies using different samples and methods are pointing to the same conclusion." (Heyes 2018, p. 50)

In my view, it is neither legitimate nor helpful to respond to these challenges with a "messy middle default," – that is, by assuming that all three sources of information contribute about equally in all cases, or by assuming out of tribal loyalty (e.g., to behaviourism or High Church evolutionary psychology) that one of them is dominant. *Cognitive Gadgets* offers and uses a methodological template for parsing cognitive development, based on the distinction between poverty and wealth of the stimulus. I would be flabbergasted if this template were exactly right. It certainly needs refinement and to be augmented by modelling, especially nonlinear modelling (**Smaldino & Spivey**). But I shall stick to my guns on what the current evidence suggests – that many distinctively human cognitive mechanisms lie at the gadget end of the continuum (see below) – and, more generally, on the necessity for empirical evidence from cognitive science to back up claims about the roles of nature, nurture, and culture in cognitive development. I will be content if *Cognitive Gadgets* proves to be "a timely provocation" (**Del Giudice**) in this respect; if it encourages those interested in human evolution to recognise that claims about the innateness and genetic assimilation of cognitive processes are not helpful unless they are backed by specific, discriminative empirical evidence. We should not allow nativism to be a matter of taste.

R4. More about gadgets

Before turning to the evidence surveyed in *Cognitive Gadgets*, I would like to say a little more about what I had in mind when I coined the term "cognitive gadgets." (Gadgets are out in the world now, so people can make of them what they will, but I still feel a bit proprietary.)

First, I have been convinced by Buskell (2018) that "minority" cognitive processes – such as those specialised for chess (**Del Giudice**), lace making, or abacus calculation – are cognitive gadgets in good standing, and that they could prove to be a valuable resource in empirical research on the cultural evolution of typically human cognition. However, following High Church evolutionary psychology, I am especially interested in the types of cognitive mechanisms – such as mindreading, episodic memory, language, imitation – that are present in most people alive today. These human-nature–defining cognitive gadgets are, for me, the paradigmatic cases. Note, with **Badcock et al.**, that many people who now identify as "evolutionary psychologists" are not High Church. I may even be one of them. But, of course, insofar as the departure from orthodoxy involves rejection of computationalism, I regard it as heresy.

Second, **Del Giudice** and **Sperber** take me to be yet more devout about associative learning than I really am. I see associative learning as a powerful engine, but not the only engine, in the construction of cognitive gadgets. As I tried to make clear in my discussions of metacognitive social learning strategies and mindreading (Heyes 2018, chapters 5 and 7), like **Dominey**, I regard language as another major generator.

Finally, I want to put my hands up and acknowledge that, although it suggests that cognitive gadgets are shaped by cultural group selection, the book says relatively little about evolutionary dynamics (**Del Giudice**; **Smaldino & Spivey**). It is the work of a cognitive scientist interested in evolution, not of an evolutionist interested in cognitive science. I hope researchers with complementary expertise will take up the challenge, using modelling and historical-anthropological data to assess the plausibility of the hypothesis that distinctively human cognitive mechanisms (along with grist – social organisation, norms, beliefs, etc.) have been shaped by cultural selection. In the meantime, let me reiterate baldly an argument in favour of cultural selection that did not make it from the book to the precis: We know of three sources of adaptive fit between a species-typical trait and its environment – intelligent design, genetic selection, and cultural selection (Dennett 2017). Intelligent design now contributes to the development of some distinctively human cognitive mechanisms (e.g., there are education programmes designed to promote literacy), but it is not a plausible candidate for most of these mechanisms (e.g., mindreading, imitation). Genetic selection is the option backed by High Church evolutionary psychology, but, I argue in *Cognitive Gadgets*, contemporary evidence from cognitive science is not consistent with the idea that genetic selection is the principal architect of the human mind. Therefore, to the extent that distinctively human cognitive mechanisms are adaptive – do their jobs well – it must be because they have been shaped by the third designer, cultural selection.

R5. Evidence

R5.1. Starter kit

R5.1.1. Face preference

Iannetti & Vallortigara draw attention to a very interesting, recently published electroencephalographic study showing a stronger neural response to upright than inverted face-like stimuli in newborns (Buiatti et al. 2019). At first I could not work out why Iannetti & Vallortigara regard this study as contrary to my suggestion that an inborn face bias is part of the genetically inherited starter kit for distinctively human cognition. The results are entirely consistent with the behavioural evidence on which I based this claim, showing that newborns have an attentional bias in favour of face-like stimuli. Having read Iannetti & Vallortigara's commentary more carefully, I think there has been a misunderstanding due to their focus on the brain (hardware) and my focus on cognition (software). They identify the inborn face bias with a particular neural response. For them, the inborn face bias *is* a neural response. Therefore, by definition, as this neural response declines the inborn face preference goes away; it is a transitory phenomenon rather than something that persists to become part of mature face processing. In contrast, for me the inborn face bias is a functional entity observed at a particular stage in development; it is whatever makes newborns attend more to face-like stimuli. On this cognitive view, the decline of a particular neural response in the first few days post-partum is entirely consistent with the inborn face bias being a foundation for growth, via domain-general learning, of more specific face-related attentional biases.

R5.1.2. Executive functions

In their commentary based on careful reading of *Cognitive Gadgets* and packed with interesting data, **Braem & Hommel** challenge my suggestion that enhanced executive functions are part of the genetic starter kit for distinctively human cognition. Instead, they (and now I) find it plausible that, insofar as inhibitory control, working memory and cognitive flexibility are more advanced in humans than other animals, it is due to genetically based changes in associative learning plus sociocultural input during development. I found myself wondering, if this is correct, how free-living nonhuman animals could get enough of the right kind of social interaction to support the development of their executive functions. But that is my only immediate reservation. I hope Braem, Hommel, and others pursue the hypothesis that executive functions are cognitive gadgets, and, whatever the answer, that this line of enquiry has the benefits identified in their final paragraph. Stimulating research of this kind is exactly what I hoped *Cognitive Gadgets* would do.

R5.2. Case studies

R5.2.1. Selective social learning

Rathkopf & Dennett encourage me – in a charmingly collegial way, but also with force – to reflect on the "benefits of embracing the messy middle," especially in relation to selective social learning. They argue that there are likely to be many varieties of social learning rule between those I describe as planetary and the explicitly metacognitive rules I describe as cook-like. There are likely to be many intermediate rules that involve increasing degrees of comprehension along with the competence. It is possible that Rathkopf & Dennett overestimate the amount of comprehension I'm packing into cook-like social learning rules. Just as a cook does not need to know the chemistry that makes it wise to bake a cake at 180°, a user of *copy digital natives* does not need to know the epistemology that makes it wise to learn IT skills from people born after 1985. But Rathkopf & Dennett's main point is well-taken: evolution is typically gradual, and therefore we should be on the lookout for intermediate forms.

The question is: Where should we look? It is easy to take any distinction between types of cognitive process and dream up a third (or fourth, or fifth …) type that shares characteristics with both. It is much harder to formulate new testable hypotheses; to conceptualise an intermediate type of cognitive process in a way that is both rooted in existing evidence and makes it possible to distinguish empirically between the new type and the types we already knew about. It is hard but, unless intermediates are conceptualised in this way, theorising about the evolution of mind will continue to float free of empirical science. I want research on the evolution of cognition to be messy in another sense – to get down and dirty with the data. With this kind of engagement as a cherished goal, I would look for intermediates between planetary and cook-like social learning rules in the cognitive science of implicit metacognition (Shea et al. 2014), not, like **Rathkopf & Dennett**, in research on "rational imitation." Experiments by Beisert et al. (2012) suggest that, in both human infants and chimpanzees (Buttelmann et al. 2007), rational imitation effects are due to distraction. For example, a head movement is less likely to be copied when the model's hands are wrapped than when they're free, not because the subject understands wrapped hands to indicate lack of free choice, but because distraction by the wrapping procedure makes it less likely that the subject will attend to the head movement. If this is correct, if rational imitation effects are due to distraction, they are produced by wholesomely planetary social learning biases (Heyes 2016b).

Like many others (e.g., **Tennie**), but in contrast with **Whiten**, I see the inheritance of behaviour via social learning in animals as importantly different from human culture because it is not cumulative; it does not afford cultural selection. However, in previous work my colleagues and I have given a straightforward answer to Whiten's question about how to test for explicit metacognition in non-linguistic creatures:

> If, contrary to our hypothesis, non-human animals have system 2 metacognition, they should be able to learn that reward-seeking behaviour is successful after making decisions that are unlikely to be correct (low confidence) and unsuccessful after making decisions that are likely to be correct (high confidence). This could be tested by, for example, using a reverse transfer test after training in a wagering task (Shea et al. 2014, p. 191).

R5.2.2. Imitation

Del Giudice is right to point out that twin studies have limited value in parsing the contributions of nature, nurture, and culture to cognitive development (e.g., Feldman & Ramachandran 2018), and that, away from my home turf of experimental psychology and cognitive neuroscience, I misreported the results of a twin study of imitation. It was Hughes et al. (2005), not McEwen et al. (2007), who found the same correlation between identical and fraternal twins. McEwen et al. found a .3 difference between the within-pair correlations, and concluded: "individual differences in imitation at age 2 years could be attributed to modest heritability, but mainly environmental influences" (p. 485). Echoing a crucial point made by **Braem & Hommel** about endophenotypes, McEwen et al. also noted: "The fact that 30% of the variance can be attributed to genetic factors could mean that genes directly influence individual differences in imitation mechanisms, although it is entirely possible that the impact is on more basic perceptual, attentional or motivational factors" (p. 485). Fortunately, the case for imitation as a cognitive gadget rests not on twin studies – which were not even mentioned in the chapter of *Cognitive Gadgets* devoted to imitation – but on experimental data confirming predictions of the associative sequence learning (ASL) model, and indicating wealth of the stimulus.

In her deep and well-informed commentary, **Powell** argues that, even if the ASL model is right about the development of imitation, the resulting cognitive mechanism may be not a cognitive gadget but a "cultural starting point"; not a mechanism favoured by cultural selection because it promotes cultural inheritance but a mechanism, made possible by social elements of the genetic starter kit and dependent on social learning for its development, that acts as a platform for the evolution of true cognitive gadgets. I find this proposal very interesting indeed, and not only because it converges with work that Jonathan Birch (2017) and I are doing on "the cultural evolution of cultural evolution." Powell is acutely aware of the challenges inherent in explaining not only how cognitive gadgets get off the ground, in evolutionary and developmental time, but also on the subtle interplay between social practices and cognitive mechanisms as targets of cultural selection (see also **McNamara & Neha**; **Smaldino & Spivey**). I am not entirely convinced by Powell's evidence that parents' imitation of infants, and social partners' positive responses to being imitated, are sustained only by "incremental increases in the human genetic predisposition for social motivation and attention." For example, many of the studies she cites, which claim to show that infants and adults respond positively to being imitated, did not include adequate controls for contingency, and there is evidence that, when imitation and contingency are dissociated, it is the latter that makes us feel warm towards others (Catmur & Heyes 2013). But these reservations aside, Powell's subtle analysis has given me much to think about. I am grateful to her.

Tennie's planet-of-the-apes reflections on imitation were also enlightening. I love the idea that "ape imitation is a gadget lent to apes by humans," and I am intrigued by his evidence that imitation evolved only about 500,000 years ago.

Whiten and I have a long, and usually friendly, history of disagreement about imitation. Instead of repeating answers to some of his "twenty questions" that I have offered in the past (e.g., Heyes 2016c), I would like to highlight a point of solid agreement between us: imitation of the topography of body movements (what Whiten calls "high fidelity copying") is important primarily for the inheritance of social, rather than instrumental, behaviour (Heyes 2013). Also, I am glad he drew attention to a key feature of the ASL model: it implies that imitation is compositional. Through social interaction (being imitated, synchronous action, mirror experience, etc.), the child builds up a repertoire, or vocabulary, of action units that can subsequently be imitated when they are encountered in novel sequences and configurations. Just as language users can understand sentences they have never heard before, imitators can copy compound body movements they have never seen before. Finally, Whiten is surely right that it would be valuable to have more information about the sources of imitogenic experience available to children in their everyday lives. However, evidence that children learn to imitate, in the manner proposed by the ASL model, is accumulating fast (e.g., de Klerk et al. 2018).

R5.2.3. Mindreading

I particularly enjoyed the commentaries that focussed on mindreading (**Apperly**; **Dominey**; **McNamara & Neha**). Although open to the idea that mindreading is culturally inherited, they identified patches where my treatment of the subject is "thin" (McNamara & Neha) and added valuable thickness.

My reading of the evidence to date suggests that much of what is culturally inherited, at least in WEIRD societies, amounts to mental state concepts. However, I would not contest **Apperly**'s proposal that, "in a long social apprenticeship," learning from others to identify relevant information is yet more important in the development of mindreading. Similarly, although I live on the information side of the information-understanding divide (see sect. R1 above), and do not embrace the extended mind for day-to-day scientific use (see sect. R2), I find great value in the ideas that mindreading is culturally inherited via narrative practice and analogical mapping (**Dominey**; **Fenici & Garofoli**; Hutto 2007). Furthermore, I was educated by **McNamara & Neha**'s evidence of how "teaching and learning environments vary across cultures to provide children with context-specific opportunities to develop the cognitive abilities needed to thrive as adults." Their reference to "culture itself" implies that the domain of culture is exhausted by what I call grist – behaviour, beliefs, artefacts, etc. – whereas a primary aim of *Cognitive Gadgets* is to show that distinctively human cognitive mechanisms are also cultural. However, that quibble did not dampen my enthusiasm as McNamara & Neha directed us to rich seams of data from cultural psychology.

R5.2.4. Language

I need to think further about the many subtle and interesting points made by **Dominey**, but I am sympathetic to his view that language is a very special cognitive gadget. I do not believe that language is necessary for all gadget construction – for example, the ASL model implies that imitation can get going without it – and I take seriously the idea that language itself is rooted in associative learning. However, once language is in place, even with a toehold, it enables the evolution and development of a wide array of other gadgets. If Dominey and I differ at all in the importance we assign to language, it is probably because he is preoccupied by sophisticated cultural grist – creation myths, mathematical concepts, the causal roles of mental states – whereas I am at least equally interested in the cultural inheritance of nonverbal social behaviour and motor skills. Verbal instruction is of more limited value in learning shibboleths – facial, postural, and vocal gestures that distinguish one social group from another – and the skills involved in making and using tools (Stout & Hecht 2017).

Jablonka et al. remind us that many peripheral mechanisms have been genetically specialised for language – "the innervation and musculature around the mouth, the larynx and the vocal cords; the unique function of the expanding muscles around the lungs" – and go on to say that "There is no reason to believe that the cognitive system, responsible for the activation and control of this physiology, somehow managed to remain unbiased towards it." Quite right, there is no reason to doubt that the mature cognitive system is biased for language. But the evidence surveyed in chapter 8 of *Cognitive Gadgets* provides many reasons to doubt that the biasing was done by selection operating on genetic variants. Research in cognitive science on the roles of domain-general sequence learning and social shaping in the development of language makes it fully plausible that, while genetic selection has done the lion's share on peripheral mechanisms, cultural selection has shaped the cognitive mechanisms responsible for language processing. If theorising about the evolution of human cognition is to be evidence-based, any claim that our minds are genetically specialised for language must, I believe, engage with that research.

R5.2.5. Autobiographical memory

Autobiographical memory was not one of my case studies but in their fascinating commentaries, **McNamara & Neha** and **van Bergen & Sutton** showed that it deserves a central place in "an expanded cognitive science of gadgets." The combination of cross-cultural and intervention studies, clinical relevance, and hypotheses linking different gadget-generating social practices with ecological conditions, makes autobiographical memory rich territory for cultural evolutionary psychology. I hope future work will examine further how elaborative and repetitive reminiscing change not only what is remembered and when, but also the computational processes of remembering. Autobiographical memory also presents an excellent opportunity to develop the idea of a compound gadget (van Bergen & Sutton; **Dominey**). All gadgets are compounds in that, like any complex cognitive mechanism, they incorporate many subroutines. But are some gadgets compounds in a deeper sense – combinations of other gadgets, such as episodic memory and mindreading, that can function alone or, in different contexts, as a single system? Like all questions about the individuation or "unitisation" of cognitive mechanisms, the answer is far from obvious and cannot be solved by intuition. The beauty of computational cognitive science is that it uses, not intuition or folk psychology, but empirical methods to find out about the structure and functions of the mind (Shallice & Cooper 2011). That is why, in *Cognitive Gadgets*, I recommend cognitive science as a valuable resource to anyone interested in human evolution.

R6. Concluding remark

Although a part of me would have preferred 30,000 words "of closely reasoned adulation," what the commentators have provided is much more invigorating and instructive. I am grateful to them all for reading the book, and offering critiques that will help evolutionary psychology to identify more and better cognitive gadgets.

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[The letters "a" and "r" before author's initials stand for target article and response references, respectively]

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