

Born Pupils? Natural Pedagogy and Cultural Pedagogy

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Abstract

The theory of natural pedagogy is an important focus of research on the evolution and development of cultural learning. It proposes that we are born pupils; that human children genetically inherit a package of psychological adaptations that make them receptive to teaching. In this article, I first examine the components of the package—eye contact, contingencies, infant-directed speech, gaze cuing, and rational imitation—asking in each case whether current evidence indicates that the component is a reliable feature of infant behavior and a genetic adaptation for teaching. I then discuss three fundamental insights embodied in the theory: Imitation is not enough for cumulative cultural inheritance, the extra comes from blind trust, and tweaking is a powerful source of cognitive change. Combining the results of the empirical review with these insights, I argue that human receptivity to teaching is founded on nonspecific genetic adaptations for social bonding and social learning and acquires its species- and functionally specific features through the operation of domain-general processes of learning in sociocultural contexts. We engage, not in natural pedagogy, but in cultural pedagogy.

Keywords

cultural evolution, evolution of cognition, imitation, infant development, pedagogy, teaching

What makes humans special? Why, unlike all other animals, do we have a built environment, agriculture, science, technology, arts, music, sports, and complex economic and political systems? Many researchers now believe that the answer to these questions is “cultural evolution”; we are unique in our capacity to learn from others the accumulated wisdom of previous generations (Campbell, 1965; Richerson & Boyd, 2005; Tomasello, 2014). Cultural evolution has been modeled in a number of ways. The basic idea is that much of the knowledge and many of the skills used by people across the world today have developed, diversified, and been refined by nongenetic evolutionary processes. These processes are evolutionary because they produce change through heritable variation in fitness. However, the inheritance occurs through social learning rather than genetic mechanisms, and fitness is defined by the number of individuals or groups who adopt a trait through social learning rather than by the number of biological offspring.

The generic term “cultural learning” refers to types of social learning that support cultural evolution (Heyes, in press-b). To understand cultural evolution, we need to understand the nature and origins of cultural learning—of the psychological rather than genetic processes that

allow knowledge to accumulate and skills to improve over human generations. Teaching is an important variety of cultural learning. The theory of natural pedagogy, which has been a focus of research on the development and evolution of human cognition for 10 years (Csibra & Gergely, 2006; Gergely & Csibra, 2005), offers an account of the processes that make infants and children receptive to teaching and how these processes evolved. In essence, the theory proposes that human infants genetically inherit a “well-organised package of biases, tendencies and skills” (Csibra & Gergely, 2006, p. 8), making them receptive to intentional communication and to deliberate attempts by adults to convey information. This package constitutes a biological adaptation for teaching; it was favored by natural selection operating on genetic variants because it enhanced infants’ receptivity to teaching and, thereby, the fidelity of cultural inheritance (Csibra & Gergely, 2011).

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The theory of natural pedagogy has been tested primarily in experiments that examined the conditions in which infants and children are receptive to intentional communications from adults, but studies of nonhuman animals are also important. Evidence that the natural pedagogy package develops very early in humans, and that some or all of its components are absent in other animals, would support the view that these components constitute a uniquely human, genetically inherited set of adaptations for teaching.

When summarizing the components of the natural pedagogy package, Csibra and Gergely (2011) often use three headings: ostension, reference, and relevance. They define ostension as when infants' sensitivity to *eye contact*, *contingencies*, and *infant-directed speech* make them more likely to learn by observing adult information that the adults intend the infants to learn. Reference occurs when in the presence of ostensive or communicative cues (i.e., when an adult is making eye contact, responding contingently and/or using infant-directed speech), infants tend to shift their attention in the direction indicated by the adult's gaze. This *gaze cuing* increases the probability that the infant will learn about the object or event that the adult intends the infant to learn about. Relevance occurs when, in the presence of ostensive cues, infants are more likely to copy features of an adult's behavior that are opaque to them than features that the infant can already understand. This *rational imitation* bias increases the probability that, as the teacher has intended, infants will acquire through observation of the teacher's behavior information that is new to them and can be used in a range of contexts.

This article first takes apart the natural pedagogy package and then puts it back together again. First, I will examine each component of the package, asking in each case whether there is compelling evidence that (a) the component is real, that is, a reliable feature of infant minds and behavior; (b) it is a genetic adaptation; and (c) the adaptive function of the component is specifically to promote teaching. Then, putting the pieces back together, I ask to what extent the theory of natural pedagogy explains the development and evolution of teaching as a process of cultural learning and why, in my view, we need to look more closely at culture itself as a source of adaptations for teaching. I will suggest that many components of the pedagogy package are nonspecific genetic adaptations—for social bonding and social learning rather than for teaching—and, in common with other psychological attributes, they become adapted for teaching through the operation of domain-general processes of learning in a social context.

First, however, a note about explanatory strategy pursued in the theory of natural pedagogy. It is not always clear whether Csibra and Gergely are proposing that

infants are receptive to teaching by virtue of low-level sensorimotor processes or high-level inferential processes. When the theory was introduced, Csibra and Gergely (2006) emphasized that many of the components of the natural pedagogy package are implemented by "low-level" processes, and they suggested, for example, that human infants' imitative learning is "triggered" by ostensive cues (Gergely & Csibra, 2005, p. 473). However, in their introductory articles, and increasingly in subsequent work (Csibra, 2010; Csibra & Gergely, 2011; Király, Csibra, & Gergely, 2013), they have also described natural pedagogy in ways suggesting that each component is mediated by high-level inferential processes. For example, Csibra and Gergely (2006) proposed that "When looking around in the world, newborns are searching not simply for faces, but for potential 'teachers'" (p. 8), raising the possibility that infants have the concept teacher. Similarly, they said that infants "conceive gaze shifts as referential acts" (Csibra & Gergely, 2006, p. 10) and described infant imitation as "rational" (Gergely, Bekkering, & Király, 2002). As a consequence of this ambiguity, the theory of natural pedagogy has been criticized both for being too lean—placing too much emphasis on automatic processes (Nakao & Andrews, 2014)—and for being too rich—attributing to infants inferential feats that are likely to be beyond their cognitive power (Beisert et al., 2012).

In what follows, I take it that the theory of natural pedagogy assumes that low-level mechanisms make young infants receptive to teaching, and when it describes infants' competence in high-level terms—using words such as "believe," "conceive," "infer," and "rational"—the authors of the theory are adopting the intentional stance. "The intentional stance is the strategy of interpreting the behavior of an entity (person, animal, artifact, whatever) by treating it as if it were a rational agent" (Dennett, 1989, 2009, p. 339) but in a "theory-neutral way"; that is, without making commitments about the kinds of internal structures and mechanisms that give rise to the behavior. In other words, I take it that Csibra and Gergely use intentional terms as a way of presenting their hypotheses about the adaptive functions of infants' competence, not about the psychological mechanisms underlying that competence.

This view of Csibra and Gergely's explanatory strategy is consistent with their having stated explicitly that many components of the natural pedagogy package can be mediated by low-level processes, their denial that natural pedagogy depends on language or theory of mind (Csibra & Gergely, 2006), and their references to Dennett's intentional stance in previous work (Gergely, Nádasdy, Csibra, & Biro, 1995). Csibra and Gergely's views may well have evolved in the last decade, such that they are now more inclined to believe that high-level

mechanisms implement natural pedagogy. If so, treating these innovations as part of the theory would make the theory more vulnerable because it would add to claims about the adaptive function of pedagogy a set of very rich hypotheses about the psychological mechanisms that implement those functions. I believe that the original version of the theory remains coherent, interesting, and ripe for further development as a functional account. Therefore, this article does not target any additional—and in my view much weaker—claims about high-level psychological mechanisms. Rather, this article takes the theory of natural pedagogy to be a set of hypotheses about the evolutionary origin and adaptive function of eye contact, contingencies, infant-directed speech, gaze cuing, and rational imitation; assesses these hypotheses against evidence from infants, children, adults, and non-human animals; identifies key insights embodied in the theory; and makes recommendations for future research on the receptive aspect of teaching.

The Components

Eye contact

The theory of natural pedagogy suggests that humans have an inborn tendency to look more at faces when the faces appear to be looking directly at the observer (direct gaze) than when the faces seem to be looking elsewhere (averted gaze) and that this is a genetic adaptation for teaching; “newborns are searching not simply for faces, but for potential ‘teachers’” (Csibra & Gergely, 2006, p. 8).

Current evidence certainly confirms that adult humans show an “eye-contact effect” (Senju & Johnson, 2009). For example, in adults direct gaze holds attention better than averted gaze (Senju & Hasegawa, 2005), facilitates discrimination of a face’s gender and identity (Hood, Macrae, Cole-Davies, & Dias, 2003), and may increase autonomic arousal (Nichols & Champness, 1971). Furthermore, there is compelling evidence that human infants distinguish direct and averted gaze from as early as 4 months of age (Vecera & Johnson, 1995). However, infants do not uniformly prefer to look at direct gaze; many of the 4-month-olds in Vecera and Johnson’s (1995) study (Experiment 1) showed that they could discriminate direct and averted gaze by looking for longer at averted gaze.

The evidence that the eye-contact effect is inborn and, therefore, is likely to be a genetic adaptation (Ray & Heyes, 2011) comes from studies reporting that infants between 1 and 5 days old look longer at naturalistic (Farroni, Csibra, Simion, & Johnson, 2002; Farroni, Menon, & Johnson, 2006) and schematic (Farroni, Massaccesi, Pividori, & Johnson, 2004, Experiment 1) faces with direct rather than averted gaze. In all of these studies, the direct

gaze stimuli were more similar than the averted gaze stimuli to the general spatial arrangement of a face (Johnson, Senju, & Tomalski, 2014). For example, in the case of the naturalistic faces, the dark “blobs” corresponding to the irises were larger in the direct rather than averted gaze images. Therefore, it is possible that humans have both an inborn face preference and an inborn eye-contact preference or that they have an inborn face preference—indicated by their tendency to look longer at a triangle of high-contrast blobs when two blobs are above rather than below the third—without an additional eye-contact preference (Farroni et al., 2004; Johnson et al., 2014; Morton & Johnson, 1991).

Even if further research reveals that newborns discriminate between direct and averted gaze when low-level features of the stimuli, such as iris size, are fully controlled, there is reason to doubt that it will reveal a bias that functions to promote attention to direct gaze under a wide range of conditions. Not only do 4-month-olds sometimes look longer at averted than direct gaze (see Vecera & Johnson, 1995), but also Farroni et al. (2006) found that newborns do not look longer at direct than averted gaze when the stimulus head is presented at an angle rather than confronting the infant directly.

Assuming, going beyond the current data, that humans have a genetic adaptation that makes us more inclined to look at direct rather than averted gaze, a further leap of faith would be needed to identify it as an adaptation for cultural learning or, more specifically, for teaching. Evidence that such an inborn bias is uniquely human would support the view that it has something to do with cultural learning, but no such evidence is available. Indeed, animals from a wide range of species—including black iguanas, mouse lemurs, and chickens—respond differentially to direct and averted gaze, some showing a preference for eye contact (Emery, 2000). Furthermore, there are signs that in some nonhuman species a preference for eye contact is present very early in development, for example, in gibbons between 1 and 6 weeks postpartum (Myowa-Yamakoshi & Tomonaga, 2001) and in rhesus monkeys at 1 week of age (Mendelson, Haith, & Goldman-Rakic, 1982). It is possible that further research will reveal that, compared with the young of other species, human newborns have an especially strong or consistent eye-contact preference. However, even this would not establish that natural selection enhanced the preference specifically because it makes human infants receptive to teaching. Other plausible hypotheses are that the function of any eye-contact preference in humans is affiliative—to elicit care or to promote bonding with caretakers—or epistemic in the broadest sense—to supply input for the development of cortical mechanisms of face processing or to make infants receptive to any information that

attentive conspecifics can provide, deliberately (i.e., through teaching) or inadvertently.

In summary, infant and adult humans really are especially attentive to eye contact, and this sensitivity appears early in development. However, I have not been able to find compelling evidence that this is because of a specific genetic adaptation—an inborn, human-unique preference for eye contact rather than an inborn preference for faces—or any such adaptation was favored by natural selection for its contribution to teaching.

Contingencies

Contingent turn taking refers to a commonly observed pattern of interaction between human mothers and infants in which the mother is still and silent while the infant is active but begins to move or vocalize as soon as the infant's activity stops. It is typically assumed that this kind of turn taking has an affiliative function, for example, that turn taking promotes the infant's identification with (Tomasello, 1999) or attachment to (Watson, 2001) the caregiver. In contrast, the theory of natural pedagogy suggests that contingent turn taking is rooted in an inborn preference for response-contingent stimulation—a tendency to attend to and enjoy stimuli that are predicted by and occur shortly after our own actions—and that the primary function of this contingency preference is epistemic rather than affiliative:

We believe that these early dyadic interactions serve an ultimately epistemic function: identifying teachers and teaching situations, and practising this process. It is adaptive to seek out such situations because they indicate the potential to acquire a commodity that has survival value: socially transmitted and culturally relevant knowledge. (Csibra & Gergely, 2006, p. 9)

There is no reason to doubt that human infants are attracted to response-contingent stimulation, whether the stimulation comes from another agent or the inanimate world (e.g., a mobile; Watson, 1972) or that this preference persists into adulthood (Catmur & Heyes, 2013). There is also evidence that our attraction to response-contingent stimulation emerges very early in development and therefore it may be genetic adaptation. In human newborns, behaviors that are followed by response-contingent stimulation increase in frequency (they are subject to instrumental or operant conditioning), not only when the response-contingent stimulation is biologically relevant (i.e., milk or the sound of the mother's voice) but also when it consists of short, affectively neutral speech sounds (Flocchia, Christophe, & Bertocini, 1997). This finding suggests that for human

newborns, some stimuli are attractive not by virtue of their intrinsic, biologically relevant properties (primary reinforcers) or because they have been paired with primary reinforcers (secondary reinforcers) but simply because they have been experienced in a contingent relation with the infant's responses.

The problem for the theory of natural pedagogy arises when we try to link the human attraction to response-contingent stimulation with teaching because the attraction is far from uniquely human. An early study suggested that rats display prosocial behavior toward a human hand that has been contingently responsive (Werner & Latane, 1974), and recent studies have shown that precocial birds have the same unlearned tendency. Newly hatched bobwhite chicks are more likely to approach the sound of a conspecific maternal call that has been heard in a contingent rather than a noncontingent relationship with the chick's own distress calls (Harshaw & Lickliter, 2007), and response-contingent exposure to the sound of a hetero-specific maternal call, recorded from Japanese quail rather than bobwhite, is sufficient to overcome the bobwhite chicks' normal preference for conspecific maternal calls (Harshaw, Tourgeman, & Lickliter, 2008). These results conflict with the primary argument in support of the view that the human contingency preference is a genetic adaptation for teaching. Csibra and Gergely (2006) suggested that our attraction to response-contingent stimulation is more likely to have a pedagogical than an affiliative function because avian species achieve close affiliation (i.e., imprinting) without such an attraction. The studies by Harshaw and colleagues (Harshaw & Lickliter, 2007; Harshaw et al., 2008), which were published after Csibra and Gergely (2006), indicate that this is not correct. Rather, in combination with the other studies reviewed in this section, the data from precocial birds suggest that humans' attraction to response-contingent stimulation is a highly conserved trait and a genetic adaptation, not for teaching but for social bonding.

Infant-directed speech

Like the evidence relating to contingencies, the data on infant-directed speech (IDS) confirm that the basic phenomenon is real and the data are broadly consistent with IDS being a genetic adaptation of some sort, but the data do not support the view that IDS is an adaptation specifically for teaching.

In regard to the reliability of the IDS phenomenon, many studies have shown that compared with speech directed to adults (ADS), IDS has distinctive acoustic properties, including higher pitch, a broader pitch range, more pronounced pitch contours, a stronger rhythm, and a slower tempo (e.g., Fernald, 1991; Trainor, Austin, & Desjardins, 2000). Furthermore, early development of a

preference for IDS is indicated by studies showing that infants from a few days to several months of age look longer at faces producing IDS than at faces producing ADS (Cooper & Aslin, 1990; Werker & McLeod, 1989), and that IDS is associated with a greater elevation in cerebral blood flow in sleeping newborns (Saito et al., 2007).

The theory of natural pedagogy suggests that infants prefer IDS because “the special prosody associated with motherese [IDS] indicates to the baby that he is the one to whom the given utterance is addressed” (Csibra & Gergely, 2006, p. 9). Some authors, taking this kind of statement at face value, assume the theory of natural pedagogy is proposing that whenever infants hear IDS, they conceptualize the adult’s utterance as an act of intentional communication directed toward the self (e.g., Schachner & Hannon, 2011). If one assumes instead, as I do throughout this article, that Csibra and Gergely are adopting the intentional stance when they characterize infants’ reactions to ostensive cues, their theory makes no specific claims about what is going on in the mind of infants when they show a behavioral preference for IDS. The psychological mechanism mediating the preference could be little more than a reflex. Rather, the theory of natural pedagogy is making a substantive claim about the adaptive function of infants’ preference for IDS: asserting that it was favored by natural selection because it made our ancestors’ infants attentive to communicative acts that were being directed toward those infants by our adult ancestors.

The problem for this functional hypothesis, as Csibra and Gergely (2006) have acknowledged, is that there are many other potential explanations for infants’ preference for IDS. IDS has a higher pitch than ADS, and the auditory system matures first for high frequencies (Schneider & Trehub, 1992). Therefore, at the leanest end of the explanatory spectrum, infants may prefer IDS simply because they are better able to hear it (Trainor et al., 2000). In addition, the infant preference for IDS may have been favored by natural selection because it facilitates language learning by emphasizing the lexical and grammatical structure of utterances (Snow & Ferguson, 1977) or because it promotes affiliation with caregivers by making infants especially attentive to them when they are expressing positive emotion (Trainor & Desjardins, 2002).

The latter emotional hypothesis has particularly strong empirical support. Trainor et al. (2000) have shown that when IDS is compared with emotional ADS rather than affectively neutral ADS—as it has been in most research on IDS to date—IDS is acoustically distinctive only in being of higher pitch, suggesting that, on the production side, human adults do not use a whole bag of vocal tricks when addressing infants. We use the same pitch range, pitch contours, rhythm, and tempo used when we are

feeling emotional while addressing other adults. It is just that we are more likely to feel emotional when addressing an infant. The one trick tailored especially for infants is the higher pitch of IDS, and our tendency to use a higher pitch when addressing infants may or may not be a genetic adaptation. Smith and Trainor (2008) found that mothers could be shaped by their 4-month-old infants to increase the pitch of their vocalizations. When mothers were consistently rewarded for higher pitch by happier behavior from the infant, the average pitch of their vocalizations increased.

What do these reflections on the production side of IDS imply about the reception side—about the preference of human infants for IDS? The reflections suggest that rather than being tuned from birth to a highly distinctive set of vocal characteristics that evolved for language training or teaching more generally, infants just like high-pitched speech. And this simple, inborn preference may be phylogenetically widespread and evolutionarily ancient. Consistent with this view, Trainor and Desjardins (2002) found that higher pitch impedes rather than facilitates vowel discrimination, which is not good for the language theory, and a number of studies have shown that animal trainers, from a range of cultural groups, have found that vocalizations like those of IDS are effective in controlling the behavior of dogs, horses, cats, and other nonhuman animals (McConnell, 1991; Snowdon, 2004, for a review).

Gaze cuing

Gaze cuing or gaze following refers to the tendency, observed in many primate and nonprimate species (Zuberbühler, 2008), to direct attention to the object, or area of space, to which another agent appears to be attending (Frischen, Bayliss, & Tipper, 2007). The theory of natural pedagogy suggests that human infants have an inborn tendency to follow gaze—to respond to movements of an adult’s head and/or eyes by shifting their gaze in the same direction as the movement—but only when the head or eye movement is preceded by another ostensive cue, such as eye contact or IDS. The putative dependence of early human gaze cuing on other ostensive cues is, according to Csibra and Gergely, the critical sign that it is a genetic adaptation for teaching: that its function is to enable human infants to pick up referential communications, deliberate attempts by an adult to get an infant to attend to a specific object. If early gaze cuing was not dependent on other ostensive stimuli, its adaptive function could be to promote “sharing” of intentional states (Tomasello, Carpenter, Call, Behne, & Moll, 2005) or simply to increase the probability that infants will attend to important or informative objects and events, regardless of whether the adult source of the gaze cue

intends his or her behavior to have any effect on the infant.

The current evidence suggests that gaze cuing occurs reliably in infants from about 4 months of age (Farroni, Mansfield, Lai, & Johnson, 2003). At 4 months, a continuous motion cue is necessary to provoke a gaze shift. It is not enough for the infant to see eyes in one position at one time and in another position shortly afterward. This raises the possibility that 4-month-olds are merely showing motion cuing: a tendency to follow any moving stimulus with their eyes. However, at 4 months the motion cue—the appearance of eyes moving to the side—makes infants shift their gaze when it is presented in an upright face but not when it is presented in an inverted face (Farroni et al., 2003). This finding suggests that, at 4 months, infants are showing gaze cuing rather than merely motion cuing—that they are especially sensitive to motion cues that are likely to come from the orienting behavior of another agent.

However, studies of infants at 4 months old and older do not provide compelling evidence that gaze cuing is modulated by other ostensive cues in the manner suggested by the theory of natural pedagogy. The best evidence in support of this view comes from a study showing that 6-month-olds were more likely to follow an adult's lateral head movement when that movement was preceded by eye contact with the infant than when it was preceded by an inanimate attention-grabbing stimulus—a colorful, moving cartoon image superimposed on the bowed head of the adult who was about to make a lateral movement (Senju & Csibra, 2008). This result may indicate, as the theory of natural pedagogy suggests, that eye contact is especially effective in promoting gaze cuing because it is indicative of referential communication. However, in this experiment the type of attention-grabbing stimulus was confounded with the trajectory of the adult's head movement—from looking ahead to looking at an object (eye contact condition) versus from looking down to looking at an object (cartoon control condition). Therefore, it is possible that the control group showed less gaze cuing because the trajectory of the adult's head movement was harder to track. A second experiment revealed a stronger gaze-cuing effect in the control condition when the cartoon was accompanied by IDS rather than ADS (Senju & Csibra, 2008, Experiment 2). This finding suggests that the infants were capable of tracking the trajectory of the control head movement, at least when it was accompanied by IDS, but does not bear on whether the between-groups difference observed in the first experiment was because of eye contact or the adult's movement trajectory. Ideally, these experiments would be repeated with a control condition in which, for example, the adults' eyes roll and flash before their heads move through the same trajectory as in the eye-contact

condition. Rolling, flashing eyes are likely to grab attention, but they do not provide an ostensive cue.

Alternatively, the infants in Senju and Csibra's (2008, Experiment 1) study may have found it more difficult to switch their attention from the cartoon to the head movement than from the direct gaze stimulus to the head movement. Consistent with this interpretation, Flom and Pick (2005) found, in an experiment where an adult made eye contact and called the infant's name at the beginning of every trial, that 7-month-olds were more likely to follow the adult's gaze when they maintained a neutral facial expression than when they appeared happy or sad. If anything, adults with emotional expressions are more likely to have an intention to communicate with an infant than those with a neutral expression, but happy and sad expressions have the potential to distract infants' attention from an adult's head movement. Therefore, Flom and Pick's result suggests that in the heartland of infancy (6–7 months) gaze cuing varies, not with the probability that the adult intends to communicate with the infant but with the extent to which contextual stimuli (e.g., eye contact, IDS, name calling, emotional expressions) draw attention toward or away from the gaze cue.

Turning to younger infants, as far as I am aware there is no evidence that gaze cuing is dependent on ostensive cues in newborns. Indeed, it is not entirely clear whether newborns show gaze cuing, rather than motion cuing, at all. Using schematic face stimuli, Farroni et al. (2004) found that infants between 1- and 5-days-old moved their eyes in the same direction as a pair of moving elongated dots (representing pupils), each surrounded by a static circle (representing the sclera). Cuing did not occur when the circles were absent, but as Farroni et al. pointed out, this finding suggests that a motion cue is necessary, not that the motion cue is only or especially effective when it is likely to represent another agent's gaze.

C. Moore and Corkum (1994) suggested more than 20 years ago that gaze cuing is learned through domain-general mechanisms, and a recent reinforcement-learning model of gaze cuing makes that hypothesis yet more plausible (Deak, Krasno, Triesch, Lewis, & Sepeta, 2014; Jasso, Triesch, Deák, & Lewis, 2012). Without evidence that infants younger than 4 months show gaze cuing, there is no reason to believe that gaze cuing, as opposed to motion cuing, is a genetic adaptation of any kind. In humans, through social interaction and domain-general processes of learning, motion cuing—an evolutionarily conserved trait—may become not only gaze cuing but also gaze cuing that is modulated by ostensive cues in the way that the theory of natural pedagogy suggests. For example, through interaction with teachers and via domain-general mechanisms, infants could easily learn that, on average, they are more likely to see something interesting when they track the gaze of a person who has

just made eye contact than when they track the gaze of a person who has not made eye contact. Indeed, the sufficiency of interaction with teachers and domain-general mechanisms is suggested by evidence that adult domestic dogs (Téglás, Gergely, Kupán, Miklósi, & Topál, 2012) show gaze-cuing effects similar to those reported for infants by Senju and Csibra (2008). In principle the dogs' sensitivity could be because of genetic changes in the course of domestication, but independent evidence suggests that when the social behavior of dogs resembles that of human infants, it is because both species are engaging in the same kind of teacher-guided learning (Udell, Dorey, & Wynne, 2008, 2010).

Rational imitation

Imitation is said to be rational when an agent, typically an infant, copies a modeled action only under circumstances where an adult observer of the modeled action would judge it likely to be the most effective means available of achieving a desired outcome. Experimental work on "rational imitation" began before Gergely and Csibra published their theory of natural pedagogy (Gergely et al., 2002), and therefore the two bodies of work can be regarded as distinct. For example, in principle, Gergely and Csibra could be right in thinking that infant imitation is rational in some sense and wrong about natural pedagogy, or vice versa. However, starting with their first major article on natural pedagogy, Csibra and Gergely (2006) have suggested repeatedly that experiments on rational imitation provide crucial support for the theory of natural pedagogy by showing that imitation "is not an end but a means. It subserves a more general human-specific adaptation of acquiring relevant knowledge from teachers" (p. 261). Therefore, in this article, rational imitation is viewed as a component of natural pedagogy, comparable with eye contact, contingencies, infant-directed speech, and gaze cuing.

When viewing rational imitation as a component of natural pedagogy, it is hard to keep in mind that the theory of natural pedagogy is concerned primarily with the adaptive functions of infants' behavioral tendencies and biases, rather than the neurocognitive processes that implement those functions. As I understand it, the theory of natural pedagogy claims that imitation is "rational in the evolutionary sense" (Király et al., 2013), which does not necessarily mean that it is rational in the psychological sense. For example, the theory is not committed to the view that infants decide what to imitate using complex, explicit inferences about the purposes of the model's actions, including the model's communicative intentions.

At its core, the rational imitation hypothesis suggests that whether and what infants and children learn by

observing an adult demonstrating an action on an object and, therefore, what they subsequently imitate depends primarily on two variables: communicative context and opacity. The first of these variables is fairly straightforward. The theory of natural pedagogy predicts that infants will imitate more when the demonstration of an act is accompanied by ostensive cues—such as eye contact, IDS, and calling the infant's name—than when the action occurs outside this communicative context. The adaptive function of this variable is to bias infants toward learning from demonstrations that are intended by the model to provide the infant with information, that is, toward learning from demonstrations in which the model is—whether the infant knows it or not—attempting to teach the infant. The second variable, opacity, is harder to characterize without using the intentional stance, but it is still possible: The theory of natural pedagogy suggests that among all the features of a demonstrated sequence of actions on an object that infants could learn about, they will learn most about the features that are maximally novel with respect to the infant's past experience of action observation. The adaptive function of this variable, in combination with communicative context, is to bias infants toward learning action features that the adult intends the infant to learn. It is likely to have this effect provided that teachers typically intend to communicate novel useful information to the infants and know enough about the infants' preexisting knowledge to identify what will be new to them. Thus, the adaptive function of the opacity bias depends on what the teacher intends and knows, rather than on what the infant intends and knows.

The first evidence in support of these predictions was published by Gergely et al. (2002). Gergely et al. tested for imitation in 14-month-old infants using a head-touch paradigm (Meltzoff, 1988). The infants observed an adult model touching a box with her forehead several times, and with each head touch a light on top of the box was illuminated. While performing the head-touch action, the model was wrapped in a blanket such that her hands were concealed (hands-occupied condition), or the blanket was draped over her shoulders and her hands were visible on either side of the light box (hands-free condition). When the infants were subsequently given access to the light box, those in the hands-free condition touched the box with their heads or bent their heads closer to the box, more often than the infants in the hands-occupied condition. It seems reasonable to assume that before the experiment, the infants were more likely to have seen adults performing instrumental actions with their heads when the adults' hands were occupied—invisible than when they were free-visible. If this is correct, the higher rate of head-touch imitation in the hands-free condition suggests that infants preferentially imitate novel features of an observed action

sequence and, therefore, supports the opacity prediction of the rational imitation hypothesis.

There is much to admire in the rational imitation hypothesis. It is a bold and interesting attempt to identify what is special about human imitation, how it differs from imitation in other animals, and how these distinctive features could enable human imitation to mediate cumulative cultural evolution. However, I think the rational imitation hypothesis has three problems.

First, the evidence that imitation varies with communicative context is not strong. Curiously, this prediction was not tested directly—in an experiment comparing the frequency of hands-free and hands-occupied head-touch imitation with and without ostensive cues (in a 2×2 factorial design)—until very recently, 11 years after the rational imitation hypothesis was first published (Király et al., 2013). The results of this crucial test showed that when head-touch demonstrations were preceded by eye contact and name calling (communicative context), infants were more likely to make head-touch responses if the model's hands had been free rather than occupied during the demonstration. There was no difference between hands-free and hands-occupied conditions when demonstrations had not been preceded by ostensive cues (noncommunicative context). This is the pattern of results predicted by the rational imitation hypothesis, but it does not establish firmly that communicative context is crucial with respect to infant imitation because there were marked differences between the communicative and noncommunicative conditions in addition to the presence versus absence of eye contact and name calling. For example, whereas the infants in the communicative condition observed the model while sitting opposite her at the same table, the infants in the noncommunicative condition were on the floor in a play area two meters away from the table. Consequently, although Király et al. (2013) reported that the infants in the noncommunicative condition were oriented toward the demonstrations for as long as the infants in the communicative condition, it is likely that their view of the model's head-touch action was not as clear as that of the infants in the communicative condition and that they were not attending as closely to the model's head movements. Furthermore, because both groups of infants were tested while seated at the table, those in the noncommunicative condition underwent a context shift between observation and testing (e.g., from floor to table and blanket to mother's lap), whereas those in the communicative condition did not, and context shifts of this kind are known to have a detrimental effect on infant imitation (Learmonth, Lamberth, & Rovee-Collier, 2004).

Not only did the recent experiment by Király et al. (2013) fail to provide compelling evidence that communicative context modulates head-touch imitation in

infants but also an earlier study, using a different paradigm, revealed no effect of communicative context on imitation of object-directed actions in 3-year-old children (Schmidt, Rakoczy, & Tomasello, 2011). Thus, even if my concerns about the recent study are disregarded, it is not clear whether any modulating effect of communicative cues generalizes across imitation tasks and from infants to children.

The second problem for the rational imitation hypothesis relates to opacity. Beisert et al. (2012) recently replicated the ground-breaking experiment by Gergely et al. (2002) described earlier but added to the hands-free and hands-occupied conditions a "hands-occupied familiarization" condition, in which the model was wrapped in a blanket, not only while she demonstrated head touching but also during the play period that preceded the demonstration for all infants. The infants in the hands-occupied familiarization condition made as many head-touch responses on test as those in the hands-free condition and significantly more than those in the hands-occupied condition without familiarization. That is, the familiarization treatment abolished the original rational imitation effect (Gergely et al., 2002). Familiarization is likely to have reduced the extent to which infants were distracted from the model's head-touch behavior by big movements of the blanket just before the demonstration or by the unfamiliar sight of a blanket-wrapped adult during the demonstration, but not to have increased the novelty, and therefore the opacity, of seeing an adult perform an action with her head when her hands were occupied. Therefore, the results reported by Beisert et al. (2012) suggest that in the absence of a familiarization treatment, infants imitate head touching more after hands-free than hands-occupied demonstration, not because head touching is more novel or opaque in the hands-free condition but because the infants are more likely to have attended to the model's head-touching action.

The final problem for rational imitation is more general and not dependent on the other two. Using the experiments by Gergely and colleagues (Gergely et al., 2002; Király et al., 2013) to show that imitation in infancy is rational (i.e., modulated by communicative context and opacity), I provide two reasons to doubt that it would promote high-fidelity cultural inheritance. The first reason arises from a study by Pinkham and Jaswal (2011), who showed that in spite of seeing a hands-free demonstration in a communicative context, 18-month-old infants do not imitate head touching when they have had the opportunity before the demonstration to discover through their own efforts that touching the box with their hands switches on the light. As Nakao and Andrews (2014) pointed out, this finding suggests that in infancy even rational imitation does not trump or overwrite individual learning in a way that would allow culturally

accumulated wisdom to be passed down from one generation to the next without corruption.

The second reason is that the copying that occurs in head-touch experiments may not be of a kind that is important for cultural inheritance (Buttelmann, Zmyj, Daum, & Carpenter, 2013; Zmyj, Buttelmann, Carpenter, & Daum, 2010). It is widely assumed that the frequency of head-touch responses is an index of the extent to which an infant has learned that touching the box with one's head makes the light come on. This kind of knowledge, of instrumental relationships, is culturally relevant. For example, it is the kind of knowledge that enables us to use tools. However, it is possible that instead of reflecting knowledge of an instrumental relation, the frequency of head touching in the head-touch paradigm reflects the extent to which infants have been primed by (a) the sight of head movement to move their own heads and (b) the sight of box illumination to approach the box. In the jargon used by researchers with a special interest in social learning, these robust effects are known as "effector priming" (Gillmeister, Catmur, Liepelt, Brass, & Heyes, 2008; Leighton & Heyes, 2010) and "stimulus enhancement" (Heyes, 1994; Spence, 1937), respectively. In the case of effector priming, observing the movement of a certain body part (e.g., a model's finger, an arm, or a head) increases the probability that observers will move their own corresponding body part, but—in contrast with imitation and motor resonance (Paulus, Hunnius, Vissers, & Bekkering, 2011)—does not influence the topography of the movement. Thus, effector priming would make infants who had seen head-touch behavior more likely to move their heads on test, but it would not encourage them specifically to bend their heads forward. In the case of stimulus enhancement, observing a model's action increases the probability that the observer will subsequently approach the object of the action simply by drawing the observer's attention to that object. Thus, stimulus enhancement could channel a nonspecific tendency to move the head (effector priming) into head movements toward the light box, without the infants having learned anything by model observation about the topography of the head-touch movement or the instrumental relation between head touching and box illumination.

Dedicated experiments would be necessary to find out to what extent head-touch copying depends on imitation rather than effector priming channeled by stimulus enhancement, but data reported recently by Király et al. (2013, Experiment 1) support the latter proposal by showing that infants' head-touch copying is of very low fidelity. Ten (36%) of the 28 imitator participants in this study performed two or three different kinds of head-touch responses in the test session; only 3 (11%) touched the box with their forehead, as the model had done; and

when first head-touch responses were analyzed there were 10 touches with the mouth, four with the nose, three with the cheek, and eight in which some part of the infant's head came close to but did not make contact with the box.

I have argued elsewhere that cultural evolutionists have tended to overestimate the extent to which imitation—copying the topography of body movements or learning instrumental relations by observation—is likely to contribute to high-fidelity cultural inheritance and to underestimate the inheritance potential of other forms of social learning (Heyes, 1993, 2013). Therefore, I do not want to claim that effector priming channeled by stimulus enhancement could not contribute to cultural learning. If it turns out that head-touch copying does not occur through imitation, however, a connection between the head-touch paradigm and cultural inheritance would certainly be harder to trace, and those who regard imitation as the only culturally relevant form of social learning might consider that connection to be broken. Most research on rational imitation assumes that the head-touch paradigm puts early cultural learning in a Petri dish but that assumption may not be well-founded.

Thus, it is not clear whether rational imitation is real: whether imitation in infancy and childhood is reliably modulated by communicative context and opacity. Even if the phenomenon is reliable, as far as I am aware there are no studies showing that it occurs in newborns (indeed, it now seems unlikely that newborns are capable of any sort of imitation; Ray & Heyes, 2011) or presenting other evidence to suggest that rational imitation is a genetic adaptation. The modulation of imitation by communicative context and opacity might well be adaptive in a broad sense. It would be likely to increase the probability that infants learn useful things by observing the actions of others. However, it is unclear whether these features would be sufficient to allow rational imitation to dominate individual learning and convey information about instrumental relations in ways that would facilitate cumulative cultural evolution.

Summary of components

I have reviewed evidence from studies of infants, adults, and nonhuman animals, relating to each of the five principal components of the natural pedagogy package, some of which has emerged since the theory of natural pedagogy was first published (see Table 1).

- *Eye contact:* Current evidence confirms that humans are, from a very young age, highly sensitive to whether another agent is looking at them directly. However, it is possible that rather than being inborn, sensitivity to eye contact is a rapidly

Table 1. A Summary of the Evidence From Research With Infants, Children, Adults and Nonhuman Animals Relating to Four Questions About the Components of Natural Pedagogy (Eye contact, Contingencies, Infant-Directed Speech, Gaze Cuing, Rational Imitation)

Component	Reliable phenomenon	Genetic adaptation	Genetic adaptation for teaching	Cultural adaptation for teaching
Eye contact	✓	?	✗	?
Contingencies	✓	✓	✗	?
Infant-directed speech	✓	✓	?	✓
Gaze cuing	✓	✗	✗	✓
Rational imitation	?	✗	✗	✓

Note: For each component, in the empirical review I asked, (a) Is it a reliable phenomenon? (b) Is it a genetic adaptation? (c) Is it a genetic adaptation specifically for teaching, rather than social bonding or social learning? (d) Is it a cultural adaptation for teaching, produced by domain-general mechanisms of learning through social interaction?

developing consequence of an inborn preference for face-like stimuli. If eye-contact sensitivity is, in this sense, secondary to a face preference, it may or may not be a genetic adaptation; its development may or may not have been canalized by natural selection operating on genetic variants to fulfil a particular adaptive function. However, evidence that our sensitivity to eye contact is shared with a wide range of nonhuman animals suggests that even if it is a primary genetic adaptation, its function is not specific to teaching.

- *Contingencies:* There is stronger evidence that humans have an inborn attraction to response-contingent stimulation, but data on imprinting in precocial birds suggest that like eye-contact sensitivity, this component has deep evolutionary roots and has not been tuned by natural selection specifically to make human infants receptive to teaching.
- *Infant-directed speech:* Similarly, human infants appear to have an inborn preference for high-pitched emotional speech, but evidence that this preference is also present in nonhuman animals suggests that, if it is a genetic adaptation, its function is to promote social bonding and coordination rather than a kind of learning that supports cumulative cultural inheritance.
- *Gaze cuing:* Motion cuing seems to be an inborn, evolutionarily conserved trait. However, the current evidence suggests that the development of gaze cuing—a specific or exaggerated tendency to follow the movement of eyes—is powered by domain-general mechanisms of learning—mechanisms which detect predictive relationships between eye movements and the location of valuable objects and events. These mechanisms may also detect that eye movements are especially good predictors of value when they have been preceded by eye contact and name calling and thereby

support the modulation of gaze cuing by ostensive cues.

- *Rational imitation:* It is not clear whether imitation in infancy and childhood is reliably modulated by communicative context and opacity. Even if imitation is rational in this evolutionary sense, there is no evidence that modulation by communicative context and opacity develops so early that it is more likely to be a genetic adaptation than a product of domain-general learning. In either case, the modulation of imitation by communicative context and opacity may function to facilitate teaching, to increase the probability that a novice will learn what an expert model intends the novice to learn, but unless rational imitation can overwrite individual learning it has limited potential to mediate cumulative cultural inheritance.

Thus, eye-contact sensitivity, attraction to response-contingent stimulation, a preference for IDS, and gaze cuing are real phenomena, but it is not clear whether imitation is rational. There is evidence that two of the five components of natural pedagogy are inborn—attraction to response-contingent stimulation and a preference for IDS—and therefore prima facie evidence that these two are genetic adaptations. However, like eye-contact sensitivity and gaze cuing, attraction to response-contingent stimulation and a preference of IDS have operating characteristics and a phylogenetic distribution suggesting that their functions relate to social bonding and/or social learning, not specifically to teaching.

The Package

In the foregoing review, I took apart natural pedagogy. I asked whether for each component, in turn, there is compelling evidence that (a) the component is real, that is, a reliable feature of infant minds and behavior; (b) it is a

genetic adaptation; and (c) the adaptive function of the component is specifically to promote teaching. Some of the answers were affirmative, but in no case did a component tick all three boxes (Table 1, columns 2–4), suggesting that, contrary to the theory of natural pedagogy, eye contact, contingencies, IDS, gaze cuing, and rational imitation are not genetic adaptations for teaching. In this section of the article, I put natural pedagogy back together again. I focus on the thinking behind the theory as a whole. Although the specific hypotheses advanced by the theory of natural pedagogy are not supported by the evidence reviewed in the previous section, I believe this theory has strengths that make it a valuable gateway for further research on the origins of teaching and the role that teaching plays in cultural evolution. Specifically, the theory of natural pedagogy contains three fundamental insights about the psychology of cumulative cultural inheritance: imitation is not enough; the extra comes not only from smart thinking but also from blind trust; and tweaking—fine adjustment made by evolutionary processes—is a powerful source of cognitive change. In this section, I discuss each of these insights in turn and explain why they are important in relation not only to teaching but also to all forms of cultural learning (for more detailed discussion see Heyes, in press-a).

Imitation is not enough

The groundwork for much contemporary research on cultural evolution was laid in the 1970s and 1980s by researchers with backgrounds in anthropology, biology, and mathematics (e.g., Boyd & Richerson, 1988; Cavalli-Sforza, Feldman, Chen, & Dornbusch, 1982). Echoing the views of many psychologists who had previously assumed a special relationship between imitation and culture (e.g., Bruner, 1983; Piaget, 1962; Washburn, 1908), these researchers suggested that imitation is the cultural analogue of the mechanisms of genetic inheritance: It allows cultural traits—contributing to skills, practices, institutions, and languages—to be passed down from one generation to the next with sufficient fidelity to allow improvements to accumulate over time. In the 1970s and 1980s it was widely believed that imitation is a distinctively human capacity, or one that humans share only with other great apes. Because cumulative cultural evolution is also distinctively human, this belief fitted well with the idea that imitation is the primary, or perhaps the only, form of cultural learning. However, in the late 1980s and early 1990s evidence began to emerge that not only apes but also a broad range of nonhuman animals are capable of imitation, and other doubts about the sufficiency of imitation began to be raised (Custance, Whiten, & Bard, 1995; Heyes, 1993). Csibra and Gergely are not alone in having responded to these developments by rethinking

the relationship between imitation and culture, but their voices are the freshest and most radical. Their theory of natural pedagogy retains a role for imitation but states clearly that imitation—or what they sometimes call “blind imitation” (Csibra & Gergely, 2006, p. 253)—is not enough. They make a persuasive case that to understand how cumulative cultural evolution is possible, researchers need to think harder about the receptive side of teaching—about the ways in which novices derive information, not from experts who are going about their business oblivious to the novices’ needs but from experts who are striving to inform them.

The extra comes from blind trust

Most researchers who recognize that imitation is not enough seek the extra among the fanciest—the most complex or at least the most obscure—processes in the catalog of cognitive science. They suggest that if one adds theory of mind (also known as “mind reading,” “mentalizing,” and “shared intentionality”) and/or language to imitation, the resulting compound is enough to support cumulative cultural inheritance (Byrne & Rapaport, 2011; Tomasello, 2014). But Csibra and Gergely have taken a different path, which is better suited to explaining the early origins of cultural inheritance: how cultural evolution got off the ground (Sterelny, 2013). The theory of natural pedagogy suggests that blind trust is at least as important as smart thinking. Infants and children select models using ostensive cues, but once they have locked onto a demonstration, they take what they are given; they copy the model’s actions, regardless of whether those actions make sense to them. Indeed, according to Csibra and Gergely, children should be especially inclined to learn from others the things that don’t make sense to them.

Tweaking is a powerful source of cognitive change

A central claim of the theory of natural pedagogy is that small changes to psychological processes—inflections (Heyes, 2003) or tweaks (Milius, 2013) that create biases in favor of certain perceptual inputs—can make a huge difference to the way that the processes function. For example, natural pedagogy theory shows us that tweaking imitation, so that it is more likely to occur when a demonstration is preceded by eye contact, and tweaking motion cuing, so that it becomes especially sensitive to eyes (i.e., gaze cuing) could transform imitation and motion cuing into major conduits of high-fidelity cultural inheritance. Csibra and Gergely’s analysis of these examples makes it plausible that the origins of the human capacity for cumulative cultural evolution lie in small

changes to the psychological processes that operated in our precultural ancestors.

The evidence I reviewed above, under the Components section, suggests that imitation may not be as reliably modulated by eye contact as the natural pedagogy theory suggests and both imitation and motion cuing may be biased or specialized by domain-general processes of learning in the course of development, rather than having been tweaked by genetic evolution in the hominid line. This evidence, however, does not undermine Csibra and Gergely's basic approach: their attempt to find the roots of cultural inheritance in small changes to psychological processes. Rather, it suggests that researchers should be more catholic when examining the drivers of change and more open to the possibility that the crucial changes are made, not by genetic evolution, but by domain-general processes of learning operating in a sociocultural context.

This openness could be usefully extended from the components of natural pedagogy to the components of "shared intentionality" (Tomasello, 2014), including social motivation and normative thinking (R. Moore, 2013). Social motivation is a good example because in the last decade the idea that human infants and children find it rewarding to behave in the same way as those around them—that they are socially motivated—has been revived by evidence of "overimitation" (Over & Carpenter, 2013). Studies of overimitation suggest that children copy the behavior of adults even when, from an instrumental perspective, it is inefficient to do so. For example, when retrieving a toy from a puzzle box 3- and 4-year-old children do not only release the latches and open the doors impeding their access to the prize but they also copy the model's extraneous actions—such as tapping the box with a wand—and engage in this overimitation even when they are apparently able to discriminate the "silly" extraneous actions from the actions necessary to get the job done (Lyons, Young, & Keil, 2007).

Whether or not they call it social motivation, contemporary researchers typically assume that the impulse to overimitate is a genetic adaptation or "evolved heuristic" (Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009): that human children have an inborn tendency or predisposition to overimitate. However, evidence published predominantly in the 1970s and 1980s, when overimitation was called "generalized imitation," suggests that this assumption is not sound. In these studies, children from preschool age up to 14 years old were tested for imitation of a set of novel actions at baseline (i.e., before imitation of any action in the set had been rewarded) and after selective reward (i.e., when imitation of some, but not all, actions in the set had begun to be rewarded). The frequency of imitation increased substantially from baseline when reward, typically praise, was introduced (Baer &

Sherman, 1964), and the children showed generalization (overimitation): Once reward had been introduced, the children were apt to imitate not only the actions for which imitation was rewarded but also other actions of the same type (Baer & Sherman, 1964; Garcia, Baer, & Firestone, 1971; Young, Krantz, McClannahan, & Poulson, 1994).

At the time, these studies of generalized imitation were interpreted within a behaviorist framework (Baer & Deguchi, 1985), but one does not need to subscribe to any particular theory of learning to feel the impact of their results. They show that experiences of social reward are a powerful determinant of imitation in childhood and thereby encourage research that investigates, rather than assumes, that the impulse to overimitate is inborn. For example, in the spirit of Csibra and Gergely's analysis, it is possible that genetic evolution has tweaked rather than reconstructed social motivation in the hominid line. Rather than giving us a whole new desire—to act like others in our social group—Mother Nature may have simply amplified the reinforcing power of social rewards, making us more likely than our ancestors to repeat anything that earns us a warm smile, touch, or sound from another person.

A more catholic approach would also be appropriate in research on the productive side of teaching. Extended discussion of how humans come to be able and willing to send teaching signals is beyond the scope of this article, which, following the theory of natural pedagogy, is concerned with the receptive side of teaching. However, it is worth noting a recent study in which adults were subjected to brain imaging while they were teaching students a series of action–outcome relationships by providing positive and negative feedback (Apps, Lesage, & Ramnani, 2015). Modeling of haemodynamic responses indicated that when people are teaching, the same part of the brain (the anterior cingulate cortex) is using the same process (calculation of prediction error or reinforcement learning) as when they are learning action–outcome relationships for themselves through unassisted trial and error. The difference is that when teaching, the anterior cingulate calculates prediction error for the student's actions and their outcomes, rather than for the actions of the teacher, who is the "owner" of the brain. These striking results suggest that teaching depends on evolutionarily ancient mechanisms of reinforcement learning and thereby that genetic evolution could have converted learners into teachers by making only small changes to those mechanisms. Thus, in combination with much older research on generalized imitation, this recent work on the cognitive neuroscience of teaching suggests that genetic tweaks are a powerful source of cognitive change because their effects can be amplified massively by domain-general processes of learning operating in a sociocultural context.

Conclusion: Natural and Cultural Pedagogy

The theory of natural pedagogy is so called because it proposes that Mother Nature has played a major role in making human infants and children receptive to teaching signals. With this specific purpose, genetic evolution has introduced at early stages in development small but crucial changes in the way that human infants process information from other people. The evidence reviewed in the first section of this article and the arguments presented in the second suggest that Mother Nature may have had less specific purposes when she did her tweaking and that Mother Culture does a lot of the hard work in preparing children to be taught. Less specific purposes are indicated by the fact that, where there is evidence that a component has been shaped by genetic evolution, there is also evidence that it was adapted, not for teaching, but for social bonding or to promote attention to other agents. A more important role for Mother Culture is indicated by evidence that some components of the pedagogy package (IDS, gaze cuing, rational imitation) and other psychological attributes (social motivation–overimitation) become adapted for teaching through the operation of domain-general processes of learning in a social context (see Table 1, column 5). For example, the evidence suggests that motion cuing becomes gaze cuing and possibly modulated by communicative cues through reinforcement learning in contexts where the eye movements of others predict the locations of interesting objects and events. Similarly, research on generalized imitation suggests that children may become overimitators through reinforcement learning in contexts where adults deliver rewards for behavior that they, the adults, judge to be similar to their own. More generally, a significant role for Mother Culture is consistent with evidence of marked cross-cultural variation in the ways and extent to which infants and children are exposed to teaching (e.g., Atran & Sperber, 1991; Hewlett, Fouts, Boyette, & Hewlett, 2011)

In these examples, learning that makes a child more teachable is guided by the actions of others, typically adults. If the adults' guiding actions, such as gaze shifting and rewarding imitative behavior, are intended to support learning by the child, then there is a very real sense in which children are taught to be teachable; their receptivity to teaching constitutes cultural, rather than natural, pedagogy. However, even when adults do not intend to influence a child—when they are going about their normal business, looking at events that interest them, and reacting warmly to behavior simply because they find it pleasing—the effect of their actions is to promote the development of psychological tendencies that make children teachable; that make them into pupils.

Whether the adults know it or not, their actions are contributing to the cultural inheritance of cultural learning (Heyes, 2012).

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