Origins of Mind: Philosophical Issues in Cognitive Development

Warwick, Autumn 2016-7
<s.butterfill@warwick.ac.uk>

Plan

How do humans come to know about objects, causes, words, numbers, colours, actions and minds? We will attempt to answer this question using a range of conceptual tools from philosophy to examine puzzles arising from some recent scientific breakthroughs.

The lectures will be organised by domains of knowledge, so that one or two lectures concern knowledge of objects, another knowledge of number, and so on. In this document I outline the material to be covered in lectures.

Introduction

How do humans come to know about—and to knowingly manipulate—objects, causes, words, numbers, colours, actions and minds? In pursuing this question we have to consider minds where the knowledge is neither clearly present nor obviously absent. This is challenging because both commonsense and theoretical tools for describing minds are generally suitable only for fully developed adult minds. Davidson writes:

> 'We have many vocabularies for describing nature when we regard it as mindless, and we have a mentalistic vocabulary for describing thought and intentional action; what we lack is a way of describing what is in between' (Davidson 1999, p. 11).

To understand the emergence of knowledge we need to find ways of describing what is in between: individuals whose movements are neither mindless nor guided by intention and knowledge. And the ways we find to describe these individuals must enable us to understand what it is like to be them, to see things from their points of view. Some progress has already been made but many challenges remain. Philosophers have much to contribute in crafting distinctions and conceptual tools useful for meeting the challenges involved in describing what is in between. There is also much for philosophers to gain: studying what is in between mindless nature and the sorts of cognition captured by commonsense psychological notions will reveal things about what minds are and how they work.

In explaining how research on developing minds bears on some existing philosophical issues and raises some new ones, this lecture introduces two scientific breakthroughs that have recently furthered understanding of how knowledge might emerge in development. As already mentioned (in the Brief Description), the first breakthrough is the discovery that preverbal infants enjoy surprisingly rich social abilities, abilities which may well be foundational for later linguistic abilities and enable the emergence of knowledge (e.g. Csibra & Gergely 2009; Meltzoff 2007; Tomasello et al. 2005). A second breakthrough is the use of increasingly sensitive—and sometimes controversial—methods to detect sophisticated expectations concerning causal interactions, numerosity, mental states and more besides in preverbal infants (e.g. Spelke 1990; Baillargeon et al. 2010). These breakthroughs are driven by researchers with conflicting theoretical positions and raise quite different issues. But both breakthroughs are needed to identify ingredients necessary for understanding the developmental origins of human knowledge.

Topic 1. Social Interaction without Words

Could social interaction enable cognitive development? This topic examines arguments for the hypothesis that it could (as offered in Tomasello & Rakoczy 2003 and Moll & Tomasello 2007). It also discusses objections to this hypothesis and introduces questions it raises.

One obstacle to even understanding the hypothesis is that much adult social interaction depends so heavily on communication by language (not to mention social networks) that it can be hard to imagine what social interaction with preverbal infants could involve. To overcome this obstacle we shall review evidence for a package of social abilities manifested in preverbal infants. These include imitation, which can occur just days and even minutes after birth (Meltzoff & Moore 1977; Field et al. 1982; Meltzoff & Moore 1983), imitative learning (Carpenter et al. 1998), gaze following (Csibra & Volein 2008), goal ascription (Gergely et al. 1995; Woodward & Sommerville 2000), social referencing (Baldwin 2000) and pointing (Liszkowski et al. 2006). Taken together, the evidence reveals that preverbal infants have surprisingly rich social abilities.

The hypothesis that these social abilities enable cognitive development faces an objection. For it seems that many of these abilities already presuppose knowledge of objects, actions and minds. For instance, twelve-month old infants will helpfully point to inform ignorant but not knowledgable adults about the location of an object (Liszkowski et al. 2008). Doesn't this show that these infants are already capable of knowing about others' knowledge and ignorance? If so, pointing and other social abilities could play at most a limited role in explaining the developmental origins of knowledge of mind. After all, we can hardly explain the emergence of something by appealing to abilities whose possession already presuppose it. We will encounter tools for replying to this objection in Topics 2 (on Objects), 6 (on Actions) and 7 (on Minds).

If this objection can be overcome, how could social abilities enable cognitive development? Some have argued that early social abilities partially explain the emergence in humans of communication by language (Tomasello 2008; see Topic 5 on Words below). This is a valuable contribution. But could social abilities also play a role in explaining the developmental origins of knowledge of things other than words—for example, in explaining the emergence of knowledge of objects, numbers, colours or minds? This question comes up in one way or another in each of the following lecture topics.

Topic 2. Objects and How They Interact

When can infants first know things about objects they aren't perceiving? For instance, when a ball falling behind a chair disappears from view, when do infants first realise that the ball is somewhere behind the chair? The ability to realise this is known as 'object permanence'. One way to test for object permanence is to ask when infants first reach for objects they can't see or when they first remove barriers to retrieve objects concealed behind them. Infants don't do this until around eight months of age (Meltzoff & Moore 1998, p. 202) or later (Moore & Meltzoff 2008). Since four-month-olds already have the planning skills they would need to execute the reach (Shinskey & Munakata 2001), their failure to reach is evidence that infants can first think about objects they aren't perceiving at around eight months or later. But another way to test for object permanence is to ask how infants respond to apparently impossible events. Suppose, for example, that infants watch as a solid object is placed immediately behind a screen and then the screen falls backwards, ending up flat as though the object were not there, which is apparently impossible (Baillargeon et al. 1985; Baillargeon 1987). If infants show heightened interest in this and similar cases, perhaps by looking at the display for longer than might otherwise be expected, this would be evidence that they can know things about objects they aren't perceiving. As it turns out, infants show such heightened interest from around four months of age or earlier. Put together, the two sorts of findings give rise to the 'paradox of early permanence' (as Meltzoff & Moore 1998 call it). The best explanation of the first sort of findings seems to be that infants cannot think about objects they aren't perceiving until eight months or later; but the best explanation of the second sort of findings seems to be that infants can do this from around four months or earlier. Clearly these explanations cannot both be correct. But neither seems to be wrong.

This conflict exemplifies a pattern that occurs again and again in investigating the developmental origins of knowledge. Here's the pattern. We ask when humans can first know about X. One set of findings provides converging evidence that the answer is: surprisingly early. Another set of findings, using a different set of techniques, provides converging evidence that the answer is: much later. Unless they arise from methodological failings, these conflicting answers force us to recognise that the question involves a mistake. The mistake is to think that there is a single kind of knowledge. In fact:

> 'there are many separable systems of mental representations ... and thus many different kinds of knowledge. ... [T]he task ... is to contribute to the enterprise of finding the distinct systems of mental representation and to understand their development and integration' (Hood et al. 2000, p. 1522).

It is one thing to propose that there are multiple kinds of knowledge, quite another to make systematic sense of this possibility. In this topic we will consider attempts to do this by appeal to notions of modularity (Fodor 1983) and core knowledge (Spelke & Kinzler 2007). Both attempts raise further questions. These questions about how to make sense of the possibility that there are multiple kinds of knowledge run through the following lectures.

Topic 3. Numbers

How might abilities based on core knowledge enable the emergence in development of knowledge proper? In this topic we consider answers to this question for the special case of knowledge of number.

In topic 2 (on Objects) we saw that core knowledge of objects is manifested early in infancy, whereas more flexible abilities involving knowledge proper first appear months or even years later. A similar pattern can be observed in the case of number. From around five months of age or earlier, infants are sensitive to the number of items in a repeatedly presented stimulus (Starkey & Cooper 1980), can sum over the number of items in a short sequence (Wynn 1996), can discriminate between small and large sets of objects (Xu & Spelke 2000), and can keep track of the precise number of items in a small set of objects following additions or subtractions (Wynn 1992).

Should we conclude that infants already have adult-like number concepts? Limits on infants' abilities show that we should not. To illustrate, at around fourteen months of age infants who have seen two objects put into a box will search in it until they have recovered two objects, and infants who have seen three objects put into the box will search three times. But after seeing four objects placed in the box, infants usually search just once (Feigenson & Carey 2003). In general, infants' abilities to deal with precise numerosity are strictly limited to situations involving at most three items (Feigenson & Carey 2003). It seems clear, then, that infants do not have adult-like number concepts.

The three-item limit on infants' abilities to deal with precise numerosity is the key to a revealing discovery. Many species besides humans have abilities to deal with precise numerosity. Because these abilities are also subject to limits like infants' three-item limit, it is reasonable to hold that they are closely related (Hauser & Carey 2003). This makes it unlikely that infants' core knowledge of number is a product of learning (Feigenson et al. 2004), and so supports a modest form of nativism.

A bolder form nativism would insist not only that core knowledge of number is innate but also that number concepts proper are innate (Fodor 1981). Against this bolder view, some have attempted to explain how core knowledge together with mastery of a sequence number words could explain how number concepts can be acquired (Carey 2009). If successful, this explanation shows that not all primitive concepts are innate and provides us with one model of how core knowledge together with linguistic abilities might enable the emergence of knowledge proper.

Topic 4. Seeing and Talking about Colours

How do children acquire colour concepts and colour words—concepts and words for red, blue and green, say? Exploring this question reveals unexpected complexity in the developmental origins of knowledge, as we will see in this lecture.

Categorical perception of colour emerges early in infancy. This has been demonstrated with four-month-olds using habituation (Bornstein et al. 1976) and visual search (Franklin et al. 2005). Slightly older infants can make use of colour properties such as red and green to recognise objects. For instance, nine-months-olds can determine whether an object they saw earlier is the same as a subsequently presented object on the basis of its colour (Wilcox et al. 2008). By the time they are two years old, toddlers who do not comprehend any colour words can use colour categories implicitly in learning and using proper names; for instance, they are able to learn and use proper names for toy dinosaurs that differ only in colour (Soja 1994, Experiment 3). So infants and toddlers enjoy categorical perception of colour and may benefit from it in recognising and learning about objects. However children only acquire concepts of, and words for, colours some time later; and colour concepts, like colour words, are acquired gradually (Pitchford & Mullen 2005; Kowalski & Zimiles 2006; Sandhofer & Smith 1999; Sandhofer & Thom 2006).

A natural hypothesis, then, is that the acquisition of colour words and concepts builds on categorical perception of colour: infants are first perceptually acquainted with colours and then learn names for them. And since infants enjoy categorical perception not only of colour but also of orientation (Franklin et al. 2010), speech (Kuhl 1987, 2004; Jusczyk 1995) and facial expressions of emotion (Etcoff & Magee 1992; Kotsoni et al. 2001; Campanella et al. 2002), we might suppose that something similar holds in these cases too. The hypothesis, then, is that categorical perception provides 'the building blocks—the elementary units—for higher-order categories' (Harnad 1987, p. 3).

This hypothesis turns out to be entirely mistaken. The extensions of colour words may be subject to universal constraints but they certainly vary significantly between languages (Kay & Regier 2003). The boundaries of adult humans' colour concepts and their perceptual colour categories are influenced by the extensions of the colour words they use (Kay & Regier 2006; Roberson & Hanley 2007; Winawer et al. 2007). It is even possible to alter the boundaries of adults' perceptual categories by teaching them new colour words (Ozgen & Davies 2002). But preverbal infants' perceptual colour categories are not influenced by colour words. Indeed, in toddlers who have recently acquired colour words, the extensions of their colour concepts do not match their perceptual category boundaries (Franklin et al. 2005). So it is a mistake to think of the development of colour words and concepts as a matter of learning to label or demonstratively refer to categories infants are already perceptually acquainted with. Quite the reverse: acquiring colour words and concepts is a prerequisite for being able to perceive the colour categories they refer to.

Can the case of colour shed light on the question of how core knowledge enables the emergence of knowledge proper? There are some parallels between categorical perception and core knowledge: for instance, both phenomena are judgement-independent and have limited effects on action. Indeed, there seems no less reason to postulate core knowledge of colour or speech than there is to postulate core knowledge of objects or agents. So the case of colour suggests that the development of knowledge proper is not always a matter of making explicit, or building on, what was earlier implicit in core knowledge. In fact core knowledge might sometimes be in competition with knowledge proper.

Topic 5. Words and Other Communicative Tools

One problem in acquiring a language is to identify which things are words; among much else, this involves working out where, in a stream of speech or gesture, one word ends and another begins. In solving this problem infants may rely on statistical learning (Saffran et al. 1996). Another problem is learning which words pick out which objects and properties; this is often called the 'mapping problem'. Philosophers have sometimes held that in solving this problem children rely on association (or perhaps other forms of statistical learning). Compare Wittgenstein (1972, p. 77):

> 'The child learns this language from the grown-ups by being trained to its use. I am using the word "trained" in a way strictly analogous to that in which we talk of an animal being trained to do certain things. It is done by means of example, reward, punishment, and suchlike.'

If this sort of view were right, abilities to communicate linguistically would not necessarily depend on knowledge proper. So it would be possible to conjecture that the emergence in development of knowledge proper is a consequence of training with language. This does indeed seem plausible for the special case of colour words, as we saw in topic 4 (on Colours); and something like it may hold for number words too (see topic 3 on Numbers). But putting these special cases aside, the experimental findings do not support Wittgenstein's claim that language is entirely acquired through training. Instead they support the hypothesis that children solve the mapping problem by general reasoning and rely on social cognition (Baldwin 1995; Bloom 2000; Sabbagh & Baldwin 2001). This hypothesis is further supported by findings that children who have learnt few or no words sometimes invent their own words (Clark 1993), and by research on profoundly deaf children brought up in purely oral environments and therefore without experience of language who, individually or in groups, create their own signed languages (Kegl et al. 1999; Senghas & Coppola 2001; Goldin-Meadow 2003).

This hypothesis—children solve the mapping problem by general reasoning—conflicts with Davidson's claims that having thoughts involves grasping the concept of truth (Davidson 2001, p. 189), and that 'we grasp the concept of truth only when we can communicate the contents—the propositional contents—of the shared experience, and this requires language' (Davidson 1997, p. 27). The objection to Davidson's view is that it has things backwards: acquiring your first words already involves thinking about what they pick out. If this objection is correct, can anything be salvaged from

Davidson's arguments? While the objection rules out claiming that being able to think depends on being able to communicate propositional contents using language, it leaves open the possibility that thought is essentially intersubjective. One challenge, then, is to explain the intersubjectivity of thought without appeal to communication by language.

So far our focus has been the mapping problem, the problem of determining which words pick what out. A distinct and no less difficult problem is how infants come to understand words as communicative tools at all. Merely associating a word or gesture with what it picks out would not enable a child to respond appropriately to uses of that word or gesture, nor to use it intelligently (contra Russell 1921, p. 75). After all, chimpanzees associate pointing gestures with their referents (Moll & Tomasello 2007, p. 6) but fail to respond appropriately to helpful pointing gestures (Hare & Tomasello 2004). Unlike chimpanzees, children not only map words to what they pick out but also use and understand them as tools for communication. What does this understanding amount to—in particular, do children learning their first words already have an adult-like understanding of communicative intention? And how do children acquire this understanding? Answering these questions may require revisions or extensions to existing philosophical accounts of communication which often presuppose conceptual sophistication (e.g. Grice 1957).

Topic 6. Actions: Teleology and Motor Awareness

Tracking a goal-directed action involves at least two things: distinguishing the action from other events and identifying to which goal or goals it is directed. Infants' expectations indicate that they can do both of these things from some time around the end of their first year of life (e.g. Csibra 2003). But tracking is not understanding. To say that infants can track goal-directed action is not yet to say anything about what they understand of action. Consider two questions about the nature of action. First, which events are actions? Second, what is the relation between an action and the goal or goals to which the action is directed? For each of these we can ask corresponding questions about infants' understanding of action. Which events do infants take to be actions? And how do they understand the relation between actions and the goals to which they are directed? We need to answer these questions in order to understand how early abilities to track action are developmentally related to knowledge of action, and also how they relate to developments in other domains including language. In this topic we explore three hypotheses about the understanding which underpins infants' abilities to track action.

The question of what actions are is usually answered by appeal to intention, a propositional attitude which plays a characteristic role in planning and coordinating action, is linked to practical reasoning and is subject to characteristic norms (Bratman 1987). On the standard view, an action is directed to an goal in virtue of the action's being appropriately related to an intention which represents this goal or some related goal. The corresponding view about understanding has it that understanding action involves understanding intentions and so having mastered propositional attitude psychology. Could this be how infants understand actions? This view would be consistent with the views of those who hold that one-year-old infants understand psychological notions like belief and desire (Baillargeon et al. 2010). But this view is incompatible with views on which early understanding of action plays a role in explaining how children later acquire knowledge of belief, desire and other mental states. We should therefore consider alternative, less conceptually demanding accounts of action understanding.

Are there alternative views of what understanding actions involves which do not demand knowledge of intentions? As before, it is helpful to start with a view about what actions are and then consider corresponding views about understanding actions. Instead of thinking of the relation between actions and the goals to which they are directed as determined by intentions representing those goals, we might instead attempt to explain the relation in terms of justification. This is the idea behind Gergely and Csibra's 'principle of rational action' which states that:

> 'an action can be explained by a goal state if, and only if, it is seen as the most justifiable action towards that goal state that is available within the constraints of reality' (Csibra and Gergely 1998: 255; cf. Csibra, Bíró, et al. 2003)

As part of an account of what actions are, this is unlikely to be correct. After all, agents sometimes fail to select actions that could be justified (or seen as justifiable) given the goal to which they are directed. Csibra et al. (2003, p. 123) themselves note this point. But the principle of rationality might serve as a useful approximation. Perhaps someone who applied the principle of rationality to work out which goals actions are directed to would be right much of the time. So perhaps infants' abilities to track actions involve understanding action in accordance with the principle of rationality. This view of action understanding requires less conceptual sophistication thanks to not requiring knowledge of intentions or other propositional attitudes as such. But it remains quite demanding, for it entails that one-year-olds are able to justify actions and engage in means end reasoning. Gergely and Csibra stress this aspect of their view:

> 'one-year-olds apply the same inferential principle of rational action that drives everyday mentalistic reasoning about inten-

> tional actions in adults' (Csibra & Gergely 1998, p. 259; compare Gergely & Csibra 2003, p. 290)

This is incompatible with the notion that infants' abilities to track action depend on core knowledge or modular representations. For, as we saw in topic 2 (on Objects), processes involving core knowledge are supposed to be informationally encapsulated; and informationally encapsulated processes cannot represent relations involving rationality or justification as such (Fodor 2000). To see whether it is even theoretically coherent to suppose that understanding action could involve core knowledge only, we must find alternative accounts of what it is to understand actions, accounts that involve neither intention nor rationality.

So far we have ignored the possibility that motor representations and processes play a role in understanding action. It is now well established that motor processes and representations are involved in observing actions—not only in producing them (Rizzolatti & Sinigaglia 2010). Furthermore, some motor representations represent outcomes to which actions are directed (Jeannerod 2006). For instance, observing another grasping a cup can involve a motor representation of the outcome, of the cup's being grasped, and not only motor representations of merely kinematic or dynamic features. Apparently, then, motor planning can be used in reverse: it can be used for inferring a goal from an observed action and not only for determining what to do in order to achieve a particular goal. We also know that, in adults and infants alike, motor representation can facilitate judgements about the goals of actions (on adults: Serino et al. 2009; Pazzaglia et al. 2008; on infants: Bekkering et al. 2000). It is possible, therefore, that infants can track actions not because they know about agent's intentions or consider the rationality of actions, but because their motor expertise enables them to determine to which goals others' actions could be directed. (This is surely not the whole story, but it can be extended to involve statistical learning as well as motor representation; see Paulus et al. (2011).) On this hypothesis, infants' abilities to track action do not involve understanding actions in the way that human adults do (or are standardly held to). For this reason the hypothesis might appear to make infants' abilities concerning action philosophically uninteresting. We can see that this appearance is mistaken by reflecting on how intentions (and other propositional attitudes) might refer to actions involving bodily movements. The considerations for the view that thought about objects depends on perceptual experience of them (see Campbell 2002) also support the view that all thought about actions ultimately depends on motor experience of them.

Topic 7. Beliefs

What is involved in representing belief? The following three claims are separately defensible but appear to be jointly inconsistent:

1. Infants can represent false beliefs from around their first birthday or earlier.

2. Being able to represent false beliefs involves being able to (i) process perspective differences or (ii) reason counterfactually (or both).

3. Infants cannot (i) process perspective differences nor (ii) engage in counterfactual reasoning until they are at least one year old.

This topic will first consider evidence and theoretical arguments in support of each claim in turn.

There is a growing body of evidence for (1). From around their first birthday infants predict actions of agents with false beliefs about the locations of objects (Onishi & Baillargeon 2005; Southgate et al. 2007) and choose different ways of interacting with others depending on whether their beliefs are true or false (Buttelmann et al. 2009; Knudsen & Liszkowski 2012; Southgate et al. 2010). And in much the way that irrelevant facts about the contents of others' beliefs modulate adult subjects' response times, such facts also affect how long 7-month-old infants look at some stimuli (Kovács et al. 2010). The variety of measures—looking time, anticipatory looking, pointing and helping—makes it hard to dismiss these findings on methodological grounds. So we cannot straightforwardly reject (1).

Why accept (2)? Part of the answer is theoretical. On any standard view, beliefs are propositional attitudes and are individuated (at least in part) by their causal and normative roles in explaining thoughts and actions (Davidson 1980, 1990). Representing states with these features arguably involves being able to process perspective differences and a core component of genuine counterfactual reasoning (Perner et al. 2007). Another part of the argument for accepting (2) is empirical. Until they are around four years of age, children systematically fail a wide range of false belief tasks. These tasks are very varied: most are verbal but some are nonverbal (Call & Tomasello 1999; Low 2010 Study 2), some involve prediction whereas others involve retrodiction or justification (e.g. Wimmer & Mayringer 1998), some concern the first-person perspective, whereas others involve a second- or third-person perspective (e.g. Gopnik & Slaughter 1991), some involve interaction whereas in others the subject is a mere observer (e.g. Chandler et al. 1989), and some involve predicting actions whereas others involve predicting desires (Astington & Gopnik 1991) or selecting an argument appropriate for someone with a false belief (Bartsch & London 2000). Despite all this variation and more, these false belief tasks all appear to measure a single developmental transition (Wellman et al. 2001), and that developmental transition is linked to developments in abilities to process perspective difficulties (Perner et al. 2002) and to reason counterfactually (Rafetseder et al. 2012). While some researchers have claimed that the developmental transition these false belief tasks measure is not a transition in understanding belief (e.g. Carpenter et al. 2002, p. 417, Bloom & Gelman 2000, and Leslie & Polizzi 1998), the wide variety of tasks used is evidence against such claims. So we cannot straightforwardly reject (2).

Can we reject (3), the claim that infants neither process perspective differences nor engage in counterfactual reasoning until they are at least one year old? One difficulty is that current developmental evidence almost uniformly supports this claim (Rafetseder et al. 2010; Beck & Guthrie 2011). A second problem is that the development of abilities to reason counterfactually, like the development of abilities to represent false belief, appears to involve working memory and inhibitory control (on counterfactuals: Drayton et al. 2011; Beck et al. 2011; on false beliefs: Apperly et al. 2008, 2009; Lin et al. 2010; McKinnon & Moscovitch 2007 experiments 4-5; Saxe et al. 2006). As even committed nativists are likely to agree, capacities for inhibitory control and working memory develop over several years and are limited in infants (e.g. Carlson 2005). So we cannot straightforwardly reject (3).

If each of the three claims (1)-(3) is true, they cannot be inconsistent after all. Can we avoid the apparent inconsistency by appealing to the distinction between core knowledge (or modular representation) and knowledge proper introduced in topic 2 (on Objects)? One objection to such an appeal concerns the flexibility of false belief understanding in infants. One-year-old infants succeed on false belief tasks which involve actively helping others, interpreting their utterances and pointing to provide information (Buttelmann et al. 2009; Knudsen & Liszkowski 2012; Southgate et al. 2010). By contrast, core knowledge is supposed to have only limited consequences for purposive action.

To the apparent inconsistency of (1)-(3) there are three main responses. One is to reject (1) (e.g. Perner & Ruffman 2005), another is to reject (2), and a third is to argue that the inconsistency is only apparent by appeal to a distinction such as that between core knowledge and knowledge proper (e.g. Clements & Perner 1994; Low 2010). We have seen objections to each of these responses. This indicates that we do not adequately understand what is involved in representing beliefs and, more generally, what it is to have knowledge of minds.

Conclusion

Are we closer to understanding how humans come to know about objects, causes, words, numbers, colours, actions and minds? Maybe. We have seen that apparent inconsistencies in developmental findings concerning knowledge of objects (topic 2) and minds (topic 7) can be resolved by distinguishing kinds of knowledge. One challenge is to make such distinctions in ways that are both theoretically coherent and empirically motivated. In addressing this challenge we appealed to the notions of modularity and core knowledge and considered how, in particular cases (including objects, numbers, colours and actions), perceptual and motor representations and processes can realise core knowledge.

A second, related challenge arises from the hypothesis that social interaction enables the emergence in development of knowledge. For this hypothesis to be coherent, there must be forms of social interaction which do not already presuppose the knowledge whose emergence is to be explained. Existing accounts of social interaction apply only to those who already have knowledge of several domains, including objects, actions and minds. The challenge, then, is to characterise these simple forms of social interaction.

Distinguishing core knowledge from knowledge proper and characterising simple forms of social interaction yielded two key ingredients of developmental theories for some special cases, including numbers, colours, words and minds. We know that these theories advance our understanding of development because they lead to new objections to various philosophical views about nativism, language acquisition and the dependence of thought on language. Of course these theories will probably turn out to be wrong. What seems secure, though, is the idea that explaining development requires distinguishing multiple kinds of knowledge, identifying simple forms of social interaction and understanding how these jointly enable development.

References

Apperly, I. A., Back, E., Samson, D., & France, L. (2008). The cost of thinking about false beliefs: Evidence from adults' performance on a non-inferential theory of mind task. *Cognition*, *106*(3), 1093–1108.

Apperly, I. A., Samson, D., & Humphreys, G. W. (2009). Studies of adults can inform accounts of theory of mind development. *Developmental Psychology*, *45*(1), 190–201.

Astington, J. & Gopnik, A. (1991). Developing understanding of desire and intention. In A. Whiten (Ed.), *Natural Theories of the Mind: evolution, de-*

velopment and simulation of everyday mindreading (pp. 39–50). Oxford: Blackwell.

Baillargeon, R. (1987). Object permanence in 3.5-and 4.5-month-old infants. *Developmental psychology*, *23*(5), 655–664.

Baillargeon, R., Scott, R. M., & He, Z. (2010). False-belief understanding in infants. *Trends in Cognitive Sciences*, *14*(3), 110–118.

Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition*, *20*(3), 191–208.

Baldwin, D. (1995). Understanding the link between joint attention and language. In C. Moore & D. Frye (Eds.), *Joint Attention : Its Origins and Role in Development*. Hove: Erlbaum.

Baldwin, D. (2000). Interpersonal understanding fuels knowledge acquisition. *Current Directions in Psychological Science*, *9*(2), 40–5.

Bartsch, K. & London, K. (2000). Children's use of mental state information in selecting persuasive arguments. *Developmental Psychology*, *36*(3), 352–365.

Beck, S. R., Carroll, D. J., Brunsdon, V. E., & Gryg, C. K. (2011). Supporting children's counterfactual thinking with alternative modes of responding. *Journal of Experimental Child Psychology*, *108*(1), 190–202.

Beck, S. R. & Guthrie, C. (2011). Almost thinking counterfactually: Children's understanding of close counterfactuals. *Child Development*, *82*(4), 1189–1198.

Bekkering, H., Wohlschlager, A., & Gattis, M. (2000). Imitation of gestures in children is goal-directed. *The Quarterly Journal of Experimental Psychology A*, *53*(1), 153–164.

Bloom, P. (2000). *How children learn the meanings of words*. Learning, development, and conceptual change. Cambridge, Mass. ; London: MIT Press.

Bloom, P. & Gelman, T. P. (2000). Two reasons to abandon the false belief task as a test of theory of mind. *Cognition*, *77*, B25–B31.

Bornstein, M., Kessen, W., & Weiskopf, S. (1976). Color vision and hue categorization in young human infants. *Journal of Experimental Psychology: Human Perception and Performance*, *2*(1), 115–129.

Bratman, M. E. (1987). *Intentions, Plans, and Practical Reasoning*. Cambridge, MA: Harvard University Press.

Buttelmann, D., Carpenter, M., & Tomasello, M. (2009). Eighteen-month-old infants show false belief understanding in an active helping paradigm. *Cognition*, *112*(2), 337–342.

Call, J. & Tomasello, M. (1999). A nonverbal false belief task: The performance of children and great apes. *Child Development*, *70*(2), 381–395.

Campanella, S., Quinet, P., Bruyer, R., Crommelinck, M., & Guerit, J. M. (2002). Categorical perception of happiness and fear facial expressions: An ERP study. *The Journal of Cognitive Neuroscience*, *14*(2), 210–227.

Campbell, J. (2002). *Reference and Consciousness.* Oxford: Oxford University Press.

Carey, S. (2009). *The Origin of Concepts.* Oxford: Oxford University Press.

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*(2), 595–616.

Carpenter, M., Akhtar, N., & Tomasello, M. (1998). Fourteen- through 18-month-old infants differentially imitate intentional and accidental actions. *Infant Behavior and Development*, *21*(2), 315–330.

Carpenter, M., Call, J., & Tomasello, M. (2002). A new false belief test for 36-month-olds. *British Journal of Developmental Psychology*, *20*, 393–420.

Chandler, M., Fritz, A., & Hala, S. (1989). Small scale deceit: Deception as a marker of two-, three-, and four-year-olds' early theories of mind. *Child Development*, *60*, 1263–1277.

Clark, E. V. (1993). *The Lexicon in Acquisition.* Cambridge: Cambridge University Press.

Clements, W. & Perner, J. (1994). Implicit understanding of belief. *Cognitive Development*, *9*, 377–395.

Csibra, G. (2003). Teleological and referential understanding of action in infancy. *Philosophical Transactions: Biological Sciences*, *358*(1431), 447–458.

Csibra, G., Bíró, S., Koós, O., & Gergely, G. (2003). One-year-old infants use teleological representations of actions productively. *Cognitive Science*, *27*(1), 111–133.

Csibra, G. & Gergely, G. (1998). The teleological origins of mentalistic action explanations: A developmental hypothesis. *Developmental Science*, *1*(2), 255–259.

Csibra, G. & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences*, *13*(4), 148–153.

Csibra, G. & Volein, Á. (2008). Infants can infer the presence of hidden objects from referential gaze information. *British Journal of Developmental Psychology*, *26*, 1–11.

Davidson, D. (1980). Towards a unified theory of meaning and action. *Grazer Philosophische Studien*, *11*, 1–12.

Davidson, D. (1990). The structure and content of truth. *The Journal of Philosophy*, *87*(6), 279–328.

Davidson, D. (1997). Seeing through language. In J. Preston (Ed.), *Thought and Language*, Royal Institute of Philosophy Supplement, vol. 42. Oxford: Oxford University Press.

Davidson, D. (1999). The emergence of thought. *Erkenntnis*, *51*, 7–17.

Davidson, D. (2001). *Subjective, Intersubjective, Objective*. Oxford: Clarendon Press.

Drayton, S., Turley-Ames, K. J., & Guajardo, N. R. (2011). Counterfactual thinking and false belief: The role of executive function. *Journal of Experimental Child Psychology*, *108*(3), 532–548.

Etcoff, N. L. & Magee, J. J. (1992). Categorical perception of facial expressions. *Cognition*, *44*(3), 227–40.

Feigenson, L. & Carey, S. (2003). Tracking individuals via object-files: evidence from infants' manual search. *Developmental Science*, *6*(5), 568–584.

Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core systems of number. *Trends in Cognitive Sciences*, *8*(7), 307–314.

Field, T. M., Woodson, R., Greenberg, R., & Cohen, D. (1982). Discrimination and imitation of facial expressions by neonates. *Science*, *218*(4568), 179–181.

Fodor, J. (1981). The present status of the innateness controversy. In *Representations*. Brighton: Harvester.

Fodor, J. (1983). *The Modularity of Mind: an Essay on Faculty Psychology*. Bradford book. Cambridge, Mass ; London: MIT Press.

Fodor, J. (2000). *The mind doesn't work that way : the scope and limits of computational psychology*. Representation and mind. Cambridge, Mass.: MIT Press.

Franklin, A., Catherwood, D., Alvarez, J., & Axelsson, E. (2010). Hemispheric asymmetries in categorical perception of orientation in infants and adults. *Neuropsychologia*, *48*(9), 2648–2657.

Franklin, A., Clifford, A., Williamson, E., & Davies, I. (2005). Color term knowledge does not affect categorical perception of color in toddlers. *Journal of Experimental Child Psychology*, *90*(2), 114–141.

Franklin, A., Pilling, M., & Davies, I. (2005). The nature of infant color categorization: Evidence from eye movements on a target detection task. *Journal of Experimental Child Psychology*, *91*(3), 227–248.

Gergely, G. & Csibra, G. (2003). Teleological reasoning in infancy: the naive theory of rational action. *Trends in Cognitive Sciences*, *7*(7), 287–292.

Gergely, G., Nadasky, Z., Csibra, G., & Biro, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*, 165–193.

Goldin-Meadow, S. (2003). *The resilience of language : what gesture creation in deaf children can tell us about how all children learn language*. Essays in developmental psychology. New York, N.Y.: Psychology Press.

Gopnik, A. & Slaughter, V. (1991). Young children's understanding of changes in their mental states. *Child Development*, *62*, 98–110.

Grice, P. (1957). Meaning. *The Philosophical Review*, *66*(3), 377–388.

Hare, B. & Tomasello, M. (2004). Chimpanzees are more skilful in competitive than in cooperative cognitive tasks. *Animal Behaviour*, *68*(3), 571–581.

Harnad, S. (1987). Psychophysical and cognitive aspects of categorical perception: A critical overview. In S. Harnad (Ed.), *Categorical Perception: The Groundwork of Cognition*. Cambridge: Cambridge University Press.

Hauser, M. D. & Carey, S. (2003). Spontaneous representations of small numbers of objects by rhesus macaques: Examinations of content and format. *Cognitive Psychology*, *47*(4), 367–401.

Hood, B., Carey, S., & Prasada, S. (2000). Predicting the outcomes of physical events: Two-year-olds fail to reveal knowledge of solidity and support. *Child Development*, *71*(6), 1540–1554.

Jeannerod, M. (2006). *Motor Cognition: What Actions Tell the Self*. Oxford: Oxford University Press.

Jusczyk, P. (1995). Language acquisition: Speech sounds and the beginning of phonology. In L. Miller, Joanne & P. D. Eimas (Eds.), *Speech, Language and Communication*. San Diego: Academic Press.

Kay, P. & Regier, T. (2003). Resolving the question of color naming universals. *Proceedings of the National Academy of Sciences*, *100*(15), 9085–9089.

Kay, P. & Regier, T. (2006). Language, thought and color: recent developments. *Trends in Cognitive Sciences*, *10*(2), 51–54.

Kegl, J., Senghas, A., & Coppola, M. (1999). Creation through contact: Sign language emergence and sign language change in nicaragua. In M. DeGraff (Ed.), *Language creation and language change: Creolization, diachrony, and development*. Cambridge, Mass.: MIT Press.

Knudsen, B. & Liszkowski, U. (2012). 18-Month-Olds predict specific action mistakes through attribution of false belief, not ignorance, and intervene accordingly. *Infancy*, *17*, 672–691.

Kotsoni, E., Haan, M. d., & Johnson, M. H. (2001). Categorical perception of facial expressions by 7-month-old infants. *Perception*, *30*(9), 1115–1125.

Kovács, Á. M., Téglás, E., & Endress, A. D. (2010). The social sense: Susceptibility to others' beliefs in human infants and adults. *Science*, *330*(6012), 1830 –1834.

Kowalski, K. & Zimiles, H. (2006). The relation between children's conceptual functioning with color and color term acquisition. *Journal of Experimental Child Psychology*, *94*, 301–321.

Kuhl, P. K. (1987). The special-mechanisms debate in speech research: Categorization tests on animals and infants. In S. Harnad (Ed.), *Categorical Perception: The Groundwork of Cognition*. Cambridge: Cambridge University Press.

Kuhl, P. K. (2004). Early language acquisition: cracking the speech code. *Nature Reviews: Neuroscience*, *5*(11), 831–843.

Leslie, A. M. & Polizzi, P. (1998). Inhibitory processing in the false belief task: Two conjectures. *Developmental Science*, *1*(2), 247–253.

Lin, S., Keysar, B., & Epley, N. (2010). Reflexively mindblind: Using theory of mind to interpret behavior requires effortful attention. *Journal of Experimental Social Psychology*, *46*(3), 551–556.

Liszkowski, U., Carpenter, M., Striano, T., & Tomasello, M. (2006). Twelve- and 18-month-olds point to provide information for others. *Journal of Cognition and Development*, *7*(2), 173–187.

Liszkowski, U., Carpenter, M., & Tomasello, M. (2008). Twelve-month-olds communicate helpfully and appropriately for knowledgeable and ignorant partners. *Cognition*, *108*(3), 732–739.

Low, J. (2010). Preschoolers' implicit and explicit False-Belief understanding: Relations with complex syntactical mastery. *Child Development*, *81*(2), 597–615.

McKinnon, M. C. & Moscovitch, M. (2007). Domain-general contributions to social reasoning: Theory of mind and deontic reasoning re-explored. *Cognition*, *102*(2), 179–218.

Meltzoff, A. (2007). 'like me': a foundation for social cognition. *Developmental Science*, *10*(1), 126–134.

Meltzoff, A. & Moore, M. K. (1998). Object representation, identity, and the paradox of early permanence: Steps toward a new framework. *Infant Behavior and Development*, *21*(2), 201–235.

Meltzoff, A. N. & Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. *Science*, *198*(4312), 75–78.

Meltzoff, A. N. & Moore, M. K. (1983). Newborn infants imitate adult facial gestures. *Child Development*, *54*(3), 702–709. ArticleType: research-article / Full publication date: Jun., 1983 / Copyright © 1983 Society for Research in Child Development.

Moll, H. & Tomasello, M. (2007). Cooperation and human cognition: the vygotskian intelligence hypothesis. *Philosophical Transactions of the Royal Society B*, *362*(1480), 639–648.

Moore, M. K. & Meltzoff, A. N. (2008). Factors affecting infants' manual search for occluded objects and the genesis of object permanence. *Infant Behavior and Development*, *31*(2), 168–180.

Onishi, K. H. & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science*, *308*(8), 255–258.

Ozgen, E. & Davies, I. (2002). Acquisition of categorical color perception: a perceptual learning approach to the linguistic relativity hypothesis. *Journal of experimental psychology. General*, *131*(4), 477–493.

Paulus, M., Hunnius, S., van Wijngaarden, C., Vrins, S., van Rooij, I., & Bekkering, H. (2011). The role of frequency information and teleological reasoning in infants' and adults' action prediction. *Developmental Psychology*, *47*(4), 976–983.

Pazzaglia, M., Pizzamiglio, L., Pes, E., & Aglioti, S. M. (2008). The sound of actions in apraxia. *Current Biology*, *18*(22), 1766–1772.

Perner, J., Rendl, B., & Garnham, A. (2007). Objects of desire, thought, and reality: Problems of anchoring discourse referents in development. *Mind & Language*, *22*(5), 475–513.

Perner, J. & Ruffman, T. (2005). Infant's insight into the mind: How deep? *Science*, *308*, 214–6.

Perner, J., Stummer, S., Sprung, M., & Doherty, M. (2002). Theory of mind finds its piagetian perspective: why alternative naming comes with understanding belief. *Cognitive Development*, *17*(3-4), 1451–1472.

Pitchford, N. J. & Mullen, K. T. (2005). The role of perception, language, and preference in the developmental acquisition of basic color terms. *Journal of Experimental Child Psychology*, *90*(4), 275–302.

Rafetseder, E., Cristi-Vargas, R., & Perner, J. (2010). Counterfactual reasoning: Developing a sense of "Nearest possible world". *Child Development*, *81*(1), 376–389.

Rafetseder, E., Hofer, C., Ecker, S., & Perner, J. (2012). Counterfactual reasoning and reasoning with beliefs: Similar steps or separate paths? *submitted*.

Rizzolatti, G. & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nature Reviews: Neuroscience*, *11*(4), 264–274.

Roberson, D. & Hanley, J. R. (2007). Color vision: Color categories vary with language after all. *Current Biology*, *17*(15), R605–R607.

Russell, B. (1921). *The Analysis of Mind*. www.blackmask.com: Muirhead Library Of Philosophy / electronic edition by Blackmask Online.

Sabbagh, M. & Baldwin, D. (2001). Learning words from knowledgeable versus ignorant speakers: Links between preschoolers' theory of mind and semantic development. *Child Development*, *72*(4), 1054–1070.

Saffran, J. R., Newport, E. L., & Aslin, R. N. (1996). Statistical learning by 8-month-old infants. *Science*, *274*(5294), 1926–8.

Sandhofer, C. M. & Smith, L. B. (1999). Learning color words involves learning a system of mappings. *Developmental Psychology*, *35*(3), 668–79.

Sandhofer, C. M. & Thom, E. E. (2006). Taking the task seriously: Reflections on measures of color acquisition. *Journal of Experimental Child Psychology*, *94*(4), 344–348.

Saxe, R., Schulz, L. E., & Jiang, Y. V. (2006). Reading minds versus following rules: dissociating theory of mind and executive control in the brain. *Social Neuroscience*, *1*(3-4), 284–298.

Senghas, A. & Coppola, M. (2001). Children creating language: How nicaraguan sign language acquired a spatial grammar. *Psychological Science*, *12*(4), 323–328.

Serino, A., De Filippo, L., Casavecchia, C., Coccia, M., Shiffrar, M., & Làdavas, E. (2009). Lesions to the motor system affect action perception. *Journal of Cognitive Neuroscience*, *22*(3), 413–426.

Shinskey, J. & Munakata, Y. (2001). Detecting transparent barriers: clear evidence against the means-end deficit account of search failures. *Infancy*, *2*(3), 395–404.

Soja, N. N. (1994). Young children's concept of color and its relation to the acquisition of color words. *Child Development*, *65*(3), 918–937.

Southgate, V., Chevallier, C., & Csibra, G. (2010). Seventeen-month-olds appeal to false beliefs to interpret others' referential communication. *Developmental Science*, *13*(6), 907–912.

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by two-year-olds. *Psychological Science*, *18*(7), 587–592.

Spelke, E. (1990). Principles of object perception. *Cognitive Science*, *14*, 29–56.

Spelke, E. & Kinzler, K. D. (2007). Core knowledge. *Developmental Science*, *10*(1), 89–96.

Starkey, P. & Cooper, R. G. (1980). Perception of numbers by human infants. *Science*, *210*(4473), 1033–1035.

Tomasello, M. (2008). *Origins of human communication*. The MIT Press.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, *28*, 675–735.

Tomasello, M. & Rakoczy, H. (2003). What makes human cognition unique? from individual to shared to collective intentionality. *Mind and Language*, *18*(2), 121–147.

Wellman, H., Cross, D., & Watson, J. (2001). Meta-analysis of theory of mind development: The truth about false-belief. *Child Development*, *72*(3), 655–684.

Wilcox, T., Woods, R., & Chapa, C. (2008). Color-function categories that prime infants to use color information in an object individuation task. *Cognitive Psychology*, *57*(3), 220–261.

Wimmer, H. & Mayringer, H. (1998). False belief understanding in young children: Explanations do not develop before predictions. *International Journal of Behavioral Development*, *22*(2), 403–422.

Winawer, J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(19), 7780–5.

Wittgenstein, L. (1972). *The Blue and Brown books* (2nd ed.). Oxford: Blackwell.

Woodward, A. L. & Sommerville, J. A. (2000). Twelve-month-old infants interpret action in context. *Psychological Science*, *11*(1), 73–77.

Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, *358*(6389), 749–750.

Wynn, K. (1996). Infants' individuation and enumeration of actions. *Psychological Science*, *7*(3), 164–169.

Xu, F. & Spelke, E. S. (2000). Large number discrimination in 6-month-old infants. *Cognition*, *74*(1), B1–B11.