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ARTICLE WITH PEER COMMENTARIES AND RESPONSE

How do children ape? Applying concepts from the study of non-human primates to the developmental study of 'imitation' in children

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Abstract

We highlight two aspects of research into social learning that have been neglected in existing developmental research, namely: (1) The role of social learning in learning to use tools, and (2) Whether children's social learning involves copying the actions themselves ('blind' imitation or mimicry), or alternatively, the effects of those actions (emulation). In Part I of the paper we argue that the failure to distinguish between these different mechanisms is closely related to the lack of research on the social transmission of tool use and that both omissions limit our understanding of early social learning. We conclude Part I by outlining the requirements for an adequate study of these two issues. In Part II, we use this analysis to critically examine data from existing developmental research with children. We also assess the data currently available in the comparative literature which address these issues more directly. We conclude that children learn only what actions to perform via observation ('blind' imitation or mimicry), and not why those actions are effective (emulation). We close by identifying important potential pitfalls and unresolved questions for the future study of the social learning of actions on objects.

Introduction

The developmental study of imitation has a long history (Guillaume, 1926/1971; Piaget, 1951/1967). In the course of that history, experimental studies of imitation have shown that observing adults is an especially powerful way of learning for children, and that the cognitive basis for imitative learning may well be present at birth (Meltzoff & Moore, 1977, 1983, 1989, 1994). Alongside its obvious utility in learning to communicate (via the reproduction of gestures and speech) imitation has been shown to be rewarding for, and to increase interaction between, the imitator and the imitated (Fouts, Waldner & Watson, 1976; Grusec & Abramovitch, 1982). Finally, imitation has been shown to be useful in learning to interact with a sizeable number of different types of object (Abravanel & Gingold, 1985; Abravanel, Levan-Goldschmidt & Stevenson, 1976; Barr, Dowden & Hayne, 1996; Meltzoff, 1988a, 1988b, 1995).

However, despite this mass of research, one aspect of social learning has been given surprisingly little attention in developmental psychology. During the past 80 or so years, little consideration has been given to how children might learn to use tools from watching other people. This is a puzzling omission from the developmental literature, especially given the long-standing importance of the social learning of tool use in the literature on non-human primates (see, for example, White, 1942). Fierce debate currently rages over the existence of unique behavioural traditions among different groups of primates (and the extent to which these indicate the existence of different primate 'cultures') and most of the relevant arguments hinge upon data about the transmission of tool use between individuals via social learning (Tomasello, 1996; Whiten, 1998; Whiten, Goodall, McGrew, Nishida, Reynolds, Sugiyama, Tutin, Wrangham & Boesch, 1999). Developmental psychology, on the other hand, has almost completely neglected the social learning of tool use (which typically involves learning the use of one object

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in conjunction with another) in human children. Instead, developmental studies have focused mainly on the imitation of facial and manual gestures (most famously, tongue protrusion), or simple actions on objects (such as pushing a button on a box).

Partly as a result of this restricted focus, developmental psychology has missed out on an important transformation in research on social learning that has taken place within comparative psychology. In recent years traditional assumptions about the extent of imitation in the animal kingdom have been overthrown. Key to this revolution has been the recognition and subsequent explication of a number of non-imitative processes of social learning. What was once thought to have been the result of imitation, is now variously described as the result of local enhancement, stimulus enhancement, mimicry or emulation, rather than imitation. Most of these mechanisms were identified and developed from work into the social learning of object manipulation and tool use, and many of the distinctions among them have yet to filter through to developmental psychology. This has resulted in a discrepancy between comparative and developmental psychology. In work with non-human primates (and other non-human species), similarity between the behaviour of two individuals is never described as imitation until a considerable array of other processes has been ruled out. In contrast, in studies of social learning in humans, any and all similarity between the actions of an observer and a model is often attributed to imitation without much further analysis. Thus, while developmental psychology has been very good at mapping out children's proclivity to replicate the actions of others, it has often said little about how they do so.

In sum, developmental psychology's current analysis of imitation is restricted in two respects: (1) It does not consider the role that social learning may play in helping children to learn about tools, and (2) It does not distinguish among some of the important mechanisms of social learning found in the literature regarding non-human animals.

In Part I of this paper, we aim to build a conceptual framework for looking at the social learning of tool use in human children. A major goal is to differentiate the key mechanisms of social learning described in the literature on non-human primate social learning and to clarify why they have been neglected within developmental psychology. In Part II of this paper, we use this framework to review the limited evidence that currently exists within the developmental literature on the social learning of tool use. We conclude by identifying interesting questions relating to the social learning of tool use that have yet to be considered by developmental psychologists.

Part I: A conceptual framework for looking at 'imitation' in children

In building our conceptual framework, we first distinguish among five key forms of social learning and then examine their application to three different types of modelled action that have been examined in studies of social learning. In doing so, we elaborate on the idea that at least part of the reason for developmental psychology's neglect of some forms of social learning is that these forms are especially relevant to the social learning of tool use. We complete our framework by outlining the conditions that must be satisfied for a well-controlled study of the social learning of tool use. These desiderata serve to guide the review of the existing developmental literature in Part II.

Five types of social learning

There is a plethora of terms used within research on animal social learning that are not in common parlance within developmental psychology. Moreover, the definitions of these terms are controversial in some cases. We focus here on only the most well-defined and conceptually important processes, as illustrated by an example, namely, chimpanzee 'termite fishing' (Suzuki, Kuroda & Nishihara, 1995). In one variety of termite fishing (of which there are several), a chimpanzee inserts a stout stick (the perforating stick) into a termite mound. In the hole created by the perforating stick, the chimpanzee inserts a softer, more flexible stick with a brush-like end (the fishing probe). The termites inside the mound attack the chimpanzee's intruding probe, at which point the chimpanzee withdraws it and eats the termites from it. For the purposes of our example, let us imagine that one chimpanzee observes another chimpanzee fishing for termites and then subsequently 'fishes' for termites. What mechanisms might theoretically underlie this case of social learning?

One fairly simple process, *local enhancement* (Thorpe, 1956/1963), refers to an increase in interest in the particular location at which one individual has seen another performing some action. If local enhancement were responsible for the learning in our example, the observing chimpanzee would have had its interest in the general area of the termite mound enhanced by witnessing the other chimpanzee's activity in that locale. The observing chimpanzee would then have been motivated to approach the mound and subsequently discovered, independently of the other chimpanzee, that the nearby sticks could be used to draw termites from the mound. *Stimulus enhancement* (Spence, 1937) refers to a similar process, but one which takes an object (which in our termite-fishing

example would be one or both of the sticks), rather than a location, as the focus of increased interest. In both these cases, all the observer has learnt is that there is something of interest somewhere in the environment. The observer has then worked out, via individual learning, how to obtain the desired goal.

Emulation learning (Tomasello, 1990) is a term that has come to mean different things to different researchers, but in its original sense, involves learning about the properties of, or causal relations between, objects (rather than just about their presence in the environment). In its intended formulation (see Tomasello, 1998) emulation learning is a process whereby an observer learns such things as the length of objects, their solidity, and so forth. In our chimpanzee example, the observer would learn that the perforating stick is long and rigid and thus able to push its way into the termite mound. The observer might also learn that the termites attach themselves to material that enters their mound. The observing chimpanzee would then piece together these 'affordances' and realize that sticks – or indeed any rigid instrument – could be used to extract termites. Note that, with emulation learning (whether of object properties or causal relations), attention is not paid to the specific actions of the model, but rather to the displacements and effects of the various objects involved. The observer is not concerned with copying the model's actions precisely, nor even the goal of the model, but adopts his or her own strategy (which may coincidentally take the same form as that which was observed) on the basis of the information gained from observing the sticks enter the termite mound.

Stemming from an alternative interpretation of Tomasello's original definition of emulation, Whiten and Ham (1992) identified what is now recognized as a separate form of social learning in its own right, namely, *goal emulation*. In goal emulation, an observer learns simply that a particular goal can be achieved (in our example, that termites can be retrieved from the mound), and sets about achieving that goal by its own means (perhaps by smashing down the mound). Again, the specific actions performed by the model are not learnt. Byrne and Russon (1998) have described goal emulation as akin to stimulus and local enhancement, in that it indicates only the presence of something (in this case, a potential goal) in the environment.

In contrast to these processes, mimicry and imitation involve learning about the specific actions of the model (rather than just about the objects or goals involved in those actions). *Mimicry* (Tomasello, Kruger & Ratner, 1993) is defined as the replication of a model's actions in the absence of any insight into why those actions are effective, or even what goal they served. In the case of our example, the chimpanzee observing the successful termite fishing of its conspecific might copy the sequence of actions witnessed (insertion of the perforating stick and then the fishing probe into the mound) but, not recognizing the goal of the original actions, do so into an ordinary mound of earth instead of a termite mound.

Imitation (Tomasello, 1990), in contrast, involves the recognition and reproduction of the goal of the observed behaviour, as well as the specific actions that brought about that goal. In our example, for the observing chimpanzee to be said to be imitating, he or she must have recognized that the model held a goal with respect to the mound (i.e. to obtain and eat the termites from it) and that the manipulations of the sticks were designed to fulfil that goal. The observing chimpanzee would then know that, when he or she desired that same goal, one way to achieve it would be to copy the actions of the model. The observing chimpanzee may not necessarily learn exactly by what process the manipulations of the termite-fishing chimpanzee led to the availability of the termites. In other words, the observing chimpanzee might learn to produce the manipulations of the termite-fishing chimpanzee, but not why they were effective. The extent to which learning of affordances (as happens in emulation) is involved in imitation is currently a matter of debate (see discussion in Want & Harris, 2001), but in principle, it need not be involved at all. Thus, an imitator might replicate both the form and the goal of an observed behaviour but fail to understand the affordances of the objects involved in that behaviour or the link between the actions and the goal they subserve, in effect becoming a *blind imitator*. For now, we restrict ourselves to the definition of imitation in this 'blind' sense, in order to maintain conceptual distance from emulation. However, during our review of the literature, we will be mindful that we are defining imitation in a restrictive fashion. It is possible that children learn imitatively and also learn about affordances (in effect, learning what to do, why they are doing it, and how it works). Thus, we may need to admit another form of social learning, which we might call, *insightful imitation*.

The above definitions illustrate just some of the most important ways in which the observation of a model may affect the subsequent performance of an observer. We have chosen to highlight these particular mechanisms because they provide a reasonable taxonomy of what can be learnt from observation (and are those that have the most support from literature on non-human social learning). At its simplest, social learning may involve an observer being attracted to an object (*stimulus enhancement*) or the location in which the model acted (*local enhancement*). Alternatively, an observer may learn one of three components of behaviour in isolation from the other two: (1) the specific actions of the model (*mimicry*),

(2) what those actions reveal about the objects and affordances involved (*emulation*), or (3) what goal the model was attempting to achieve (*goal emulation*). Finally, an observer might learn both components (1) and (3) but not (2) (*blind imitation*), or all three components (*insightful imitation*).

An important point to note is that the diagnosis of each of these types of social learning critically depends on isolating the knowledge that an observer brings to the episode of social learning. Before any social learning takes place the potential observer may already: (1) have carried out similar actions to those of the model, (2) have knowledge of any object affordances involved in the model's actions and/or (3) share a similar goal to the model. In this case, when finding evidence of these elements in post-demonstration behaviour, we cannot say these elements have been acquired from the observation of the model's action. We return to this issue when outlining the requirements for an adequate study of the mechanism of social learning in children.

Three types of action

In research on social learning, three distinct categories of action have typically been modelled: (1) bodily movements, both facial and manual (e.g. hand-waving or tongue protrusion); (2) simple actions on objects (e.g. pushing a button on a box, or shaking an object); and (3) complex actions[1] on objects, including, but not limited to, tool use (e.g. termite fishing as described above). With the increasing complexity of these actions (as we move from Categories 1 to 3) there is a concomitant increase in the number of mechanisms of social learning that could underlie replication of each type of action.

In looking for the replication of facial and manual gestures (Category 1) there are few mechanisms of social learning to consider. Take, for example, the replication of tongue protrusion. In such an act there are no external locations or objects to which attention can be drawn and hence the two varieties of enhancement (local and stimulus) cannot operate. The absence of objects also precludes learning by emulation: with no objects involved there are no object affordances to be learnt. In the framework we have outlined, the only mechanisms that could be responsible for an act of gesture replication are imitation, mimicry and goal emulation. Indeed, it could be argued that for such simple gestures, which have no effect on the environment, the distinction between action and goal cannot be made. If the observer does not recognize and copy a distinctive goal on the part of the model (but nevertheless reproduces the model's actions) he or she is best seen as a mimic.[2]

Once we look at the replication of actions involving objects (Categories 2 and 3) we open up the possibility that when an individual copies an action with an object, they do so simply because they have become more interested in the object we manipulated (stimulus enhancement) or the setting in which it was manipulated (local enhancement). Additionally, rather than copying the action *per se*, they may well have noted our goal, or some key affordance of the object during the action and then conducted their own exploration of that goal (goal emulation) or object affordance (emulation), coincidentally replicating the form of our action.

Although some researchers (most notably, Meltzoff, 1988a, 1988b) have included careful controls to rule out local and stimulus enhancement, research on the social learning of human children has not systematically distinguished between imitation and emulation (either goal or 'regular' emulation). As we can now see, this is understandable in the case of studies of gestural replication. Emulation is simply not an option for an individual faced with replicating gestures. However, emulation learning is a potential explanation for any act that involves learning how to act upon objects.

It seems likely that developmental psychologists have neglected the key distinction between imitation and emulation (and in many cases, neglected to consider local and stimulus enhancement) because they have mainly focused on simple rather than complex actions on objects (i.e. Category 2 as opposed to Category 3). In the case of simple actions (e.g. stacking one box on another) it is conceivable that children are learning new properties of the objects via emulation (e.g. that the boxes can be balanced upon one another because of their particular shape), but it seems more likely that children already understand the relevant affordances. Perhaps justifiably then, emulation learning has not routinely been considered as an explanation for children's learning. Nevertheless, even in such studies, most researchers have also neglected to consider whether the actions are best described as imitation or mimicry.

To distinguish between imitation, mimicry and the two types of emulation, one must independently assess whether the observer has learnt the means and/or the goal of the actions witnessed. When only simple actions

[1] We define complex actions (along the lines of Abravanel & Gingold, 1985) as 'reiterative or sequentially co-ordinated actions'.

[2] Note that, with such simple bodily actions, it is even possible that replication is more reflexive (like a contagious yawn) than voluntary. Although recent work seems to show that neonatal gestural copying is not simply reflexive (Meltzoff & Moore, 1994), it is still an open question (but not the focus of this review) as to whether very young children's acts of replication are mediated by goals (see Gattis, Bekkering & Wohlschläger (in press) for a discussion of this issue).

are demonstrated, the means and the goal are not easily distinguished. There is often only one means to the desired goal and little room for variation in the manner in which those means are enacted. In acts of tool use, however, the goal of the observed action is, for example, the retrieval of a desired object. Therefore, the means (the use of a tool) can be viewed separately from that goal and mimicry, emulation, goal emulation and imitation can be teased apart.

Emulation versus 'blind' imitation

In this section, we expand on the distinction between emulation and 'blind' imitation, a distinction that is especially pertinent to the use of tools. These two forms of social learning are useful in different circumstances and, in terms of what an observer learns from a model, the two processes may be thought of as complementary. While a 'blind' imitator learns to perform actions for a specific goal, but does not learn the affordances involved in those actions, an emulator learns the affordances involved, but not the actions or the goal. Intuitively, emulation offers a highly flexible form of knowledge. It is the kind of learning that results in the knowledge that, for example, it is the sharp blade that affords a knife the ability to cut, the hollow interior that affords a glass the ability to contain and the length that allows a stick to be used to contact an out-of-reach object. Knowing why some objects are useful and effective (and some are not) allows you to find or fashion other objects to fulfil the same role as the original object (by seeking out or creating objects with the same affordance/s) and to use the original object for novel purposes (by recognizing that the object affords many actions).

However, it is not always the case that one must understand why an action is effective in order to carry it out. While it may appear to be so for actions carried out with relatively simple objects, such as sticks, knives or containers (in that, at least among adult humans, those who use them usually know why they are effective), the same is not true of more complicated objects, such as computers or cars. For example, in order to use a car key effectively, one does not need to know how it works. The workings of a car engine are non-obvious and are not usually accessible to the person who is attempting to drive the car. It may require less cognitive effort to rely on the replication of the simple strategy required to make use of the key, which can be brought about by imitation. There is therefore a trade-off here, in that emulation learning may take more effort than learning by imitation, yet it also provides more flexible knowledge about an action and its function than does imitation. Although imitation provides less flexible knowledge it permits learning even when opportunities to witness an action's effects are limited or non-existent. Hence, either imitation or emulation may have a privileged role to play in transmitting knowledge and they may be useful in different situations.

The distinction between 'blind' imitation and emulation has been given some intriguing support in recent work with apraxic patients. Goldenberg and Hagman (1998) have speculated that adults typically have two types of knowledge about how to use a tool. They make a distinction between a tool's 'instruction of use', which specifies the prototypical action associated with the tool, and the 'direct inference of function' gained from examining the properties of the tool. The first of these types of knowledge is akin to what would be acquired by a 'blind' imitator. It is the knowledge of what action to take with the tool, in order to fulfil its primary, or most usual, function. The second type of knowledge is the kind of information that emulation would provide. It is the knowledge of how the tool works, based on its particular properties. While Goldenberg and Hagman suggest that 'normal' adults have both of these types of knowledge, they found a double dissociation between these two types of knowledge in some of their apraxic patients. Some of their patients could correctly select an appropriately shaped novel tool to enable them to pick up a cylindrical object, demonstrating the ability to infer function from form. However, they could not pantomime the prototypical use of various named (and briefly shown) tools, showing that they lacked the 'instructions for use' for those tools. On the other hand, there were also other patients who demonstrated the reverse pattern of impairments. Finally, some patients could do neither type of task, demonstrating that they had neither type of knowledge about tools.

Only those of Goldenberg and Hagman's patients who had at least one type of knowledge were able to successfully use a variety of familiar tools. Those patients who had neither type of knowledge frequently used tools incorrectly. By implication, 'normal' people possess knowledge such as would be gained by both 'blind' imitation and emulation. In addition, the two types of knowledge can exist independently of each other, and each type of knowledge alone is sufficient to enable the use of tools. There is therefore evidence to justify a theoretical distinction between 'blind' imitation and emulation. The distinction has also proved to be productive, albeit controversial, in recent work with great apes.[3] Researchers have been divided into two camps. Accumulating evid-

[3] In primate work, the recent focus in work on social learning and tool use has been on the great apes because monkeys only minimally use tools and also, contrary to popular conception, seem not to be particularly good at learning from each other (Galef, 1996; Lefebvre, 1995; Visalberghi & Fragaszy, 1996).

ence leads some to claim that the great apes are primarily emulative, learning only about objects and their properties (Call & Tomasello, 1995; Heyes, 1998; Nagell, Olguin & Tomasello, 1993; Tomasello, Davis-Dasilva, Camak & Bard, 1987; Tomasello *et al.*, 1993), whereas others claim they are imitative, learning about the form of behaviour, rather than about objects (Custance, 1998; Whiten, 1998; Whiten, Custance, Gomez, Teixidor & Bard, 1996). Notwithstanding the current lack of consensus, the distinction between 'blind' imitation and emulation has proved stimulating to both the theory and the practice of research into non-human primate social learning. Below we consider how the distinction between imitation and emulation can be made with respect to children's tool use.

How to study the social learning of tool use

The aim of this next section is to specify the requirements for a well-controlled study of the particular mechanisms of social learning involved in actions on objects. These specifications will help to guide our review of what little literature speaks to this issue.

A first priority is to ensure that we are studying social *learning*. As previously stated, whatever type of task is used, it is important to assess the child's pre-existing: (1) repertoire of action on the task, (2) knowledge of the task and the objects involved in it and (3) goal with respect to the task. One way to circumvent the problem of making this assessment is to present children with a task which is totally novel to them, in terms of action, affordances and goals. However, presenting a completely novel task may preclude certain types of learning. In particular, emulation learning of causal relations may be impossible when faced with a completely novel task. Consider, for example, a child learning to solve the 'trap-tube' task (Visalberghi & Limongelli, 1996), illustrated in Figure 1. In this task, the child must use a stick to push a desired object (a toy) out from inside a narrow tube. In doing so, the child must take care to select the correct side of the tube for insertion, lest s/he push the toy into a 'trap' located within the tube and lose it.

Consider a child who knows very well the basic affordances of the tool in this task (namely the stick) – s/he knows that it is long, narrow and rigid. This child may go on to realize, subsequent to a demonstration of the task's solution, that objects with these properties may be inserted into the apparatus (by virtue of their shape) and can push other objects along (by virtue of their rigidity) and that they do so in the direction in which they are pushed. This child has realized that certain properties of the stick are causally related to the outcomes it can produce.

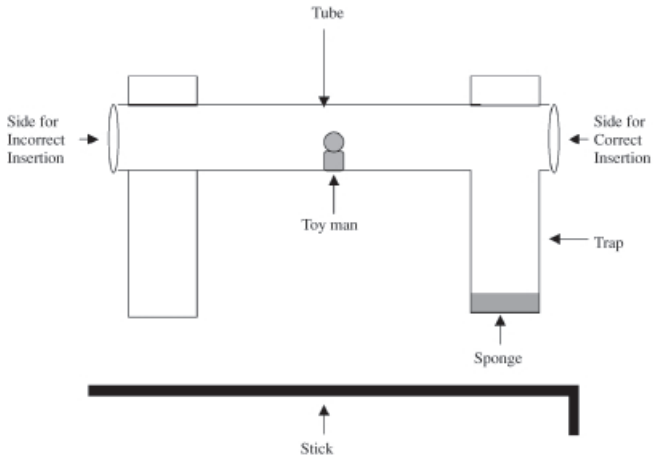

Figure 1 *Illustration of the trap-tube apparatus, showing the location of the toy, the trap and the side for correct or incorrect insertion.*
From Want & Harris (2001), reprinted with the permission of Blackwell Publishers.

Consider, by contrast, a child who does not yet know the basic properties of the stick (its length, width and rigidity). Having witnessed the solution to the trap-tube task, even if the child can, in principle, learn causal relationships via observation, his/her lack of knowledge of the properties of the stick may preclude this. The child might first have to be in possession of knowledge about the properties of the stick before 'higher-level' information about causal relations can be acquired from observation. In such a circumstance, this child may be forced to imitate. Without an understanding of the basics of how the stick works, the child may be able to make only limited sense of the demonstration. An impoverished understanding of the relevant affordances may leave children with the option of either blindly imitating every aspect of the demonstration (both functional and non-functional elements) or imitating the general strategy used. This analysis suggests that the type of learning children engage in will critically depend on their prior knowledge. Therefore, the importance of establishing what children know about a task before it is administered cannot be understated, neither can the use of a variety of tasks (about which children have varying degrees of knowledge) in assessing social learning.

An obvious second consideration is to think about ways to separate out the various types of social learning. If we are primarily interested in looking at the 'higher-level' processes of imitation and emulation then we need to rule out local and/or stimulus enhancement as potential explanations. This can be done in two ways. The first method is to include a control condition in which a model manipulates the experimental apparatus in a

non-informative way which does not serve any apparent goal (the manipulation control). If the process at work in the social learning of young children were something as simple as local or stimulus enhancement (an increase in interest caused simply by the presence of another at a location or acting with an object), then this demonstration should be as effective as any other. In addition, this demonstration may help to detect mimicry. If an observer is learning by mimicry (which is blind to the goals behind actions), then s/he should be just as likely to replicate the actions shown in this meaningless demonstration as the actions in any demonstration which uses the object in a goal-directed manner.

A second method of ruling out local and stimulus enhancement, the so-called two-action method (Dawson & Foss, 1965), involves the same result being produced in one of two different ways with the same object. If the observer copies the method used by the demonstrator in preference to the alternative method, then local or stimulus enhancement cannot be the only processes of social learning operating because these processes involve only increased interest in the immediate stimulus environment and do not involve learning about specific actions or events.

In order to distinguish between imitation and emulation, we need to assess children's social learning on relatively complex tasks. Because both imitation and emulation frequently result in the same actions being produced, it is often difficult to determine which of them is responsible for social learning, especially when very simple actions are being produced. As we have already discussed (see p. 5), tool-using tasks will be especially useful in overcoming this problem.

Part II: A review of the literature on social learning

Having laid out the conceptual framework, we review the existing literature to determine what can currently be said about the way in which children learn actions on objects from watching other people. Granted their relevance for the distinction between different types of social learning, we focus on Categories 2 and 3 as defined earlier

The social learning of actions on objects (Category 2)

There have been many developmental studies on social learning that have examined actions on objects (Abravanel & Gingold, 1985; Abravanel *et al.*, 1976; Barr *et al.*, 1996; Killen & Uzgiris, 1981; Meltzoff, 1988a, 1988b). These studies have shown that, by around 12 months of age, children are able to replicate simple actions on objects (e.g. shaking or touching objects). However, although useful in determining when children can replicate different types of action, these studies typically fail to pinpoint the type of social learning involved, for two reasons stated earlier (see p. 4). They either involve (1) simple actions so that imitation, mimicry and emulation cannot be teased apart, or (2) actions on familiar objects, whose affordances children are likely to understand before they enter the experiment (thus reducing the potential contribution of emulation learning).

While most developmental studies have not been systematically concerned with the distinctions between imitation, mimicry and the two forms of emulation, some clues have emerged as to which best characterizes children's social learning. A small number of studies have shown that children tend to replicate irrelevant or non-functional actions with objects when reproducing a causally related sequence of actions (Bauer & Mandler, 1989; Harnick, 1978; Sibulkin & Uzgiris, 1978). For instance, Harnick (1978) showed children how to remove nested cups from the top of an open tube and then drop a marble into the tube. While demonstrating this, Harnick also produced a variety of irrelevant actions (such as hand-waving and making nonsense noises), which the children also produced when copying the actions with the marble and tube. Copying the modelled actions, including those irrelevant to the production of the goal of the task, is something that would be expected of a 'blind' imitator or a mimic. In the absence of an understanding of how the actions brought about the result, the whole behaviour is recreated, rather than just those parts that are functional. These studies suggest that children (aged 14–28 months) can either 'blindly' imitate or mimic actions on objects.

Harnick (1978) and Sibulkin and Uzgiris (1978) also claim that when simpler actions are shown, children do not replicate the irrelevant actions. For example, when Harnick showed children how to drop the marble straight into the tube (the nested cups were removed prior to the apparatus being shown to the child) the children copied only that action and not the irrelevant ones. Copying only the functional actions of the model is something that would be expected on the basis of emulation (either goal or 'regular' emulation). However, neither study included a pre-test phase in which children's ability to solve the tasks independently of the demonstrations was assessed. Thus, children may not have replicated the irrelevant actions when given this simpler task because they already knew how to solve it prior to any demonstration. Hence, neither study convincingly demonstrates that children are able to emulate actions with objects.

Meltzoff (1988a) showed children that a light could be made to come on by depressing a switch. However, he

demonstrated this by the highly unusual action of bending at the waist and touching the switch with his head. Having witnessed this act, 14-month-old children subsequently copied exactly those movements, turning on the light with their heads, rather than with their hands (which they never did in baseline and control conditions in which they saw the adult touch the object). Instead of emulating the demonstration, by noting that the light could be turned on by depressing the switch and doing so by using their hands, the children seem to have mimicked or 'blindly' imitated the demonstration, copying exactly the actions that were demonstrated.

Carpenter, Nagell and Tomasello (1998) replicated and extended Meltzoff 's (1988a) study and attempted to determine whether 'blind' imitation or mimicry was responsible for the children's behaviour. Carpenter *et al.* demonstrated actions similar to those used by Meltzoff to children aged between 9 and 15 months. Children aged below 13 months copied the actions the adults produced but did not seem to pay attention to the outcome of the actions they were copying. Children older than 13 months also copied the actions that the adults performed but, in contrast to the younger children, checked to see whether their actions produced the same result as the adults. For example, when bending at the waist to turn on a switch with their heads (which activated a light as in Meltzoff 's study), older children looked at the light, whereas younger children did not. By implication, the younger children were oblivious to the goal of those actions and thus copied them via mimicry. The older infants, on the other hand, did pay attention to the goal of the actions, suggesting that they imitated the action they had seen with the intention of producing the same outcome as the adult.

In a study looking for evidence of the understanding of intention, Meltzoff (1995) presented 18-month-old children with displays consisting of various failed attempts to achieve a goal (for example, putting a stick in a hole or pulling a toy apart). In response to these displays, children re-enacted the intended actions, rather than the actual failed actions. Meltzoff inferred that young children could understand the intention behind the actions they had witnessed, suggesting that children, at least by 18 months, can recognize and replicate actions on the basis of goals. Bellagamba and Tomasello (1999) have replicated this finding with another group of 18-month-old children, but failed to replicate it with a group of 12-month-old children. Whereas the 18-month-old children produced the intended actions significantly more often following incomplete demonstrations of those actions than following control demonstrations (in which the objects were manipulated in an uninformative fashion), 12-month-old children did not. The learning displayed in these two studies seems most like goal emulation in that the (intended) goal of the actions was noted and the children independently produced the actions that led to those goals. Thus, it seems that, by 18 months children are capable of goal emulation.

Finally, supportive evidence for imitation of actions on objects by 14- to 18-month-olds comes from Carpenter, Akhtar and Tomasello (1998). These authors showed that children between these ages were more likely to copy actions marked as intentional (the demonstrator exclaimed 'There!' after having produced them) than actions marked as accidental (the demonstrator exclaimed 'Whoops!' after having produced them). This again indicates that, between the ages of 14 and 18 months, children's replication of actions is mediated by goals and thus can be said to be imitative.

In summary, the available evidence suggests that infants below 13 months are limited to mimicking others' actions, whereas older children can learn by imitation and goal emulation. We have yet to identify a study showing that children can learn object properties or causal relations via emulation. However, the picture so far painted is incomplete because of the paucity of relevant developmental studies. Firmer conclusions about the mechanism of social learning will arise from the next section, in which we discuss the literature that deals specifically with how children learn and apply their knowledge of tools.

The literature on the social learning of tool use in human children (Category 3)

With regard to determining when (but not how) children can learn complex actions on objects (e.g. tool use) through observation Meltzoff (1995) has claimed, and Visalberghi and Limongelli (1996) have demonstrated, that children are ready to copy acts of tool use by around 15 to 18 months. Some investigators have also studied children's ability to transfer knowledge from one tool-using task to another. If children observe the solution to one task and then transfer that solution to another task, their performance on the second task provides us with some insight as to how they learnt (via observation) the solution to the first task. Children may either transfer the strategy used on the first task to the second, without adapting that strategy to the second task, or else they may transfer their knowledge of the causal relations of the first task to the second. In the first case, we would attribute 'blind' imitation learning to the child and in the second case, emulation learning, or possibly 'insightful' imitation.

While some transfer studies do seem to show that children can learn to transfer knowledge on the basis of object affordances (Brown, 1990; Chen, Sanchez &

Campbell, 1997) there are others that do not (Parsonson & Baer, 1978). Moreover, all the studies fall short of satisfying us for one of two reasons. One common problem is that authors do not distinguish between those children who learnt the solution to be transferred by themselves, and those who learnt the solution via observation. In order to make claims about social learning we are only interested in the second group. However, researchers interested in the transfer of knowledge (however it was originally learnt) do not report the data from this second group separately, making their data uninterpretable for our purposes. In addition, the majority of studies give children an opportunity to observe the solution *and also to perform it themselves*, before asking them to transfer the solution to other tasks. Again, this complicates interpretation of the results because children can benefit from two sources of learning: from observation of the model and from their own interaction with the initial task.

For more compelling evidence regarding children's social learning of tool use, based on well-controlled studies, we turn to the literature from comparative psychology. A number of comparative studies have looked specifically at learning to use tools, rather than at reproducing gestures or simple actions. They point to the conclusion that young children rely on a strategy of faithful imitation and rarely, if ever, resort to emulation.

Thus, Nagell *et al.* (1993) argue that the social learning of young children is best characterized by what we have called 'blind' imitation. These researchers examined children's performance on a tool-using task that they also presented to chimpanzees. Two-year-old children were shown either one of two demonstrations of the use of a tool, or a control demonstration. The first demonstration of tool use (the *flip* condition) showed a rake, initially resting on its prongs, flipped over to rest on its complete edge and then used to retrieve an out-of-reach object. The other demonstration (the *no-flip* condition) showed the rake, initially resting on its complete edge (rather than its prongs) used to retrieve an out-of-reach object. The control demonstration involved no action with the rake at all. Regardless of the demonstration they witnessed, the children were then presented with the rake resting on its prongs.

Children from the control condition simply pulled the rake toward them, attempting to use the prongs to manoeuvre the object into reach. This strategy was quite inefficient because the object frequently slipped between the prongs and contact had to be re-established between the toy and the rake. The children from the *flip* condition, after an initial period of using the prongs of the rake, used the more efficient edge strategy, flipping the rake onto its back and using the complete edge to retrieve the object. The most interesting finding comes from the children in the *no-flip* condition. These children had seen the complete edge of the rake used in the demonstration. However, they had not seen the rake flipped over from its prongs to its complete edge. When presented with the rake resting on its prongs, these children simply used it in that configuration to attempt to retrieve the object. They did not flip the rake onto its complete edge, despite having seen it used in that way during the demonstration.

These findings are taken as evidence for imitation in young children. Children used the strategy they had seen demonstrated (either flip then pull for the *flip* condition, or simply pull for the *no-flip* condition). Had children been emulating the demonstrations, they should have realized that the rake was most efficiently used on its back, with the complete edge in contact with the object.[4] Thus, in both conditions they should have used the complete edge of the rake to retrieve the object. Instead, children simply 'blindly' imitated the strategy they had seen, regardless of its utility given the situation they were faced with.

Similar findings have been reported by Whiten *et al.* (1996) in their comparative work with 2- to 4-year-old children. These researchers gave both chimpanzees and children the task of retrieving an object from inside an 'artificial fruit', a clear Perspex box locked with bolts and a latch. Both the bolts and the latch could be removed from the box in several ways, only some of which were actually demonstrated to the children. For example, the bolts of the box could either be simply poked out with one finger, or grasped in several fingers and twisted free of the box. Following these demonstrations, children of all ages were most likely to copy the exact form of the action they had witnessed, rather than using one of the other available methods. They even copied actions that were not functional, and whose redundancy should have been clear to them. Many children, for example, persisted in twisting the bolts from the box, even after discovering that the bolts could simply be poked out of the box without the need for any rotation. Whiten *et al*. (1996, p. 11) therefore suggested that:

[4] Indeed, there is evidence that 3-year-old children were capable of this kind of emulation. When presented with the two demonstrations presented to the 2-year-old children, the 3-year-olds Nagell *et al*. tested seemed to learn the more efficient edge strategy and did not simply copy the strategy they had seen. They therefore seemed to emulate the successful action they had seen. However, these results are confounded by the fact that the control 3-year-olds (who had seen no demonstration) also used the rake in the edge position. Although they did so only around half as often as those from the demonstration conditions, this finding suggests that the 3-year-old children knew, before any demonstration, that the rake's edge was more efficient than its prongs.

> The striking cultural and conventional tendency of the children (for high-fidelity imitation) may be so adaptive as a general strategy for humans that it remains habitual even in a specific situation in which less fidelity would actually afford more efficiency.

While it is true that, in the case of Whiten *et al*.'s study, high fidelity imitation resulted in less than maximum efficiency, there are circumstances in which such imitation is advantageous. Call and Tomasello (1995) presented 3- and 4-year-old children and orangutans with the task of manipulating a lever attached to a large box, in order to produce a food reward. The means by which the manipulations of the lever inside the box caused the food to appear were not visible (although the ultimate effect – the appearance of the food – was visible). Hence, when children observed the experimenter, they were only able to observe the actions (and not the means) by which the experimenter produced the effects. In such circumstances (which may be typical for complex tool use) imitation is the only social learning mechanism that could provide children with the requisite knowledge to retrieve the food. Emulation learning, learning about the means by which the tool has an effect on the environment, is not a useful mechanism in this case, because the means by which the tool produces its effects are hidden. In addition, neither local/stimulus enhancement nor goal emulation can provide the specific information required to manipulate this apparatus correctly.

When exposed to the demonstration of this task, 3-year-old children learned the required manipulations on approximately 40% of trials and 4-year-old children on 70% of trials. Most errors occurred on trials where children were required to perform complex sequences of actions to produce the reward. However, even in these cases, children were able to enact the simple component elements of the sequences, often failing only because they did not reproduce them in the correct sequence. This seems to be good evidence that children at 3 and 4 years of age can imitate actions in order to achieve a goal, without needing to see how those actions led to that goal.[5]

In summary, studies from comparative psychology all indicate that young children, from the age of $1\frac{1}{2}$ to 4-years-old are imitators. Indeed, they imitate in situations where they could learn more efficiently by focusing less on the particular strategy they observe and more on the means by which the strategy produces its effects. This raises the possibility that young children lack the cognitive ability to emulate: they do not learn how certain objects, notably tools, afford particular causal outcomes, by observing a model. Below, however, we consider alternative explanations for the dearth of emulation.

Potential hazards in the study of social learning in young children

One potential confound in studies of social learning is that imitation serves a social as well as a cognitive function. The exact imitation of another's behaviour has been shown to be rewarding, both for the imitator and the imitated (Fouts *et al.*, 1976) and thus may act as a mechanism of social *interaction* and not just social *learning*. Grusec and Abramovitch (1982) have shown that imitative exchanges between children, and between children and adults, often lead to greater subsequent social interaction between the imitator and the imitated. Killen and Uzgiris (1981) suggest that, around the end of the second year of life, children imitate the nonsense actions of other people in order to 'keep the game going', and to continue interaction with another person.

What we might have witnessed in reviewing the literature on social learning is a confound between imitation as a learning mechanism and imitation as a means of socially engaging with another person. Children, when they appear to 'blindly' imitate rather than emulate (by copying the model's exact actions rather than only the functional ones), may do so because they want to engage with the model, and not because imitation is the only social learning mechanism of which they are capable. One way to explore this proposal is to present children with tool-using tasks that they do normally solve in an entirely functional way, and to offer them a demonstration that includes non-functional elements as well as functional elements. If they reproduce both functional and non-functional elements, we shall be able to disentangle such 'social' imitation (in which the child has understood why the actions are effective, but has chosen to replicate the model's actions fully) from 'genuine' imitation (in which the child has not understood why the actions are effective).

A further consideration concerns the generality of children's social learning. Given the arguments we advanced earlier (see p. 6) the form of children's social learning may have a critical interaction with their initial knowledge, especially when we are considering emulation. We may have seen no evidence of emulation of causal relations (no evidence of learning a flexible form of knowledge) because we have been looking at tasks

[5] Call and Tomasello do not directly discuss the issue of goal recognition and mimicry with regard to human children. However, they also tested an orangutan, Chantek, known to be capable of human-like mimicry, on this task. Chantek performed particularly poorly on the task, suggesting that mimicry alone is not sufficient to solve this task.

about which children know very little. In particular, they may know little or nothing of the simple properties of the objects involved, therefore precluding emulation of causal relations.

Following this argument, instead of conceiving of social learning as context-independent (in that all children of a certain age use one type of mechanism with all tasks) we may have to conceive of social learning as context-specific. Instead of thinking of children's social learning as, at any one time, bound to one particular form (albeit one that may change *over* time), the alternative hypothesis is that children of a given age are capable of both imitation and emulation, and that the form that their social learning takes is determined by their knowledge of the actions they witness. If a child has virtually no knowledge of the affordances of the action shown, he or she will be limited to imitating that action. On the other hand, if the child knows much about the objects involved then it will be easier to understand and enact the task's solution via emulation. Thus, children of all ages (and indeed adults) may both imitate and emulate, and other factors, notably task or domain knowledge, determine which mechanism operates.

However, note that children of the same age have never displayed an ability to imitate and to emulate in a single study (possible exceptions being the confounded results of Harnick, 1978 and Sibulkin & Uzgiris, 1978). Furthermore, evidence contrary to the idea of context specificity was obtained by Nagell *et al*. (1993). Two-year-old children were presented with a simple retrieval task, using a rake to retrieve an object. Previous studies (Brown, 1990; Piaget, 1953) had suggested that 2-year-olds understand how to use a rake to pull a toy. However, when presented with a demonstration which, if copied, would lead to an inefficient solution, the children chose to perform the demonstrated strategy, paying no heed to the effects of the strategy on the array. As we have already seen, Whiten *et al*. (1996) suggest that the tendency to copy what an adult does (to imitate his/her behaviour) may be so strong in young children, that it even persists in situations where it leads to an inefficient solution (even though a more efficient one may be readily apparent to them). Hence, the extent to which children's knowledge affects their social learning remains an open question.

Conclusions and unanswered questions

Having reviewed the relevant literature on the mechanism of social learning, we first summarize our main conclusions and then outline key questions for future research.

1 The developmental literature has largely been concerned with the question of when social learning arises and not by which mechanism it operates. Nevertheless, the available evidence suggests that the mechanism of social learning in young children develops from mimicry (possibly from birth, certainly from about 6 to 13 months), to imitation and goal emulation (from 13 months onwards).
2 The literature from comparative psychology suggests that young children, from age $1\frac{1}{2}$ to 4 years old are best characterized as learning by imitation.
3 The ability to emulate (in the sense of learning causal relations) may arise at a still later stage. Additionally, we have reason to believe that the type of social learning demonstrated by children will depend on the nature of the problem they are faced with and on their social motivation.

The first key issue for future investigation is therefore as follows:

Q.1 What is the mechanism of social learning in young children? Are there age-related changes in the mechanism of social learning?

The most plausible answer to this question, at present, appears to be that children may well be born with the ability to match the actions of the self to the actions of another (Meltzoff & Moore, 1977), but this ability is likely to be 'a highly constrained form of mimicry' (Hayne, 1998). Over the course of development, children's social learning becomes mediated by a representation of the model's goal. At this point, both imitation and goal emulation come on-line. Eventually, the child may gain the ability to learn from others' actions without copying them and the ability to emulate arises. However, so far we have seen no evidence that children can emulate a model's actions. Perhaps children (and indeed adults) only learn what actions to perform on a task from observation, without learning why they are effective (but see Want & Harris, 2001). They subsequently fill in the details of why those actions are effective via trial-and-error, or from informed instruction. Our developmental sequence is therefore one of mimicry, followed by imitation and goal emulation and ending (potentially) with emulation of causal relations.

Given that the mechanism of social learning changes over time we may ask the following additional question about the nature of this age-related change:

Q.2 If there are age-related changes in social learning, what is at the heart of such changes?

Here, there are a number of equally plausible answers:

A.2.1 Age changes are context-independent and reflect children's increasing cognitive sophistication, most notably their insight into the goal-directed nature of a model's action.

A.2.2 Age changes are context-independent and reflect the role that replicating another's behaviour plays for young children (be it social learning, or social interaction).

To elaborate, age changes in social learning may represent changes in the type of learning that takes place *regardless* of the kind of task the child is faced with. Thus, the knowledge that children have of the affordances involved in the task has no effect on the type of social learning they engage in when shown a solution. Context-independent changes of this kind may be brought about either by increasing cognitive sophistication (in particular, imitation may come on-line when children begin to conceive of others as goal-directed agents), or by developmental changes in the role that replication of another's behaviour plays for young children (perhaps serving as a means of social interaction first, and then later as a means of social learning).

A.2.3 Age changes are context-specific; understanding of a particular task and its affordances enables emulation, whereas a lack of understanding causes a reliance on imitation.

The type of social learning that children engage in may be affected by their understanding of the task. When children are shown the solution to a novel task and can detect and understand the relevant affordances, the solution can be emulated. However, when the task involves invisible or 'mysterious' affordances, they are reduced to imitating the demonstration.

In answering this question therefore, we need to examine the effects of object understanding on the mechanism of social learning and also the role of imitation as a mechanism of social interaction. Both of these factors, as we have seen, may play a role in determining the form of social learning in which children engage.

In conclusion, our review highlights an intriguing paradox. Few would deny that the transmission of tool use from one generation to the next is a major characteristic of the human species. Yet developmental psychology has typically ignored the basis for such learning. Fortunately, the study of non-human primates has recently highlighted the need to study such learning and provided some intriguing lessons in how to do so.

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