

# Investigating children as cultural magnets: do young children transmit redundant information along diffusion chains?

Emma Flynn\*

*Department of Psychology, Durham University, Science Laboratories, Durham DH1 3LE, UK*

The primary goal of this study was to investigate cultural transmission in young children, with specific reference to the phenomenon of overimitation. Diffusion chains were used to compare the imitation of 2- and 3-year-olds on a task in which the initial child in each chain performed a series of relevant and irrelevant actions on a puzzle box in order to retrieve a reward. Children in the chains witnessed the actions performed on one of two boxes, one which was transparent and so the lack of causality of the irrelevant actions was obvious, while the other was opaque and so the lack of causal relevance was not obvious. Unlike previous dyadic research in which children overimitate a model, the irrelevant actions were parsed out early in the diffusion chains. Even though children parsed out irrelevant actions, they showed fidelity to the method used to perform a relevant action both within dyads and across groups. This was true of 3-year-olds, and also 2-year-olds, therefore extending findings from previous research.

**Keywords:** social learning; culture; children; overimitation; imitation; emulation

## 1. INTRODUCTION

Understanding how we learn from others has been of interest to psychologists for over a century (Baldwin 1902; Rogers & Williams 2006), and during this time it has been investigated by a range of disciplines including anthropology, cognitive neuroscience, robotics and philosophy, as well as developmental, social and comparative psychology (Dautenhahn & Nehaniv 2002; Meltzoff & Prinz 2002; Want & Harris 2002; Frith & Wolpert 2003; Bekkering *et al.* 2005; Breazeal *et al.* 2005; Hayashi *et al.* 2005; Hurley & Chater 2005; Kubota 2005; Lukowski *et al.* 2005). Research into children's social learning is undergoing a major expansion, stimulated in part by the integration of developmental and comparative perspectives (Want & Harris 2002; Call *et al.* 2005; Carpenter *et al.* 2005; Tomasello *et al.* 2005; Horner *et al.* 2006; Tennie *et al.* 2006; McGuigan *et al.* 2007), which has allowed the distinction of social learning processes from the simple, such as local or stimulus enhancement, to the complex, including imitation and goal emulation. Such an examination has important implications for our understanding of cultural acquisition as children are *cultural magnets*, with some researchers arguing that processes such as imitation are the bedrock of the acquisition of culture (Boyd & Richerson 1985; Tomasello 1999; Plotkin 2003; Richerson & Boyd 2005), although others highlight the role of trial-and-error learning in the transmission and development of cultural forms (Sterelny 2006).

With this expansion, there has been debate regarding the definition of key terms within social learning.

In the present study, definitions for two critical social learning mechanisms, emulation and imitation, are taken from McGuigan *et al.* (2007), which stated 'One such process is emulation, where the observer attempts to reproduce the results of a model's actions, rather than the more complete copy of the model's behaviour that distinguishes imitative learning' (p. 353). The present study investigated whether groups of 2- and/or 3-year-olds transmitted newly acquired behaviour through emulation or imitation, or a combination of the two. In order to do this, the phenomenon of overimitation, the adoption of inefficient strategies that an individual has seen a model use, was used, therefore establishing whether a series of irrelevant actions would be transmitted from child to child along a chain of children. The phenomena of overimitation and diffusion chain designs are explained in full in the following sections.

### (a) *Overimitation*

Young children have been shown to have a number of social learning mechanisms at their disposal. For example, 14- to 18-month-olds are likely to imitate the method used to achieve a goal when they appear to be intentional, but not when they are accidental (Carpenter *et al.* 1998) and 12- to 18-month-olds use context to decide whether to copy means (imitation) or outcome (goal emulation; Gergely *et al.* 2002; Carpenter *et al.* 2005). Twenty-month-old children will emulate by reordering the sequence of a series of actions that they witness so that enabling actions are put together, even when the demonstration presented a sequence in which enabling actions were interspersed with non-enabling actions; thus, they reach the same end state but do so through a different sequence of actions (Bauer 1992). Nielsen (2006) found that by

\*e.g.flynn@durham.ac.uk

One contribution of 11 to a Theme Issue 'Cultural transmission and the evolution of human behaviour'.

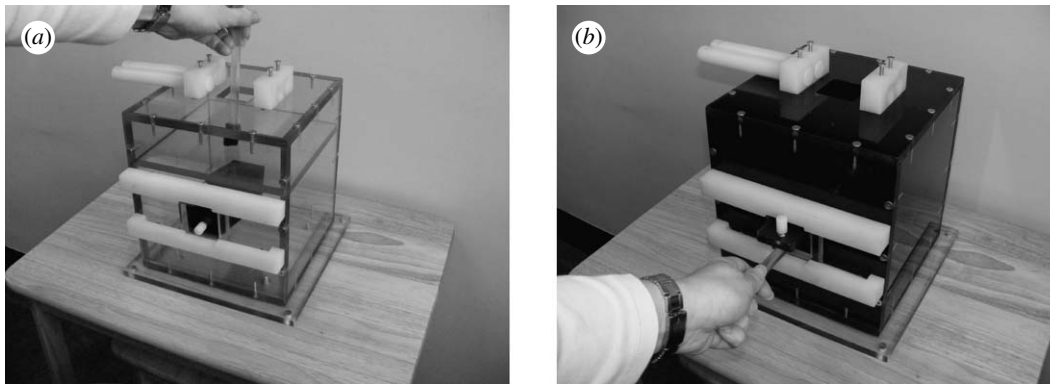


Figure 1. The two glass ceiling boxes: (a) the transparent box with the tool being tapped in the upper compartment and (b) the opaque box with the door in the lift position and the tool inserted into the opaque tube that contains the reward.

2 years of age children imitated by using a tool that had been used by a model to open a box, even though they often found this ineffective and would have been more successful at the task had they emulated and used their hand as younger children had done. Even though very young children have a diverse set of social learning mechanisms available to them, by 3 years children begin to persistently imitate adults' actions, even when these actions are not the most task efficient method, leading to a phenomenon that has been labelled 'overimitation' (McGuigan *et al.* 2007). It is unclear at which point overimitation ceases, if indeed it does. Research with adults has shown that they are 'optimum imitators', using even the same digit to poke at a bolt defence, but they are also emulators as they discover and adopt more efficient variants of these behaviours over trials (Custance *et al.* 2006).

Making a distinction between the two social learning mechanisms, imitation and emulation, is critical to the investigation of the phenomenon of overimitation. In the present study, two different perspectives were used to draw such a distinction. First, a participant witnessed a model retrieve a reward from a box after completing a series of seven actions, critically only two of these actions were causally necessary to retrieve the reward, while the other five actions in the sequence were not relevant. Imitation could be said to occur if a child copied the relevant *and* irrelevant actions, thus producing overimitation as inefficient causally irrelevant actions were reproduced. Emulation of a goal occurred if a child only reproduced the two relevant actions. Second, within the series of actions, certain behaviours were able to be undertaken using one of two methods, e.g. lifting or sliding a door (Dawson & Foss 1965; Whiten *et al.* 2006; Flynn & Whiten 2008, *in press*). The two-method design allows a distinction to be drawn between imitation and emulation. If the individuals in an experimental group witness a model use method A to complete an action (e.g. lifting a door) and subsequently adopt method A in their own attempts at the task, while the individuals in a second experimental group witness a model use method B (sliding the door) and subsequently adopt method B, imitation can be said to have occurred. However, if there is no distinction between the two experimental groups, those who witnessed method A and those who witnessed method B, in terms of the method they adopted during their attempt then children are not

systematically imitating the method they have witnessed used to reach the same end state, instead they are emulating the goal.

The task used in the present study was the glass-ceiling box (henceforth referred to as the GCB), which consists of two boxes that are identical except that one is opaque and the other transparent (figure 1). Both boxes contained an opaque tube, and for the experiment each tube was baited with a reward, a Velcro-backed sticker. To retrieve this reward a door situated at the front of the box had to be opened, either by lifting or sliding left or right, and a rod tool with a Velcro end inserted into the opaque tube. During the demonstration, children witnessed a series of actions that included five irrelevant actions directed towards an opening at the top of the box to a chamber that is hollow and does not make any connection with the reward or the opaque tube that contains the reward. It should be clear to children who witness the series of causally relevant and causally irrelevant actions on the transparent box, as it is to chimpanzees (Horner & Whiten 2005), that only those actions directed at the front opening are necessary, while children who witness the series of actions performed on the opaque box are not privileged to such a distinction.

Horner & Whiten (2005) and McGuigan *et al.* (2007) found that 3- and 5-year-olds copied all actions a model performed on the GCB, irrespective of their opportunity to see the causal relevance of the actions, i.e. whether they were presented with the opaque or transparent box. Such a finding is surprising given that younger children are able to parse out or reorder actions that are irrelevant to a goal (Bauer 1992). Children were also found to be faithful to the method used to undertake the actions, showing that not only do 3- and 5-year-olds imitate by copying causally irrelevant as well as causally relevant actions, but they also imitate by copying the specific method used by a model.

McGuigan *et al.* (2007) found that under certain conditions, such as watching a preconstructed video demonstration of a model's hands completing the task in contrast to a live demonstration, the tendency to overimitate decreases for 3-year-olds as they were more likely to parse out irrelevant actions, but 5-year-olds were just as likely to overimitate after having watched the video. Lyons *et al.* (2007) found that 3- to 5-year-olds imitate irrelevant actions under conditions that should reduce such a tendency,

including when trained to identify irrelevant actions performed by an experimenter, or when children believe the experiment is over and they are under a time constraint to prepare for the next participant, and also when given direct instructions to ignore any unnecessary actions. It was only under conditions in which the demonstrator's irrelevant actions actually broke the contact principle, i.e. the rule that mechanical interactions cannot occur at a distance, that children overcame their tendency to overimitate. It has been suggested that overimitation occurs because children attempt to share experience with a demonstrator (Uzgiris 1981; Carpenter 2006; Nielsen 2006, *in press*) or learn about initially opaque aspects of causality (Lyons *et al.* 2007), as well as when they assume a demonstrator is trying to teach them something (Gergely & Csibra 2005, 2006).

To summarize, children younger than 3 years appear to be able to implement different observational learning mechanisms depending on the scenario, yet by their third birthday children tend to overimitate. At 3 years children imitate all aspects of a model's demonstration, even actions that are causally irrelevant and therefore less task efficient. Research examining overimitation has concentrated on investigating overimitation during dyadic interactions where an adult model has demonstrated to a participating child. The present study aimed to extend our understanding of the phenomenon of overimitation by examining whether overimitation is transmitted across groups of children; such an investigation is essential to our understanding of the transmission of traditions. The primary question addressed in the present study was whether 2- and/or 3-year-old children transmit traditions that contain redundant elements, therefore transmitting a tradition that is not task efficient.

### **(b) Transmission of information across groups**

In order to discover more about social learning in the real world it is important to examine the transmission of information or behaviour from a variety of models, and across a variety of settings. For example, children often learn by observing other children, who may be viewed as less rational, knowledgeable and have less authority than adult-experimenter models. Although the majority of social learning studies have used adult-experimenter models, some studies have used children as models and have shown a high level of fidelity to the demonstration witnessed (Horner *et al.* 2006; Flynn & Whiten 2008). Another critical aspect of observational learning studies is that the majority use dyadic transmission in which an experimenter performs a demonstration for a child who subsequently attempts the task, but the transmission ends there. Social learning in the real world and culture, which is so closely related to imitation and observational learning of others (Boyd & Richerson 1985; Tomasello 1999; Plotkin 2003; Richerson & Boyd 2005), is bigger than simple dyadic relations and involves the transmission of information across generations, from one individual to another. Therefore, it is essential that social learning experiments mimic the transmission of information and behaviour across groups. The present study adopted a diffusion chain design, which offers a controlled, micro-level representation of culture going

beyond the usual dyadic designs of observational learning studies.

A number of studies have examined such transmission in non-human animals and adults using diffusion experiments, which were introduced by Bartlett (1932; human adults: Bangerter 2000, Kirby *et al.* 2008, see Mesoudi & Whiten (2008) for further examples; chimpanzees: Menzel *et al.* 1972, Whiten *et al.* 2005; rats: Laland & Plotkin 1990; guppies: Reader & Laland 2000; blackbirds: Curio *et al.* 1978; pigeons: Lefebvre 1986; see Whiten & Mesoudi (2008) for further examples). Initially in diffusion studies a model is trained to perform a behaviour, such as how to open a puzzle box in a particular way. In diffusion chains, the transmission of this behaviour is then investigated along 'chains' of individuals through repeated dyadic interactions, such that the model (individual A) is observed by individual B while completing the action, individual B is subsequently observed completing the task by individual C, who in turn is later observed completing the task by individual D, and so on. Chains continue until the number of participants is exhausted or until the information fails to be transmitted. This allows the transmission of information across 'cultural generations' to be examined, thus referring to consecutive social transmissions from individual to individual, which in real life may coincide with genetic generations (parent to child) or not (e.g. peer to peer).

It is only recently that such methods have been used to examine the transmission of information across groups of children (Horner *et al.* 2006; Flynn & Whiten 2008). Horner *et al.* (2006) showed that 3-year-olds showed high fidelity in the extraction of a reward from a puzzle box by using one of two methods, either lifting or sliding a door that concealed the reward. The method seeded in the original child in a chain was transmitted successfully along the chain, so that all the children including the eighth and final child used the same method to open the door of the puzzle box.

Flynn & Whiten (2008) used a more complex task in which children had to use one of two tools to extract an object from a puzzle box, either using a pronged tool to stab the object and extract it through a hole in the roof of the box, or a sliding tool that slid along the floor of the box and allowed the objects to be guided to a protruding chute that was bottomless and from which the objects could fall. They found that children in the diffusion chains conformed to the technique they witnessed, with 5-year-olds displaying more robust transmission than 3-year-olds.

The present study used diffusion chains to investigate the cumulative effect of transmission of behaviour across chains of 2- and 3-year-olds. A central question in the study was whether irrelevant information is transmitted, i.e. whether the overimitation seen in dyadic studies would be transmitted across groups, and if not, how and at which point it is parsed out. If the irrelevant actions were faithfully transmitted along the length of the chain this would provide evidence that 2- and 3-year-olds transmit traditions that contain irrelevant actions. Alternatively, the irrelevant actions could be parsed out immediately with children in the chain only transmitting actions that were relevant to



the goal, thus showing that young children will remove redundant items so that traditions are task efficient. If the irrelevant actions were parsed out of the transmitted information, a further point of the study was to discover more about the *process* of transmission of behaviour. Did parsing occurred suddenly, with all elements removed at the same time or, was it gradual, with individual elements being discarded at each generation until they were all removed?

In order to examine the transmission of traditions from a second perspective, i.e. the imitation and transmission of specific actions across groups, this study used the powerful two method, three group design. Thus, the first child in each chain was trained to use one of two methods to perform an action, e.g. lifting rather than sliding a door. This produced two experimental groups, chains seeded with method A and chains seeded with method B. In the present study, two sets of actions could be undertaken using different methods, one of these actions was irrelevant (the bolts at the top of the GCB could be either dragged from the left using the tool or poked with the tool from the right) and one was a relevant action (the door could be opened by sliding left or right and by lifting). If the specific methods seeded at the beginning of each chain was transmitted faithfully along each chain, then this would provide evidence of the transmission of traditions across groups. The design also included an important third group, referred to as a no-model control condition, in which children were presented with the task but receive no demonstration. Such a control condition permits the level of success through individual learning to be established, allowing an analysis to be undertaken to establish whether observational learning has occurred in the diffusion chains. Furthermore, the no-model control condition allows an investigation of the predisposition to produce the actions of interest. For example, if all children in the no-model control condition remove the bolts in the GCB and tap the tool into the upper compartment, then it is not possible to establish whether performance of such actions by children in the diffusion chains is due to social or asocial learning.

### (c) *Predictions*

The critical questions in the present study were whether children transmitted traditions that contained irrelevant actions and whether children faithfully transmitted the method that a model used to complete an action. The present study further examined whether each form of transmission (irrelevant actions and specific methods) was affected by age (2- versus 3-year-olds) and access to causal information (opaque versus transparent). In line with dyadic studies of overimitation, it was predicted that children in the diffusion chains would reproduce and therefore transmit irrelevant actions, thus transmitting traditions that were not task efficient.

Overimitation increases from 3 years, and so it was predicted that 3-year-old children would show a significantly higher level of imitation of causally irrelevant actions than 2-year-old children in chains where the box was transparent. Yet, in chains where the opaque box is presented it was predicted that 2- and

3-year-olds would show a similar level of overimitation, reproducing the irrelevant actions, as young children will overimitate when the goal is not clear (Williamson & Markman 2006).

A comparison of chains of 2- versus 3-year-olds offered an interesting counterpoint to previous research because until now diffusion chain studies have recruited chains of 3- and 5-year-olds, which have shown good fidelity in their transmission of both the methods used and the specific action used to achieve these methods. Including chains of 2-year-olds in the present study addressed whether younger children are capable of faithfully transmitting behaviour over generations in relation to the transmission of irrelevant actions *and* the specific actions used to achieve a transmitted method.

## 2. MATERIAL AND METHODS

### (a) *Participants*

Eighty children participated, divided equally between 2- and 3-year-olds. Thirty-two children, half of which were 2-year-olds, were allocated to a no-model control condition and 48 children, half of which were 2-year-olds, were allocated to diffusion chains. Each chain contained six children of the same age group. The mean age of the 2-year-old children in each chain ranged from 2 years 6 months to 2 years 8 months (standard deviation (s.d.) ranged from 3 to 4 months), and the mean age of the 3-year-old children in each chain ranged from 3 years 6 months to 3 years 9 months (s.d. ranged from 3 to 6 months). The mean age of the 2-year-old children in the no-model control condition was 2 years 6 months (s.d. = 2 months) and the mean age of the 3-year-old children in the no-model control condition was 3 years 6 months (s.d. = 4 months).

### (b) *Design*

The study used a between-group, diffusion chain design to compare observational and individual learning in relation to age (2- versus 3-year-olds) and access to causal information (opaque versus transparent box). Children were allocated to a no-model control condition or a diffusion chain, each chain containing six children in total. Two chains were run for each of the four conditions defined by these two factors (as in Flynn & Whiten 2008), yielding eight chains in all.

### (c) *Materials*

The GCB consists of two boxes that are identical except for the fact that one box is transparent and the other is opaque (figure 1). Each box has a hole on the roof, covered by a bolt defence, and a second hole on the front face of the box covered by a door defence. Behind the front hole is a sloping tube, opaque in both boxes, which contains a reward (a Velcro-backed sticker). In order to retrieve the reward the door must be opened (either by sliding or lifting), a tool (a 22 cm long rod with Velcro on the end) inserted and then the reward can be pulled out. Actions directed to the front of the box are causally necessary to retrieve the reward, whereas actions directed to the top of the box are not, because inserting the tool in the top hole results in hitting a barrier (the 'glass ceiling') that prevents physical access between the tool and the tube containing the reward.

### (d) *Two-action design*

The extent of the participants' imitation of the demonstrated actions on the bolt and door defences was examined using the 'two-action' design (Horner *et al.* 2006; Whiten *et al.* 2006;

Flynn & Whiten 2008, in press). The door, which was hinged at the top, could either be lifted or slid to the side to reveal the opening to the tube. Similarly, the bolts could be dragged from the left with the tool, or pushed from the right with the tool in order to reveal the top hole. A model was trained to use one of these two or three actions, (i) lifting the front door or sliding it to the left or right and (ii) dragging or pushing the bolts on the top of the box.

#### (e) Procedure

Each of the eight chains contained six children of the same age group (2- versus 3-year-olds), who saw a model retrieve a reward from either the opaque or transparent box. Testing took place in a quiet room away from the other children in the nursery. For children in the diffusion chains, initially the experimenter said to the first child, 'Okay watch me and then you can have a go'. Then the child watched the experimenter perform a series of actions either on the opaque or transparent box. The child witnessed the experimenter either push or drag the bolts from the top hole, the tool was then inserted into the top hole and tapped on to the glass ceiling below three times, after which the experimenter either lifted or slid the door away from the hole at the front of the box, inserted the tool and then removed the reward. Having witnessed two demonstrations, the child was allowed to have a turn, 'Now it is your turn'; the goal of retrieving the Velcro-backed sticker was never explicitly stated. The first child in every chain was trained to retrieve the sticker using feedback until she/he had incorporated all of the elements demonstrated by the experimenter, so that the first child's attempt was a replication of the experimenter's demonstration. Once the model was proficient, the second child in the chain was brought into the room, and told to wait while the first child had two attempts, then it would be his/her turn. No explicit instructions were given about watching, teaching or copying and the tool was never handed to a child but placed on the table in front of the GCB. The experimenter made sure that each child had a clear view of the GCB and the actions upon it. Children were retained as a model for the following child in the chain as long as they attempted to remove the reward, irrespective of the method used during their attempt. Children were only discounted if they performed no meaningful actions on the box. After the first child's two demonstrations, the second child, who had been present during the demonstrations, had two solo attempts before becoming a demonstrator for the next child in the chain. This procedure continued to the final child, who had only two attempts, as there was no need for him/her to demonstrate.

In the no-model control condition, children were brought into the room and presented with the GCB and tool, being told, 'Lots of boys and girls have had a go, and now it is your turn'. Testing ended if a child successfully retrieved the sticker, refused to continue after general encouragement, or after 4 min of interaction with the GCB. Children who struggled in the no-model control condition were given general encouragement, including, 'What do you think you do now?', 'You can touch it as much as you like, you can't break it' and 'You're doing really well, what do you think you do next?'.

Three children in the diffusion chains refused to participate, two of these were at the end of the chains, and one was in the second position along the chain. For the child in the second position, this child was not included further in the chain as he undertook no meaningful behaviour on the box. Instead, the original model was asked to return and acted as a model for the following child in the chain. All children,

irrespective of success, received a sticker as a reward at the end of the testing session.

#### (f) Coding and inter-rater reliability

Each child's performance was scored on four separate variables: (i) whether she/he removed the bolts, and if so, the method used, (ii) whether she/he tapped in the top of the box, and if so, how many times, (iii) whether she/he opened the door, and if so, which method she/he used, and (iv) whether she/he inserted the rod to remove the sticker and was therefore successful. From this coding, a score could be given for the number of irrelevant actions undertaken from (i) the number of bolts removed and (ii) the number of taps in the top of the box (the original model in each chain performed five irrelevant actions: removing both bolts and tapping three times into the upper compartment). An independent observer, who was blind to the rationale of the study, coded 18 per cent of the sample (14 children made up of two chains and two control children resulting in 50 incidents of behaviour). All Cohen's kappa scores (remove bolts by pulling, dragging or poking; number of taps in upper compartment; open door by sliding left or right or lifting; removing reward) were 0.91 or above, showing a good level of reliability.

### 3. RESULTS

The analyses followed a series of questions, which were considered in turn. First, did social learning occur and how did children in the no-model control condition behave? Second, did children copy the irrelevant actions that were originally seeded in chains? Third, did children copy the specific method they witnessed used to perform actions? Finally, were behaviours transmitted along chains from the original model, therefore producing traditions?

#### (a) Did social learning occur and how did children in the no-model control condition behave?

When the level of success of the diffusion chain children's first attempt<sup>1</sup> was compared to the level of success of children in the no-model control condition it was clear that social learning had occurred. Children in the diffusion chains were significantly more successful at retrieving the reward (success rate = 94%) than children in the no-model control condition (success rate = 9%;  $\chi^2_1(n=80) = 56.93$ ,  $p < 0.001$ ). Of the 32 children in the no-model control condition, 27 touched the GCB and/or tool suggesting that the lack of success within this condition was not due to a lack of interaction with the task.

It was also important to note when children in the no-model control condition produced behaviours that were of interest in the diffusion chains, as this provides a baseline for their occurrence during individual learning. For example, no child poked the bolts with the tool, but nine children dragged the bolts, two using the tool and the remaining seven using their hands. Of the 32 no-model control children, 23 opened the door of the GCB at least once. Six children lifted the door open, 22 children opened the door by sliding it to the right, and 20 opened the door by sliding it to the left. Finally, none of the no-model control children tapped the tool into the upper compartment of the GCB.

**(b) Did children copy the irrelevant actions that were originally seeded in chains?**

This analysis was concerned with whether children in the diffusion chains produced any of the five irrelevant actions (removing two bolts and tapping three times into the upper compartment) performed by the first child in each chain. This coding was not concerned with the manner in which these behaviours were performed, e.g. dragging or pushing the bolts, but in whether the behaviour was actually undertaken. An 'irrelevant action' score was given for each child's attempt by adding the number of actions performed out of the original five irrelevant actions. From this a mean irrelevant score, ranging from 0 to 5, was awarded across each child's attempts.

A repeated measures analysis of variance was undertaken on the children's mean irrelevant action scores according to the child's position in the chain, age and box type. As assumptions of sphericity were not met, Huynh-Feldt corrections were used. It was found that for the between-participant factors there was no main effect for age ( $F_{1,2}=9.47$ , n.s.) or box type ( $F_{1,2}=13.07$ , n.s.). For the repeated measures analysis there was a significant effect for the number of irrelevant actions produced depending on a child's position in the chain ( $F_{4,91,9,81}=37.87$ ,  $p<0.001$ ). *Post hoc* Bonferroni tests showed that children in the first position (mean=5.00) made significantly more irrelevant actions than children in the third, fourth, fifth and sixth positions (mean=0.60 (third position), 0.70 (fourth position), 0 (fifth and sixth positions)). Children in the first position did not differ significantly in the number of irrelevant actions made from children in the second position (mean=2.90), and children in the second position did not differ to children at any other position. There was also an interaction between position and box type ( $F_{4,91,9,81}=5.12$ ,  $p<0.05$ ). Children who were first in the chains with either the opaque or transparent GCB (mean for both was 5) made significantly more irrelevant actions than children in all the other positions.

Figure 2 presents an illustration of the children's behaviour in each of the chains. It shows that the causally irrelevant action of tapping the tool into the top hole was never transmitted beyond the second generation in a chain, and even then in only three of the eight chains did the second person in each chain tap the tool into the upper compartment. The action of removing the bolts was also irrelevant. However, removing the bolts was more resistant to being discarded than the tool tapping, with bolt removal being transmitted in four chains; two chains until the second position and two chains until the fourth position. A repeated measures analysis of variance using Huynh-Feldt corrections found that there was an effect for the number of bolt removals according to the position that the child was in the chain ( $F_{4,91,9,81}=5.66$ ,  $p<0.05$ ), but there was no effect for age ( $F_{1,2}=3.79$ , n.s.) or box type ( $F_{1,2}=3.13$ , n.s.).

**(c) Did children copy the specific method they witnessed used to perform actions?**

The transmission of the method used to perform certain actions across each dyadic interaction was investigated. Children's actions on the bolts were not

included in this analysis because too few participants actually performed actions on the bolts. Of the eight children who did remove the bolts, six were faithful on at least one of their attempts to the method they had witnessed.

The method used to open the door could be examined in detail, as all the children who remained in the chains undertook this causally relevant action. Children were coded in terms of whether the method they used to open the door was the same as the method they witnessed the previous child in the chain use. In order to include the majority of children, each attempt was analysed separately. At their first attempt significantly more children (87%) imitated the method that they had witnessed used to open the door than children who used an alternative method (13%;  $\chi^2_1(n=37)=19.70$ ,  $p<0.001$ ). The five instances of lack of imitation occurred when children slid the door in the opposite direction to that which they had witnessed. Similar results were produced for the second, third and fourth attempt, with no less than 77 per cent of children imitating the same method used to open the door to that which they had witnessed rather than using a different method ( $\chi^2$  ranged from 9.32 to 11.92 with  $p<0.01$ ). This high level of fidelity to the door method witnessed did not differ according to age group, across all of the attempts all  $\chi^2$  scores (ranging from 0.06 to 0.99) which contrasted 2- with 3-year-olds were not significant, or box type, across all of the attempts all  $\chi^2$  scores (ranging from 0.01 to 0.50) which contrasted the opaque and transparent GCB were not significant.

**(d) Were behaviours transmitted along chains, therefore producing traditions?**

The previous analysis has shown that children were not transmitting behaviour traditions that contained irrelevant behaviour, as these were parsed out early in the chains. However, it was possible to investigate whether traditions were produced in relation to a relevant behaviour, the manner in which the door was opened. In order to establish whether traditions were transmitted along the chains, in relation to the method used to open the door, the behaviour that children produced during their demonstrations was coded creating four possible combinations: left-left, right-right, left-right and right-left. These behaviours were compared to the behaviours that the children had witnessed their model produce, and a rating of 'same as model' or 'different to model' was created. The number of changes (i.e. the number of different to model scores) in the door-opening behaviour produced along each of the chains could then be recorded. In order to make comparisons across all of the chains, only the first to fifth children were included in the analysis, as not all chains contained six children. If the method used to open the door was faithfully reproduced along all generations in a chain (e.g. left-left to left-left to left-left to left-left to left-left or right-left to right-left to right-left to right-left to right-left), then the chain would achieve a 'change score' of 0; however, if every child in a chain produced a different door-opening behaviour to that which they had witnessed (e.g. left-left to right-right to left-left to right-right to left-left) then the chain would be awarded a change score of 4. The fidelity of the

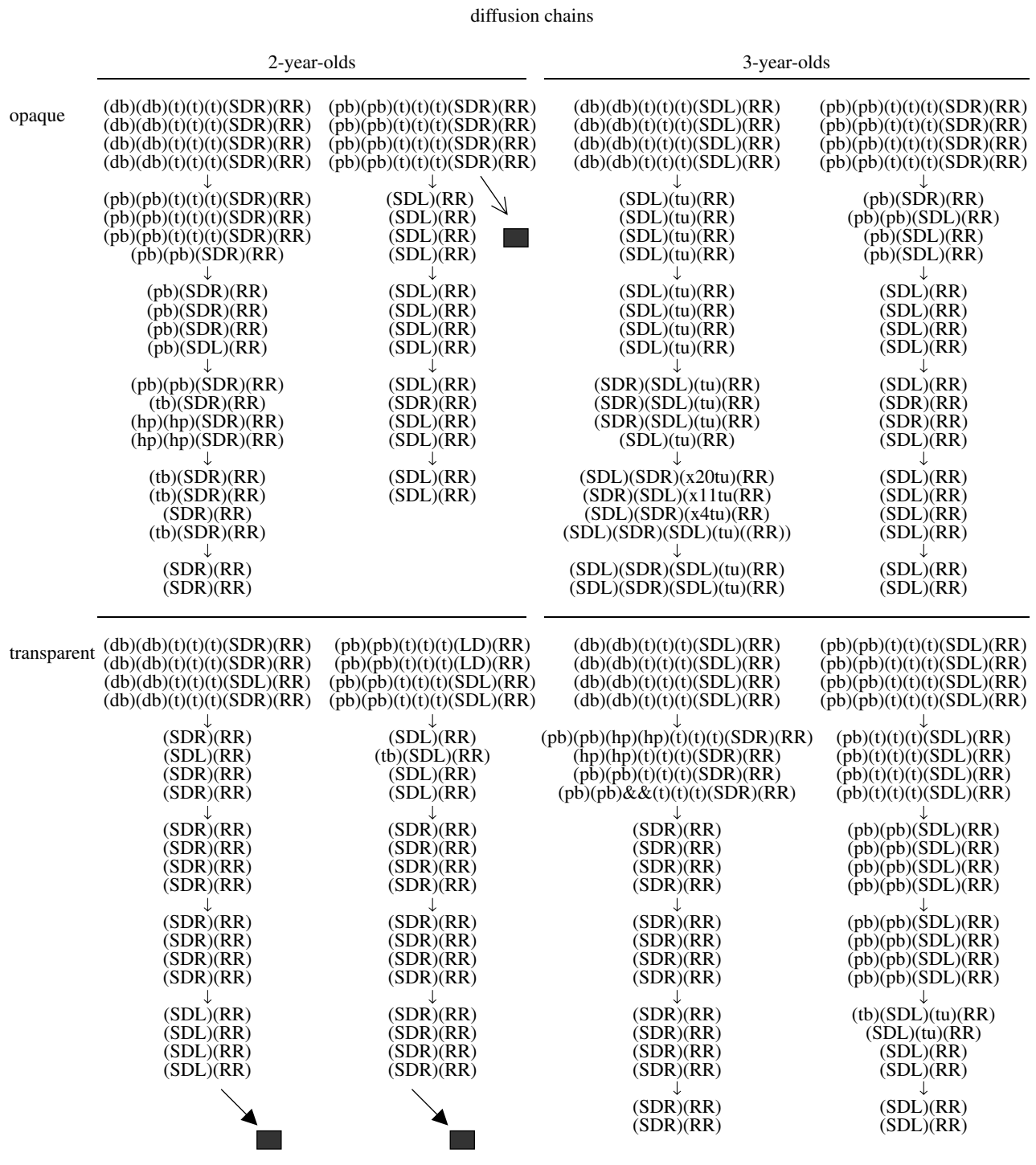


Figure 2. Transmission along diffusion chains. Each row of seven bracketed symbols represents a child’s attempt on a GCB. The upper two rows of each set of four are attempts and the lower two rows are demonstrations: (db) represents dragging the bolts, (pb) represents pushing the bolts, (hp) represents poking and pulling the bolts with one’s hand, (tb) refers to children who touched the bolts but did not move them, (t) represents tapping into the upper compartment (the initial demonstrator did this three times, only the first three taps are illustrated although some children made more), (LD) represents lifting the door open, (SDL) or (SDR) represent sliding the door open either towards the left or right, (tu) refers to children who used the tool rather than their hand to move the door, sometimes children moved the door more than once (e.g. ×20 means moving the door 20 times) and (RR) represents retrieving the reward. A symbol that does not appear means that the behaviour it represents was not produced during that attempt. A black rectangle to the side of a chain represents a child who was allocated to a chain but did not participate in the chain. Actions represented with uppercase letters are causally necessary actions, while actions represented with lowercase letters were not causally necessary.

transmission of children in the diffusion chains followed a binomial distribution from which the expected distribution of scores could be calculated. The distribution of scores in the actual diffusion chains

was compared to the expected distribution of scores using a chi-squared statistic. The goodness-of-fit test proved to be significant ( $\chi^2_{32} = 53.63, p < 0.001$ ; Spiegel 1961). It was found that there were more cases with



change scores of 0, 1 or 2 in the diffusion chains than would be expected by chance, and less chains producing change scores of 3 or 4 than expected by chance. Observation of the data showed that 2- and 3-year-olds did not differ from one another in the number of changes produced in the chains (mean for 2-year-olds = 1.50; mean for 3-year-olds = 1.50).

#### 4. DISCUSSION

The primary goal of this study was to investigate the cumulative effect of transmission of behaviour across groups of 2- and 3-year-old children, addressing questions such as whether irrelevant information is transmitted, and if not, how and at which point it is parsed out. Furthermore, the present study extended previous diffusion chain studies by investigating whether younger children to those previously tested, specifically 2-year-olds, were capable of transmitting the details of the method used to perform an action, therefore producing a tradition. Before the main findings are discussed, it must be acknowledged that although diffusion chains offer an exciting opportunity to investigate the transmission of traditions and provide a micro-representation of culture, the size of the samples used in diffusion chain studies is small. Therefore, the strength of the conclusions made in diffusion chain studies, including the present study, needs to be considered in the light of this small sample size. Specific caution must be used when interpreting the findings in this study relating to age and box type, as the small sample size may lead to type II errors.

##### (a) *Overcoming overimitation*

A core question of the present study addressed whether there would be fidelity of transmission across cultural generations when the demonstrated behaviour contained irrelevant actions. Unlike previous studies that have found strong and persistent fidelity to traditions across generations of up to eight children for all demonstrated behaviour, children in the present study were very quick in parsing out the irrelevant actions and transmitting only those actions that were relevant to the goal. Indeed, the third child in the chains, as well as all the subsequent children, made significantly fewer irrelevant actions than the initial model in each chain. Examination of the chains found that for five of the eight chains irrelevant actions were removed together, rather than seeing a gradual removal. For the other three chains, removal of the irrelevant actions was gradual, with the tapping being removed from the sequence initially and later the actions on the bolts, with the bolt actions sometimes making it until the fourth child in the chain. Copying only the actions on the bolts is interesting, as one would assume that if participants did not tap into the top, the action of removing the bolts would seem particularly redundant. However, it is clear that access to causal information and causal relations does not always assist in overcoming overimitation, as children overimitate on both opaque and transparent boxes (Horner & Whiten 2005). Lyons *et al.* (2007) found that certain types of causal information, such as behaviour that breaks the contact principle, facilitates children's parsing of

irrelevant actions. Yet, in the present study the causal irrelevance of removing the bolts when one does not follow this by tapping into the upper compartment did not seem to assist in children's parsing of this irrelevant act. The tendency to overimitate the removal of the bolts may be because this was the first action within the sequence, and was therefore subject to a primacy effect. Future work could examine children's imitation of same-aged peers' irrelevant actions on a task when such actions are presented at different positions within a sequence. Similarly, children's lack of fidelity to the full sequence of actions was not due to the memory demands of the task, as some children were able to replicate the full sequence of actions, and previous work, which has used a similar sequence of actions that were all relevant to the task, has shown that children are capable of remembering and reproducing such sequences (Flynn & Whiten 2008, *in press*).

Age and access to causal information did not affect children's ability to parse out the irrelevant actions. It was predicted that as overimitation increases from 3 years, the diffusion chains containing 3-year-olds would show a significantly higher level of imitation of causally irrelevant actions than the chains of 2-year-olds when the GCB was transparent. Yet, in chains where the opaque box is presented it was predicted that 2- and 3-year-olds would show a similar level of overimitation, reproducing the irrelevant actions, as young children will overimitate when the goal is not clear (Williamson & Markman 2006). This was not found to be the case; 3-year-olds were just as likely to parse out the irrelevant information as 2-year-olds, therefore showing a lack of overimitation. Also the level of causal information available, whether the GCB was opaque or transparent, did not affect children's reliance on the behaviour of the original model to achieve the same goal. However, as stated at the beginning of the discussion, caution must be used when interpreting the findings in this study relating to age and box type, as the small sample size may lead to a type II error.

##### (b) *Transmission across generations*

Previously diffusion chain studies that have examined the transmission of behaviour across groups of young children have shown a strong and persistent replication of behaviour from the first child in the chain to the last. This is a process of canalization, where an individual's exploration of a task is reduced from potentially limitless options to only a subset of behaviours that she/he has seen performed by others (Horner *et al.* 2006; Flynn & Whiten 2008). The present study is the first to include relevant and irrelevant actions within the original model's demonstration. It is clear from the results that there was strong tendency to imitate the relevant actions within the demonstration, producing traditions similar to those produced in Horner *et al.* (2006), as both studies examined the method of opening a door. In the present study, the fidelity to the relevant actions was strong across age groups and box types within the dyadic interactions, i.e. children copied the method they had witnessed. This was also true across the whole chains, as both 2- and 3-year-olds



showed fewer changes in transmitted behaviour along the chains than would be expected by chance.

Although based on a small sample, this study provides an example of children's cumulative cultural evolution (CCE; see Caldwell & Millen (2008) for further exploration of this concept). The term CCE is used to describe the way that,

some individual or group of individuals first invented a primitive version of the artefact or practice, and then some later user or users made a modification, an 'improvement,' that others then adopted perhaps without change for many generations, at which point some other individual or group of individuals made another modification, which was then learned and used by others, and so on over historical time in what has sometimes been dubbed 'the ratchet effect' (Tomasello *et al.* 1993)

(Tomasello 1999, p. 5).

Often CCE refers to the elaboration of cultural techniques or artefacts, e.g. the development of sophisticated technologies. However, in the present study, traditions are improved by the removal of irrelevant actions rather than the addition of behaviours, and this creates a more efficient and streamlined tradition. Thus, it appears that children as young as 2 years are capable of participating in CCE.

### (c) *Future directions*

There was a significant reduction in the present study in children's overimitation in comparison to previous studies. One possible cause for this difference was that unlike previous studies that have shown overimitation in young children, in the present study peers rather than adult experimenters were used as models. Peers may be viewed as less rational and knowledgeable and as having less authority, which would explain why observing children should be less likely to imitate the irrelevant actions within the demonstration. It is clear that the lack of transmission of irrelevant actions was not due to the diffusion chain design, as the parsing of irrelevant actions occurred early in the chains, at a point where cumulative effects could not have built up. That is during the point at which most parsing occurred (the child 1 to child 2 transmission), the experiment is similar to the usual dyadic design. Thus, a more likely explanation is that the tendency to overcome overimitation is facilitated when the model is a same-age peer rather than an adult experimenter. This finding needs further support from a larger sample with a dyadic design, where direct comparisons are made of children's imitation of adult- and peer models. Further work also needs to examine why children are less likely to overimitate from a peer. For example, is it due to a difference in the perceived knowledge, authority or rationality of the model? Alternative explanations may be that there is less of a desire to be like one's peers compared to an adult, or that there is less motivation to perpetuate the social interaction with one's peer.

Finally, an interesting and unexpected effect within the diffusion chains was the production and transmission of idiosyncratic behaviour. For example, in one of the chains children began to touch but not move the bolts, a behaviour that was transmitted along

generations. In another chain, children began to use the tool to move the door rather than their hand, which was consistently transmitted across generations, and also the door was moved in both directions (in one case 20 times) before a child inserted the tool into the opaque tube. Such transmissions of naturally produced behaviour provide an interesting avenue for future work regarding the production and transmission of participant-produced behaviour, and most importantly, provide an opportunity to investigate the identity of these innovators of traditions.

## 5. CONCLUDING REMARKS

The ability of human children to copy others outstrips that of other animals (Tomasello 1990), and is so significant that Meltzoff (1988) dubbed us, *Homo imitans*. The present study extends our understanding of children's imitative abilities, by investigating the transmission of traditions in the context of the phenomenon of children's overimitation, and has resulted in a number of critical findings. The present study is one of the first diffusion chain studies to show that children's transmission of behaviour across groups does not necessarily involve a strong level of fidelity. Previous diffusion chain studies with young children have shown a strong replication of behaviour from the beginning of the chain to the end. This study shows that this is not an inbuilt phenomenon of diffusion chains. Instead, children are able to parse out irrelevant behaviours from a sequence of demonstrated actions.

This study, along with other diffusion studies, has shown that the transmission of traditions by young children can be examined within the laboratory to explore interesting phenomena, such as the effects of age and gender (Flynn & Whiten 2008), comparisons of different species (Horner *et al.* 2006) and the effect of the relevance of behaviour to the goal (the present study). Examining the transmission of behaviour and information across groups appears to be ripe for further exploration, as has been highlighted by Flynn & Siegler (2007). The next step appears to be an examination of young children's cultural transmission using open diffusion designs, in which a trained model and a task are introduced to a group of participants at the same time. Open diffusion studies offer a more realistic micro-representation of culture, as children choose when and who they observe, allowing issues such as the role of children's social status, popularity and friendship patterns to be investigated.

I would like to thank all the children, parents and staff at the nurseries who participated in this research. I would also like to thank Kenny Smith and Stephan Lewandowsky for editing this issue and inviting my contribution.

## ENDNOTES

<sup>1</sup>Comparing the level of success of the diffusion chain, children's first attempt meant that this result was not confounded with the possibility of individual learning that may have occurred at later attempts.

<sup>2</sup>The degree of freedom is 3 because in the analysis the expected values were estimated from the binomial distribution and this has been taken into account.

## REFERENCES

- Baldwin, J. M. 1902 *Development and evolution*. New York, NY: MacMillan.
- Bangerter, A. 2000 Transformation between scientific and social representations of conception: the method of serial production. *Br. J. Social Psychol.* **39**, 521–535. (doi:10.1348/014466600164615)
- Bartlett, F. C. 1932 *Remembering*. Oxford, UK: Macmillan.
- Bauer, P. 1992 Holding it all together: how enabling relations facilitate young children's event recall. *Cognit. Dev.* **7**, 1–28. (doi:10.1016/0885-2014(92)90002-9)
- Bekkering, H., Brass, M., Woschina, S. & Jacobs, A. M. 2005 Goal-directed imitation in patients with ideomotor apraxia. *Cognit. Neuropsychol.* **22**, 419–432. (doi:10.1080/02643290442000275)
- Boyd, R. & Richerson, P. 1985 *Culture and the evolutionary process*. Chicago, IL: University of Chicago Press.
- Breazeal, C., Buchsbaum, D., Gray, J., Gatenby, D. & Blumberg, B. 2005 Learning from and about others: towards using imitation to bootstrap the social understanding of others by robots. *Artif. Life* **11**, 31–62. (doi:10.1162/1064546053278955)
- Caldwell, C. A. & Millen, A. E. 2008 Studying cumulative cultural evolution in the laboratory. *Phil. Trans. R. Soc. B* **363**, 3529–3539. (doi:10.1098/rstb.2008.0133)
- Call, J., Carpenter, M. & Tomasello, M. 2005 Copying results and copying actions in the process of social learning: chimpanzees (*Pan troglodytes*) and human children (*Homo sapiens*). *Anim. Cogn.* **8**, 151–163. (doi:10.1007/s10071-004-0237-8)
- Carpenter, M. 2006 Instrumental, social, and shared goals and intentions in imitation. In *Imitation and the social mind: autism and typical development* (eds S. J. Rogers & J. Williams), pp. 48–70. New York, NY: Guilford Press.
- Carpenter, M., Akhtar, N. & Tomasello, M. 1998 Fourteen- to 18-month-old infants differentially imitate intentional and accidental actions. *Infant Behav. Dev.* **21**, 315–330. (doi:10.1016/S0163-6383(98)90009-1)
- Carpenter, M., Call, J. & Tomasello, M. 2005 Twelve- and 18-month-olds copy actions in terms of goals. *Dev. Sci.* **8**, F13–F20. (doi:10.1111/j.1467-7687.2004.00385.x)
- Curio, E., Ulrich, E. & Vieth, W. 1978 Cultural transmission of enemy recognition: one function of avian mobbing. *Science* **202**, 899–901. (doi:10.1126/science.202.4370.899)
- Custance, D. M., Prato Previde, E., Spiezio, C., Rigamonti, M. & Poli, M. 2006 Social learning in pig-tailed macaques and adult humans on a two-action Perspex fruit. *J. Comp. Psychol.* **120**, 303–313. (doi:10.1037/0735-7036.120.3.303)
- Dautenhahn, K. & Nehaniv, C. L. (eds) 2002 *Imitation in animals and artifacts*. Cambridge, MA: MIT Press.
- Dawson, B. V. & Foss, B. M. 1965 Observational learning in budgerigars. *Anim. Behav.* **13**, 470–474. (doi:10.1016/0003-3472(65)90108-9)
- Flynn, E. & Siegler, R. 2007 Measuring change: current trends and future directions in microgenetic research. *Infant Child Dev.* **16**, 135–149. (doi:10.1002/icd.502)
- Flynn, E. & Whiten, A. 2008 Cultural transmission of tool-use in young children: a diffusion chain study. *Social Dev.* **17**, 699–718. (doi:10.1111/j.1467-9507.2007.00453.x)
- Flynn, E. & Whiten, A. In press. Imitation of hierarchical structure versus component details of complex actions by 3- and 5-year-olds. *J. Exp. Child Psychol.* (doi:10.1016/j.jecp.2008.05.009)
- Frith, C. D. & Wolpert, D. M. (eds) 2003 *Neuroscience of social interactions: decoding, influencing & imitating others*. Oxford, UK: Oxford University Press.
- Gergely, G. & Csibra, G. 2005 The social construction of the cultural mind: imitative learning as a mechanism of human pedagogy. *Interact. Stud.* **6**, 463–481. (doi:10.1075/is.6.3.10ger)
- Gergely, G. & Csibra, G. 2006 Sylvia's recipe: the role of imitation and pedagogy in the transmission of human culture. In *Roots of human sociality: culture, cognition, and human interaction* (eds N. J. Enfield & S. C. Levinson), pp. 229–255. Oxford, UK: Berg Publishers.
- Gergely, G., Bekkering, H. & Király, I. 2002 Developmental psychology: rational imitation in pre-verbal infants. *Nature* **415**, 755. (doi:10.1038/415755a)
- Hayashi, M., Mizuno, Y. & Matsuzawa, T. 2005 How does stone-tool use emerge? Introduction of stones and nuts to naive chimpanzees in captivity. *Primates* **46**, 91–102. (doi:10.1007/s10329-004-0110-z)
- Horner, V. & Whiten, A. 2005 Causal knowledge and imitation/emulation switching in chimpanzees (*Pan troglodytes*) and children (*Homo sapiens*). *Anim. Cogn.* **8**, 164–181. (doi:10.1007/s10071-004-0239-6)
- Horner, V., Whiten, A., Flynn, E. & de Waal, F. B. M. 2006 Faithful replication of foraging techniques along cultural transmission chains by chimpanzees and children. *Proc. Natl Acad. Sci. USA* **103**, 13 878–13 883. (doi:10.1073/pnas.0606015103)
- Hurley, S. & Chater, N. 2005 *Perspectives on imitation: from mirror neurons to memes*. Cambridge, MA: MIT Press.
- Kirby, S., Cornish, H. & Smith, K. 2008 Cumulative cultural evolution in the laboratory: an experimental approach to the origins of structure in human language. *Proc. Natl Acad. Sci. USA* **105**, 10681–10686. (doi:10.1073/pnas.0707835105)
- Kubota, N. 2005 Computational intelligence for structured learning of a partner robot based on imitation. *Inform. Sci.* **171**, 403–429. (doi:10.1016/j.ins.2004.09.012)
- Laland, K. N. & Plotkin, H. C. 1990 Social learning and social transmission of foraging information in Norway rats (*Rattus norvegicus*). *Anim. Learn. Behav.* **18**, 246–251.
- Lefebvre, L. 1986 Cultural diffusion of a novel food-finding behaviour in urban pigeons: and experimental field test. *Ethology* **71**, 295–304.
- Lukowski, A. F., Wiebe, S. A., Haight, J. C., DeBoer, T., Nelson, C. A. & Bauer, P. J. 2005 Forming a stable memory representation in the first year of life: why imitation is more than child's play. *Dev. Sci.* **8**, 279–298. (doi:10.1111/j.1467-7687.2005.00415.x)
- Lyons, D., Young, A. & Keil, F. 2007 The hidden structure of overimitation. *Proc. Natl Acad. Sci. USA* **104**, 19 751–19 756. (doi:10.1073/pnas.0704452104)
- McGuigan, N., Whiten, A., Flynn, E. & Horner, V. 2007 Imitation of causally-opaque versus causally-transparent tool use by 3- and 5-year-old children. *Cognit. Dev.* **22**, 353–364. (doi:10.1016/j.cogdev.2007.01.001)
- Meltzoff, A. N. 1988 The human infant as *Homo imitans*. In *Social learning: psychological and biological perspectives* (eds T. Zentall & B. G. Galef), pp. 319–341. Hillsdale, NJ: Erlbaum.
- Meltzoff, A. N. & Prinz, W. 2002 *The imitative mind: development, evolution, and brain bases*. Cambridge, UK: Cambridge University Press.
- Menzel, E. W., Devenport, R. K. & Rogers, C. M. 1972 Proto-cultural aspects of chimpanzees' responsiveness to novel objects. *Folia Primatol.* **17**, 161–170.
- Mesoudi, A. & Whiten, A. 2008 The multiple roles of cultural transmission experiments in understanding human cultural evolution. *Phil. Trans. R. Soc. B* **363**, 3489–3501. (doi:10.1098/rstb.2008.0129)
- Nielsen, M. 2006 Copying actions and copying outcomes: social learning through the second year. *Dev. Psychol.* **42**, 555–565. (doi:10.1037/0012-1649.42.3.555)

- Nielsen, M. In press. The imitative behaviour of children and chimpanzees: a window on the transmission of cultural traditions. *Primatologie*.
- Plotkin, H. 2003 We-intentionality: an essential element in understanding human culture. *Perspect. Biol. Med.* **46**, 283–296. (doi:10.1353/pbm.2003.0028)
- Reader, S. M. & Laland, K. N. 2000 Diffusion of foraging innovations in the guppy. *Anim. Behav.* **60**, 175–180. (doi:10.1006/anbe.2000.1450)
- Richerson, P. & Boyd, R. 2005 *Not by genes alone: how culture transformed human evolution*. Chicago, IL: University of Chicago Press.
- Rogers, S. & Williams, J. (eds) 2006 *Imitation and the social mind*. New York, NY: Guilford Publications.
- Spiegel, M. R. 1961 *Theory and problems of statistics*. New York, NY: Schaum Publishing Company.
- Sterelny, K. 2006 The evolution and evolvability of culture. *Mind Lang.* **21**, 137–165.
- Tennie, C., Call, J. & Tomasello, M. 2006 Push or pull: imitation versus emulation in human children and great apes. *Ethology* **112**, 1159–1169. (doi:10.1111/j.1439-0310.2006.01269.x)
- Tomasello, M. 1990 Cultural transmission in the tool use and communicatory signaling of chimpanzees? In *Language and intelligence in monkeys and apes: comparative developmental perspectives* (eds S. Parker & K. Gibson), pp. 274–311. Cambridge, UK: Cambridge University Press.
- Tomasello, M. 1999 *The cultural origins of human cognition*. Cambridge, MA: Harvard University Press.
- Tomasello, M., Kruger, A. C. & Ratner, H. H. 1993 Cultural learning. *Behav. Brain Sci.* **16**, 495–552.
- Tomasello, M., Carpenter, M., Call, J., Behne, T. & Moll, H. 2005 Understanding and sharing intentions: the origins of cultural cognition. *Behav. Brain Sci.* **28**, 675–691. (doi:10.1017/S0140525X05000129)
- Uzgiris, I. 1981 Two functions of imitation during infancy. *Int. J. Behav. Dev.* **4**, 1–12. (doi:10.1016/S0163-6383(81)80003-3)
- Want, S. C. & Harris, P. L. 2002 How do children ape? Applying concepts from the study of non-human primates to the developmental study of ‘imitation’ in children. *Dev. Sci.* **5**, 1–13. (doi:10.1111/1467-7687.00194)
- Whiten, A. & Mesoudi, A. 2008 Establishing an experimental science of culture: animal social diffusion experiments. *Phil. Trans. R. Soc. B* **363**, 3477–3488. (doi:10.1098/rstb.2008.0134)
- Whiten, A., Horner, V. & de Waal, F. B. M. 2005 Conformity to cultural norms of tool-use in chimpanzees. *Nature* **437**, 737–740. (doi:10.1038/nature04047)
- Whiten, A., Flynn, E., Brown, K. & Lee, K. 2006 Imitation of hierarchical structure in actions by young children. *Dev. Sci.* **9**, 574–582. (doi:10.1111/j.1467-7687.2006.00535.x)
- Williamson, R. & Markman, E. 2006 Precision of imitation as a function of preschoolers’ understanding of the goal of the demonstration. *Dev. Psychol.* **42**, 723–731. (doi:10.1037/0012-1649.42.4.723)