

## Imitation and Modeling<sup>☆</sup>

**Andrew N Meltzoff**, University of Washington, Seattle, WA, United States  
**Rebecca A Williamson**, Georgia State University, Atlanta, GA, United States

© 2017 Elsevier Inc. All rights reserved.

<b>Introduction</b>	2
<b>Humans as the Imitative Animal</b>	2
<b>Conceptual Distinctions: Distinguishing Imitation From Other Forms of Social Learning</b>	2
<b>Explaining Human Imitation</b>	3
The Binding Problem	3
Learning to Imitate by Operant Conditioning	3
Learning to Imitate by Associative Learning	3
Piaget's Theory of Imitative Development	4
<b>Imitation of Facial Acts</b>	4
Active Intermodal Mapping Theory	5
Neural Mirroring Systems and Imitation	5
<b>Using Imitation to Learn About Objects</b>	6
Imitation of Novel Acts From Memory	6
<b>Imitation of Peers Outside the Dyad</b>	7
<b>Using Imitation to Learn About People</b>	7
Imitation and Social Communication	7
Roots of Social Cognition: Others "Like-Me"	7
<b>The Regulation of Imitation: Who, What, and When to Imitate</b>	8
Regulation of Imitation by Goals and Intentions	8
Regulation of Imitation by Emotions: Emotional Eavesdropping	8
Regulation of Imitation by Prior Experience and Success of the Model	9
<b>Infant Imitation as an Interdisciplinary Field</b>	9
Autism	9
Social Robotics	9
<b>Summary and Future Directions</b>	10
<b>Acknowledgments</b>	10
<b>Further Reading</b>	10

### Glossary

**Binding Problem** Binding refers to the mechanism by which a particular motor response is triggered or prompted by particular perceptual input—usually a visual or auditory stimulus.

**Intermodal** A connection that spans across perceptual modalities, for example touch to vision or audition to vision. Watching someone else speak provides intermodal input because they are seen as well as heard.

**Invisible or Opaque Imitation** A term used to refer to a particular kind of imitation in which the behavior of the model and imitative response cannot be perceived within the same modality. Facial imitation qualifies: Although the actor can see the model's face, she cannot see her own face. It remains invisible.

**Proprioception** The perceptual process by which we monitor our own body position in space and the relation between our moving body parts. If you close your eyes and move your fingers, hands, or feet you can "sense" the form your body takes through proprioception. You monitor your own facial expressions through proprioception.

**Social Cognition** Perception and cognition about other people (as opposed to space, objects, numbers). Social cognition typically involves processing other people's internal states including their wants, thoughts, intentions, and emotions; but more elementary levels may involve processing how other people move, behave and other basic social information.

<sup>☆</sup>*Change History:* February 2016. Andrew N Meltzoff and Rebecca A Williamson updated sections on: Neural Mirroring, Systems and Imitation, Using Imitation to Learn About Objects, Using Imitation to Learn About People, Regulation of Imitation, Imitation as an Interdisciplinary Field, and References.

## Introduction

Young humans excel in learning by watching and imitating. Imitation is a means by which young children profit from information that has been learned by previous generations. Imitation provides an efficient channel through which the young incorporate behaviors, skills, customs, and traditions from experts in the culture. Imitation is faster than independent discovery (the type of learning emphasized by Piaget) and safer than trial-and-error learning (the type of learning emphasized by Skinner).

The imitative skills of human infants go hand in hand with the motivation of adults to teach their young. Adult pedagogy, in the form of purposely showing a child what to do, is so common in our everyday lives that it is often taken for granted. Adult modeling and infant imitation are pillars of human culture.

## Humans as the Imitative Animal

Bona fide instances of imitative learning in nonhuman animals are rare enough to provoke scientific debate. Animal behavior texts devote discussion to the unusual case of Japanese macaques who began washing their sweet potatoes in the sea after watching a few juveniles who invented this technique. Rigorously controlled experimental studies yield some evidence of imitation in chimpanzees and other nonhuman primate species, but the data suggest that the animals are less likely to imitate a wide range of arbitrary acts than are humans. Moreover, when they do copy, nonhuman primates are unlikely to reproduce the exact acts they see. In contrast, even casual observation of human behavior reveals myriad instances of imitation in young children—the imitation of parental postures, facial expressions, tool use, vocalizations, mannerisms, and customs.

In the 1930s, Margaret Mead highlighted the role of childhood imitative learning in non-Western societies. She published photographs from her research of the Balinese people in Indonesia. Mead's plates provide snapshots of behavior that would be unusual in Western infants and may be partly attributable to imitation of the adults in that culture. One photo shows an infant just under 1 year of age wielding a machete-like knife. Another shows an older infant using the distinctive manual techniques employed by musicians to play a "tjoengklink," a bamboo instrument.

A bold experiment in comparative psychology from the 1930s also underscores the special imitative prowess of *Homo sapiens*. Ironically, the goal of this study was to show that the chief behavioral differences between the young humans and chimpanzees were attributable to differential rearing conditions. The Kelloggs raised an infant chimpanzee alongside their infant son, providing them with environments as identical as possible. Both were diapered, talked to while playing on the Kelloggs' laps, hugged, and enculturated. Much to the researchers' disappointment, the infant chimpanzee never grew to be very human-like. But the report reveals that the human infant learned a great deal from watching the chimpanzee. The boy was reported to scrape paint off walls with his teeth, to engage in certain mauling play tactics, and most dramatically, to imitate the barks and grunts of the chimp when he saw a favorite food. It seems likely that these behaviors were performed by the human child in imitation of the ape—a direction of transmission unanticipated by the Kelloggs.

## Conceptual Distinctions: Distinguishing Imitation From Other Forms of Social Learning

So far the concept of imitation has been used in a commonsense way to mean that the observer duplicates the act that the model performs. Researchers have sought an operational definition of imitation that can be used in designing experiments with rigorous controls. Imitation requires that three conditions are met: (1) the perception of an act causes the observer's response, (2) the observer produces behavior similar to that of the model, and (3) the equivalence between the acts of self and other plays a role in generating the response. In imitating, the goal of the observer is to match the target behavior. Equivalence need not be registered at a conscious level, but if it is not used at any level (neurally, cognitively, computationally), then lower-order nonimitative processes may be more parsimonious.

Several decades of careful analysis have taught us that distinguishing imitation from other forms of social learning is useful. There are a variety of mechanisms underlying social learning and true imitation, when defined and measured rigorously, is more prominent in humans than in other species. Conceptual distinctions can be drawn among imitation, social facilitation, contagion, and stimulus enhancement.

Social facilitation is an increase in the production of a target behavior due to the mere presence of a conspecific. Suppose an adult waves bye-bye to a young baby. In response the baby may flap her arms, duplicating the motor pattern that was demonstrated. This could be an imitative response, but if the arm flapping is due to the child being excited at seeing an adult, it would be more sensibly classified as social facilitation.

Contagion covers an increase in an instinctual behavior pattern upon observing a similar pattern by a conspecific. For example, some animals increase their eating behavior upon seeing other animals eat. In this case the observer is neither learning a new behavior nor sculpting a behavior in its repertoire to match what it sees. Seeing another animal eat triggers feeding behavior in the observer and the shared bodily morphology assures that the stimulus and response take the same form.

Stimulus enhancement (and local enhancement) refer to the fact that performing actions on the world draws an observer's attention to certain stimulus objects and locations. Jane Goodall noted that the juvenile chimpanzees in the Gombe Stream Reserve were often attracted to the place where the adults fished for termites, and that they played with the same sticks that the adults used. If they

later use the sticks to obtain termites, this could be because the young chimps discovered this through their own chance manipulations of the sticks rather than through strict imitation of the adult's actions.

In addition to these distinctions, comparative researchers such as Michael Tomasello, Josef Call, and Andrew Whiten have attempted to differentiate imitation from what they call emulation. In both imitation and emulation there is an attempt to match. In the former the bodily act is copied; in the latter it is only the end-state or outcome that is duplicated. For example, if the adult puts one block on top of another with a flourish, the child might copy: (1) the distinctive motor pattern used (the specific "flourish"), which is imitation or (2) the end result of one block on top of the other even if it is accomplished via a different motor movement, which is called emulation. A current debate is whether these should be considered different processes or whether they are two exemplars of the more general category, one oriented toward the bodily act and the other toward the end-state.

## Explaining Human Imitation

### The Binding Problem

There is no question that children are avid imitators, but there is debate about when imitation begins in human ontogeny and what mechanisms underlie it. Questions about development and mechanism are intertwined. The fundamental issue is how infants come to "glue" together an observed stimulus with a matching response of their own. What links the observed behaviors of others to one's own body parts and actions, underwriting the imitative response? This conundrum has also been called the mechanism question or the correspondence problem. We will call this the binding problem, a phrase that has the advantage of remaining neutral with respect to the psychological processes and neural underpinnings involved. Whatever one's theory of imitation, the stimulus and matching response are linked, bound, or connected.

There are three classical explanations of how infants first come to match the acts of others and solve the binding problem: operant conditioning, associative learning, and Piagetian theory.

### Learning to Imitate by Operant Conditioning

Skinner proposed that imitation is simply a special case of operant conditioning where the stimulus and response happen to match. He noted that pigeons can be conditioned to peck a key when they see other pigeons peck. If a pigeon (P-1) pecks at a key and an observer pigeon (P-2) is reinforced with food for pecking upon seeing this event, P-2 will eventually be shaped to peck when seeing P-1 pecking. Note that P-2 did not produce this act because it was motivated to match the other animal's behavior. All that has happened is that the behavior of P-1 became a discriminative cue for eliciting a conditioned response in P-2. The observer pigeon could be conditioned to perform a mismatched act just as easily. The similarity of the stimulus and response plays no role.

Strong operant conditioning theorists hold that there can be no infant imitation without a prior period of shaping that binds the discriminative cue to the response. For example, when a young infant sees a mother perform a simple act such as shaking a rattle, the infant at first does not know what movements to use to copy this act. Rather, the parent needs to shape the child's response through operant conditioning. Mom shakes the rattle, and the infant responds with random motor acts. Mom selectively reinforces those acts that are similar to her own shaking movements. Over time, the mother's motions come to serve as a discriminative cue (a red light would do as well) that elicits the reinforced act (the baby's rattle shaking).

Infants and young children may learn certain acts in this way, but there are two drawbacks to this theory as a complete account of imitation. First, it cannot easily explain the imitation of novel acts—acts that the caretakers have not explicitly shaped up. Second, most ethnographic reports of parent-child interaction do not report the type of extensive shaping procedures needed to account for the range of acts infants and young children can imitate.

### Learning to Imitate by Associative Learning

A second theory about the origins of imitation, and solution to the binding problem, is based on associative learning. In this view, the infant's act and the adult's act are bound together because they frequently occur near each other in time—temporal contiguity. To understand how this applies to the current case it is useful to consider what happens when parents imitate their children. When the baby waves her hand, the parent may enthusiastically wave back; when baby bangs an object, the parent also bangs an object to play a reciprocal game. According to the associative learning view, infants come to associate their own acts with the similar ones of the parents. Thus, when they later see the parent's act, they produce the matching act that has been associated with it through regular temporal contiguity. In a sense, infants come to imitate adults to the extent that the adults have previously imitated their infants.

There have been reports of parents copying their infants, so there is an opportunity for infants to bind together certain acts of self and other through practice with these reciprocal imitation games. However, the associative learning view has difficulty explaining the imitation of *novel* acts that have not served as familiar games in the past. Moreover, observers of parent-child interaction have shown that parents usually embellish and vary the behavior they see the infant perform, rather than simply mirroring it. This would predict associations between nonidentical behaviors; it would predict imitative errors of a type that have rarely been observed. (A variant of this view holds that infants learn to imitate others through associating an action such as shaking a rattle with the outcome; then when the adult later produces the outcome, the infant generates the associated motor actions. Again the challenge

is provided by the imitation of novel acts that are not familiar games for the infant.) The theory of associative learning was espoused by John Locke, David Hume, and other British Empiricists in the 17th–8th Century. Despite its longevity, it is not clear that it can, taken by itself, explain the full richness and specificity of human imitation. Something more is needed.

### Piaget's Theory of Imitative Development

The fact is that human beings, at some age at least, are capable of spontaneously imitating novel adult displays for which there is no previous training history, no physical molding of the body, and no coaxing in any way other than the brief presentation of the model. Jean Piaget devoted his book *Play, Dreams and Imitation in Childhood* to the ontogenesis of this capacity. He was not concerned with trained matching responses that derived from conditioning or associative learning. Indeed, Piaget dismissed such behavior as mere “pseudoimitation.” In his view imitation is intertwined with cognitive development and unfolds in a series of invariantly ordered stages.

Piaget postulated six stages in infants' imitation, and for ease of summary they will be collapsed into three major levels. In level-1 (0–8 months of age; sensorimotor stages 1–3) infants are restricted to the imitation of simple hand movements and vocalizations. For example, the Piagetian 6-month-old would be expected to imitate a simple hand-opening gesture or an /a/-vocalization even if the infant had never had the relevant associative learning experience. Piaget's notion is that both of these types of imitation can be accomplished on the basis of an intramodal matching process. In principle, the infant could directly compare the adult's hand movements with those of his own visible hand, and thereby use vision as a guide in the matching process. Similarly, the infant could use audition to monitor both his own and the model's vocalizations and to guide his own vocalizations until they sounded like the model's.

In level-2 (8–18 months of age; sensorimotor stages 4–5) infants first become capable of imitating facial behaviors and novel acts. The fundamental claim made by Piaget is that the difficulties involved in manual and vocal imitation pale in comparison to those involved in facial imitation. Because infants cannot see their own faces, they cannot directly compare their own acts with the ones they see. According to Piaget, facial imitation (or invisible imitation as it is sometimes called) is a landmark cognitive achievement that is first passed during stage 4 of the sensory-motor period.

Finally, level-3 (18–24 months; sensorimotor stage 6) is characterized by the emergence of deferred imitation—the ability to perceive a behavior at one point in time and then, without having responded in the presence of the demonstration, to delay the duplication for a significant period. Deferred imitation directly implicates mnemonic and representational capacities, and Piaget argued that it emerged synchronously with other complex cognitive abilities such as high-level object permanence (the search for invisibly displaced objects), symbolic play, and insightful problem-solving. All these synchronous developments constituted what Piaget termed stage 6, the last sensory-motor stage of infancy.

In summary, Piaget's cognitive-developmental hypothesis is that infants gradually become able to imitate events that are farther and farther removed from the immediate sensory field. First they imitate those involving intramodal comparisons (manual and vocal acts), next those involving cross-modal comparisons (facial acts), and finally those implicating a stored representation of the modeled act (deferred imitation). Piaget rejected the idea that infant imitation was based on learned associations, but rather argued that it was based on a cognitive sophistication that emerged gradually in stages. Piagetian theory makes at least three strong predictions that have sparked empirical work: (1) facial imitation is impossible before about 8–12 months of age (stage 4), (2) deferred imitation is impossible until about 18 months of age (stage 6), and (3) infants will progress through the stages in an invariant order, it being impossible to reach higher stages without having achieved the milestones of the preceding stage. As we will see below, these predictions have not been borne out in laboratory studies. This, in turn, has generated new theorizing about the origins and development of human imitation.

### Imitation of Facial Acts

Evaluating the three classical solutions to the binding problem (operant conditioning, associative learning, Piagetian development) has been challenging. The problem, in most cases, is that one does not have full knowledge of the child's (or animal's) reinforcement and learning history. Using a novel act as the target is one way to address this issue. A different approach is to test infants at a young age before they have had a chance to learn to link the stimulus and response through conditioning or association. Such demonstrations of imitation prior to the required learning would demand a different explanation than operant conditioning and associative learning. The Piagetian view could explain the early manual and vocal imitation, because infants can compare their own acts with the ones they see and hear. Infants cannot, however, see their own faces. If they are young enough they will never have seen their own faces in a mirror. Piaget predicts that facial imitation is beyond the cognitive abilities of the infant younger than about 8–12 months of age. Because it provides such a powerful test of extant theories of imitation, developmental psychologists have actively investigated the first appearance of facial imitation in human infants.

In 1977, Meltzoff and Moore reported the surprising results that 12- to 21-day-olds imitated four different gestures, including facial and manual movements. The infants responded differentially to an observed tongue protrusion by producing a tongue protrusion, and not lip protrusion, suggesting that they can identify the specific body parts involved. They also responded differentially to lip protrusion versus lip opening, showing that different action patterns can be imitated with the same body part. In 1994, the same authors extended this research by showing that young infants (1) differentially imitate

two different types of movements with the tongue and (2) also correct their imitative behavior to more closely match the target they see. At the current point in time, published studies of early imitation have documented a range of acts that can be imitated, including mouth opening, lip protrusion, tongue protrusion, selected emotional expressions, head movements, and simple hand and finger movements. In all, there are more than 30 published studies of early imitation from more than 13 independent laboratories. Attention has shifted beyond tests of the raw existence of early behavioral matching to investigations of the mechanisms underlying it and its functional significance.

These findings argue against all three of the traditional solutions to the binding problem. Neither associative learning, nor operant conditioning, nor Piagetian theory can account for these empirical results. Current scientific approaches are now investigating both the psychological processes and the neural underpinnings for linking the perception and production of isomorphic acts. Two behavioral discoveries are key. First, early imitation is not restricted to immediate duplication. In one facial imitation experiment, the infants had a pacifier in their mouths so that they couldn't imitate during the demonstration. The pacifier was then withdrawn, and the results showed that the infants initiated their imitation in the subsequent 2.5 min response period while looking at a passive face. Second, infants correct their imitative response. Infants converge on the match without feedback from the experimenter. An infant's first response to seeing a facial gesture is the activation of the corresponding body part with a gradual homing in on the action demonstrated.

### Active Intermodal Mapping Theory

Meltzoff and Moore proposed the active intermodal mapping (AIM) theory to explain facial imitation. The key claim is that early imitation is a matching-to-target process. The active nature of the matching process is captured by a proprioceptive feedback loop. The loop allows infants' motor performance to be evaluated against the seen target and serves as a basis for infants to correct their acts. AIM proposes that such comparison is possible because the observation and execution of human acts are coded within a shared framework or "supramodal act space" that is not restricted to modality-specific information (visual, tactile, motor, etc.). In this view, although infants cannot see their own facial expressions, they still have perceptual access to their facial movements through proprioception. AIM does not rule out the existence of certain basic acts that can be imitated on first try without the need for feedback, but it allows proprioceptive monitoring and the correction of responses for novel acts.

This idea of a supramodal coding of human acts that emerged from developmental studies fits well with proposals from cognitive science about action coding (the common coding thesis of Wolfgang Prinz) and discoveries in neuroscience about the representation of action.

### Neural Mirroring Systems and Imitation

There has been an explosion of interest in imitation in the neuroscience community. In part this owes to the fact that in the 1990s Giacomo Rizzolatti, Vittorio Gallese, and a team of other neuroscientists in Parma, Italy discovered neurons in the premotor cortex of the monkey's brain (area F5) with peculiar properties. These were dubbed mirror neurons because these neurons fire both when the monkey performs certain goal-directed acts, such as grasping food, and also when they observe another perform the same act. These neurons code the act regardless of whether it is performed by the self or the other. Some have theorized that mirror neurons provide the neural substrate for imitation.

Following the initial discovery of mirror neurons in monkeys, Marco Iacoboni, Jean Decety, and others have used functional magnetic resonance imaging to provide evidence of neural circuits in adult humans that have similar mirror properties. These shared circuits become activated whether the adult performs a certain act (for example, raising and lowering his index finger) or merely observes another person doing so. Nonetheless, newborn humans are different from monkeys, who are in turn different from human adults. In order to provide neuroscience data and theory that is relevant to infant imitation, there is a need for brain studies using human infants as subjects.

Relevant results are now beginning to emerge. For example, Peter Marshall, Andrew Meltzoff, and colleagues have found evidence of systematic neural activity during studies of imitation in infants. For these studies, the infant electroencephalogram (EEG) was employed. The researchers discovered similar activation in infants' sensorimotor cortex whether a target act was produced or simply observed. Further, the particular area within the sensorimotor cortex that showed activation differed as a function of the specific body part used (a hand vs. a foot). Thus, consistent with the infant imitation data and the AIM theory, these results demonstrate a neural mapping between self and other in infancy.

Much more developmental neuroscience work is needed to delineate the neural systems underlying human imitation. Indeed, the extant infant neuroscience data suggest that classical mirror neurons cannot be the whole story in the case of human infancy. In a 2014 article in the *Philosophical Transactions of the Royal Society*, Marshall and Meltzoff draw three key distinctions between classical mirror neurons as reported in monkeys and the results on imitation in human infancy. First, mirror neurons are best suited to explaining immediate resonance phenomena (such as unconsciously adopting the same posture as someone else), and although immediate motor resonances exist in adults and children, they do not exhaust the imitative capacities of human children. Second, infants can observe an act and then imitate it at a later time (deferred imitation), which demands more than mirror neurons alone. Third, human infants correct their imitative responses, which suggests a feedback loop that goes beyond mirror neurons per se. Moreover, human children continue to develop, and the imitative skills found in the preschool period are more complex than

have been tested in neuroscience studies to date. The next sections of this article move beyond the origins of imitation to consider data from toddlers and preschool age children that will set the agenda for future neuroscience work.

## Using Imitation to Learn About Objects

### Imitation of Novel Acts From Memory

For imitation to serve as a powerful learning mechanism in infancy and early childhood, infants need to imitate not only facial gestures and other simple body acts, but also tool-use and other instrumental behaviors. Moreover, they need to imitate novel acts after significant memory delays. Meltzoff conducted a series of studies probing infants' imitative abilities. One study with 14-month-olds had three features: (1) imitation was tested after a 1 week delay, (2) infants were required to remember not just one demonstration but multiple different demonstrations, (3) novel acts were used. One of the acts was to bend forward from the waist and touch a panel with one's forehead, which made the panel illuminate. This unusual act was not observed in more than 100 infants in free play, and certainly qualified as a novel display (baseline measures were also taken in the experiment).

Infants in the imitation group were shown different acts on six different objects on the first day of testing. They were not allowed to touch or handle the objects and were confined purely to watching the displays. Infants were then sent home for the 1-week delay. Upon returning to the laboratory, the infants in the imitation group were presented with the objects. In a baseline control group, the adult met the infants in session-1, but he did not manipulate the test objects; he simply talked pleasantly to the mother and child. Session-2 with this baseline group assessed the spontaneous likelihood of the infants producing the target acts in the presence of the adult, and thus controlled for social facilitation. Stimulus and local enhancement were ruled out through a third group called the adult-manipulation control. For this group, the adult manipulated the same objects as in the imitation group during session-1; but he did so using different movement patterns. The results showed significantly more target acts in the experimental group than in each of the two control groups, providing rigorous evidence for deferred imitation after a 1-week delay (Fig. 1) at an earlier age than is predicted by Piagetian theory. Rachel Barr, Harlene Hayne, and Andrew Meltzoff have also reported that infants in the 6- to 9-month-old age range can also perform deferred imitation, which is well before Piaget's 18-month-old mark.

With development, children's imitation of object-oriented acts becomes increasingly complex. In the second half of the first year of life, children move beyond reproducing individual acts and become able to reproduce action sequences. Patricia Bauer, Leslie Carver, and colleagues have coupled behavioral studies of sequence imitation with EEG measures to begin to document the neural networks used to support infants' imitation from memory. Other studies have combined long-term memory with changes in context. One example comes from a study by Pamela Klein and colleagues in which 12-month-old infants were shown how to use objects in a room that was covered in a bright orange and white polka-dotted tent. After a 4-week delay, the infants' imitation was tested in a standard white-walled lab room. Infants readily performed deferred imitation and reproduced the adult's acts across temporal delays and a change in context.

During the second year of life, children show developmental changes in the tendency to imitate actions on objects with high fidelity. In work by Mark Nielsen, children saw an adult use a tool to disengage a latch on box lid. At age 24 months, but not



**Figure 1** Fourteen-month-old infants can imitate novel acts such as touching their head to a panel. After successful imitation, infants often smile at the adult as shown in picture #6. This figure was published in Meltzoff, A.N., 1999. *Origins of theory of mind, cognition, and communication*. J. Commun. Disord. 32, 251–269, Copyright Elsevier 1999.

12 months, children used the tool (instead of their hand) to manipulate the latch. Through childhood and even in adults the tendency to imitate the exact means used by others is high. Indeed, young children will reproduce actions that are unnecessary for achieving a goal. Derek Lyons, Victoria Horner, Andrew Whiten, Frank Kiel, Nicola McGuigan and others have characterized this curious phenomenon, often called “overimitation.” Investigations are currently probing its causes. It is likely that the fidelity that humans show in the reproduction of others’ behaviors is important for the rapid and faithful spread of new innovations through human social groups.

As children move into the preschool period, they begin to use imitation to learn increasingly deep things about the physical world. A prime example is that they begin to use imitation to learn about “nonobvious properties” of objects, such as their weight. In a 2015 article published by Zhidan Wang and colleagues, 4-year-olds watched an adult lift visually identical objects and categorize them into two groups based on their felt weight. When children were later given their first opportunity to handle the objects, they too sorted the objects into two groups based on weight, although control groups did not. Children also generalized this categorization strategy to a novel set of objects that differed in kind and weight from the original set. Critically, this categorization by weight was found only when children saw the intentional sorting behaviors of the adult. Without this, children showed no evidence of success. The observation of the adult’s intentional behaviors, coupled with children’s imitation of the physical act of “hefting” the objects, provided the input necessary for children to learn and implement the categorization. This line of work opens up the (Vygotskian) possibility that social learning and imitation can contribute to children’s cognitive development, leading children to a deeper understanding of the invisible properties of objects.

### **Imitation of Peers Outside the Dyad**

Parents and other adults engage in purposeful pedagogy and play an important role in children’s socialization. However, other children can also provide important behavioral examples. Elizabeth Hanna tested whether infants take advantage of this source. In one study, 14-month-old naïve infants observed tutor infants. These tutors had been previously trained to play with the toys in novel ways. When the naïve infants were later presented with the test objects in the absence of the peer, they imitated. Further research extended to a daycare setting in which the demonstration was not one-to-one. Instead the tutor infant played with objects while a large group of naïve infants simply observed. The naïve infants were not allowed to approach or touch the toys. After a 2-day delay, a new experimenter brought a bag of objects to the infants’ homes and laid them out on a convenient table or floor. The results showed significant imitation, providing evidence for deferred imitation across a change in context (a shift from daycare to home site).

Emma Flynn and Andrew Whiten conducted related studies examining the transmission of a novel behavior over a series of child peers. In this work, a child (age 3–5 years) was shown how to use a tool to retrieve a reward from a puzzle box. That child then served as the example for a second child, and the second child for the third. Their results showed that novel behaviors can be successfully transmitted through chains of five different peers. The fact that young children imitate a variety of actors, can transfer their imitative learning to a different environment from the one in which they observed the model, and can do so after a delay implicates imitation as a mechanism for cultural transmission that extends beyond the laboratory.

## **Using Imitation to Learn About People**

### **Imitation and Social Communication**

As shown in the foregoing studies, children use imitation to learn about the physical world. However, children also use imitation for social purposes, such as communicating, sharing, and affiliating with others. There are differences in what should be imitated to engage another person socially versus learning an instrumental task (such as how to use a tool). Behaviors used for physical problem-solving often involve causal manipulations of the inanimate world. Those used for social purposes are more arbitrary and conventional. The imitation of unusual social acts is often incorporated into identification routines (a private “handshake” or cultural practice) and used in communication to establish and maintain common ground. Important cultural rituals can involve arbitrary acts—only the in-group knows the routine, which fosters group membership and cohesion. Indeed, as noted by Christine Legare and colleagues, actions involved in social rituals may not produce any changes in the physical world at all. Thus, the criteria for choosing what to imitate may be different for achieving physical versus social goals.

Moreover the motivation to be similar to the social other is an important component of human imitation. Human infants and young children strive to match their acts to those they see. Humans do not need to be motivated by food in order to imitate (as is the case in many nonhuman animal experiments); imitation is its own reward, a goal in itself. The motivation to “be like” the other suggests a drive for social connection and communication in typically developing children.

### **Roots of Social Cognition: Others “Like-Me”**

Scholars concerned with social cognition have often commented on the gulf between knowing the self and the other—the “problem of other minds.” We experience our own thoughts and feelings but do not see ourselves from the outside as others see us. We perceive visual and auditory signals emanating from others but do not directly experience their mental states. Analogously and

for similar reasons, developmental scientists are struck by the binding problem in behavioral imitation. Infants experience their own bodies and movements from the inside, but watch the movements of others from a completely different point of view. There seems to be a gap between the behaviors they see and their own behaviors. There are attempts to explain how infants bridge this gap, at both the psychological level (AIM theory) and at the cognitive neuroscience level (involving action representation and neural mechanisms), but more work is needed to provide detailed models.

Beyond this, however, the fact that typical children have the capacity for behavioral imitation provides them an important foothold in social development. Human parents often engage in reciprocal social games, and infants show sensitivity to behavioral matching through their looking and social responses. Recent EEG studies by Joni Saby and colleagues suggest that the same neurocognitive machinery involved in producing imitation also underlies the sensitivity to being imitated by others. EEG measures of the sensorimotor cortex show a special neural signature when infants observe an adult produce the same act that the infant just produced. This response is observed specifically when the adult's act matches the infant's; a mismatching temporally contingent act is not as effective at eliciting this EEG response.

In 2007, Meltzoff articulated a view of early social cognition called the "Like-Me" Framework, which proposes that parental imitation of children's behavior holds special significance not only because of the temporal contingencies involved, but because infants can recognize the structural congruence between the adult's acts and their own. The detection that some entity in the world is "like me," and can do what I do, could have cascading developmental effects. Children make a crucial social inference—entities who behaviorally act like me also share my internal emotions, desires, goals, and intentions. According to this framework, imitation is not only an aspect of early social cognition but also an engine in its development.

Allison Master, Dario Cvencek, and colleagues have extended this "Like-Me" Framework to preschool and elementary school children. They have used it to explain how social groups can influence learning of academic subjects. This work shows that social groups and a sense of belonging can be harnessed to increase children's motivation and engagement in STEM disciplines (science, technology, engineering, and mathematics), because children care so deeply about what others "like me" are thinking and doing.

## The Regulation of Imitation: Who, What, and When to Imitate

Adults are not blind imitators. They choose when, what, and whom to imitate. Developmentalists are beginning to investigate the regulation of imitation by children. The results are intriguing because they show that children do not automatically imitate what they are shown. Instead, there is a high degree of selectivity, flexibility, and control in childhood imitation.

### Regulation of Imitation by Goals and Intentions

Children do not always imitate what you do. If an adult makes a mistake or is unsuccessful in his attempt to complete a task, children will copy the intended goal instead of the outcome they observed. For example, Malinda Carpenter and Michael Tomasello showed 14–18-month-olds two actions that produced an interesting effect on an object. One of these acts was done in an accidental way and verbally marked by saying, "Woops!" The other act was done cleanly and the adult looked satisfied saying, "There!" The children skipped over the accidental acts and imitated those that appeared purposeful.

Actions do not have to be linguistically marked for children to understand the goal of the adult's act. Children will also use patterns of behaviors to infer the model's goal, even if he does not successfully achieve it. Meltzoff showed 18-month-olds an adult who repeatedly pulled at the ends of a barbell-shaped object, as if striving to pull it apart, but his hands slipped off each time he tried. When given a chance to manipulate the object, the children firmly wrapped their hands around the ends and yanked the object apart. Even though they had never seen the completed act, the children inferred the goal of the act from his try-and-try again behavior. The children did not slavishly imitate the unsuccessful motion by letting their fingers slip from the object, but instead completed the intended goal.

Jeff Loucks and colleagues have shown that children use inferred goals to organize their memory for action sequences and social events. In this study, 36-month-olds saw an adult perform two series of multistep acts, each leading to a different goal (e.g., bathing a doll vs. feeding the doll). In the critical experimental group, children saw these two sequences of actions interleaved, as if the adult was multi-tasking. The adult interwove these acts, instead of completing one goal and then starting the other. Despite this, children separated the two different goals in their imitative responses. Thus, they did not imitate exactly what they saw, but organized their imitative response so that they first performed all of the steps leading to one goal, and then the steps for the other. Instead of imitating the surface sequence of acts, children abstracted and reproduced a structure underlying the inferred goals. This and other related work strongly suggests that young children interpret what the adult is trying to do and re-enact the goal of the act, not what was literally done.

### Regulation of Imitation by Emotions: Emotional Eavesdropping

Experiments by Betty Repacholi and colleagues investigated whether 15- and 18-month-old infants use emotions to regulate their imitation. In this work, a model performed a series of novel acts on objects and a bystander either became angry (indicating these were forbidden acts) or remained pleasantly interested in what the model was doing. After this emotional reaction, the bystander adopted a neutral face. The infant simply watched this interchange between the two adults; they were not part of

the interaction. The question was whether infants regulated their subsequent imitation based on the bystander's emotional reaction. A second factor that was also manipulated was whether the bystander was looking at the infant when she was given a chance to imitate. Experimental conditions included: (1) the bystander left the room when the infant was given the chance to imitate, (2) the bystander was present but had her back turned, (3) the bystander looked at a magazine instead of at the child and (4) the bystander watched the infant. Each of these conditions was crossed with whether the bystander had exhibited anger or interest in the action when it was shown.

The results showed that if the adult had not exhibited anger at the action, the infants readily imitated (whether or not the adult could see them during the response period). But if the adult had exhibited anger at the action, then the infants were less likely to imitate the acts only when the adult was watching the infant and monitoring their behavior. If the previously angry adult left the room or had her back turned, the infants' did not diminish their imitation.

These effects cannot be explained by emotional contagion, because the infant had the chance to "catch" the adult's emotion equally well in all groups. Instead the toddlers' were regulating their imitation based on the conjunction of two factors: (1) whether the bystander had a negative emotional reaction to the act and (2) whether the bystander was watching what the infant did. Imitation is thus not automatic and inflexible. Instead, toddlers choose when to imitate. If imitating an act is likely to lead to anger in an adult, then infants refrain from imitating (as long as the adult is watching them). This is executive function in action.

### Regulation of Imitation by Prior Experience and Success of the Model

Rebecca Williamson and colleagues further investigated whether children are blind imitators or if they flexibly employ imitation depending on the circumstances. In one series of studies, the effect of prior experience with a task was investigated. Children, age 3 years, were given a straight-forward task, such as to open a drawer to retrieve a toy. One group of randomly-assigned children had an easy experience, the door opened easily. In contrast, children in the second group had a difficult experience in achieving the outcome; the drawer was surreptitiously held shut by a resistance device. Then all children saw an adult demonstrate opening the drawer by using a distinctive action. When given a second chance to perform the task, children were significantly more likely to imitate after a prior difficult experience with the task. Children who had prior difficulties were more motivated to adopt the adult's technique (with implications for educational practice and hands-on learning approaches).

Extensions of this work have shown that children also weigh *other* people's track record when deciding whether to imitate. For example, after watching one actor struggle to complete a task, 36-month-olds were more likely to imitate a second actor's novel technique. Just as children can consider their own efficacy, they can also use others' efficacy to regulate their imitation. Further, even children who had a difficult prior self-experience were unlikely to imitate an adult's ineffective example. If the adult's technique did not produce the desired outcome (e.g., the adult couldn't open the drawer), children did not imitate that model.

Studies by Stephen Want and Paul Harris showed that preschool children learn from seeing the steps that led up to a successful end-state performance. Children who saw the model make mistakes and correct the behavior were more likely to imitate that successful act than those who did not see the preceding errors. Mark Nielsen adapted this procedure for 12-month-olds. If the infants first saw an adult try but fail to open a box with his hand, they were more likely to imitate his subsequent demonstration of how to use a certain tool to succeed. Taken together, this research suggests that infants and young children are not blind imitators, and imitation is not uncontrolled and automatic. Infant and child imitation is altered depending on a the context and the larger envelope of the model's behavior. Imitation is selective and actively regulated by the child.

## Infant Imitation as an Interdisciplinary Field

### Autism

Children with autism spectrum disorders have a core deficit in the ability to communicate with others and in understanding others' thoughts, feelings, and actions. It has long been known that children with autism have deficits in a cluster of skills such as language, symbolic play, and social reciprocity. There has been excitement about empirical studies establishing that children with autism also show atypical performance on a variety of imitation tasks. This has been demonstrated in both high- and low-functioning children with autism, even after carefully matching for mental age. Further research is needed to characterize the precise nature of the imitative deficit in children with autism, and to distinguish when different aspects of the model's behavior (means, ends, goals, intentions) are imitated. One provocative possibility is that children with autism lack the fundamental motivation to imitate social others, to "be like" their social partners.

### Social Robotics

The work on imitation in infants and children has sparked collaborative work between computer scientists and developmental scientists. One reason is that roboticists want to build robots that interact more naturally with humans. They have noted that imitative responses are part and parcel of natural social exchanges and may help make robots more user-friendly.

A second motivation is that it is burdensome or impossible to write code that anticipates all of the novel acts that a user may want the robot to perform. An imitative robot would allow the owner to show the robot what to do in much the same way you teach a pre-verbal child—by showing them. If you want your robot to pour a cup of tea, you demonstrate how to pour your

particular teapot in front of the robot's sensors and a processor would translate the observed actions into commands to the robot's effectors.

A third motivation for increased collaboration between roboticists and imitation researchers is to give robots new, more human-like social capacities. When learning to recognize others, infants do not just consider what the other person looks like. They also track the distinctive behaviors that others use to engage them. Meltzoff and Moore argued that these distinctive behaviors are often learned through reciprocal imitation games. They call this the "social identity function" of imitation. A 2016 paper by David Cohen and colleagues described a computational model for recognizing adults, avatars, and autistic children based on how these partners responded in a mutual imitation game. The work grew directly from the idea that children learn person-recognition routines through imitation. The upshot is that there is now a better computer algorithm that can be used by a robot to re-identify a social individual after a break in perceptual contact.

A final motivation for this interdisciplinary work derives from the developmentalists themselves. Computer models provide psychologists a rigorous means of testing their theoretical hypotheses regarding the mechanisms underlying imitation. For example, a 2015 article by Michael Chung, Rajesh Rao, and colleagues reported an algorithm for robotic learning based on ideas from Meltzoff's "Like-Me" framework. This algorithm allowed a robot to monitor the consequences of its own actions and, after sufficient self-experience, to use this information to predict the goals of *another* person. Further, when put into an imitative context, the robot was able to engage in goal-oriented imitation. This work successfully uses Bayes nets to embody the idea, derived from developmental science, that self-experience and goal-inference are key components of infant imitation. The hope is that this interdisciplinary work will help computer scientists to design better robots and developmental researchers to construct better theories.

## Summary and Future Directions

Imitation provides a mechanism, prior to language, through which the human young learn from and about people. Researchers have adopted a definition of imitation that distinguishes imitation from other related concepts (e.g., social facilitation, contagion, and stimulus enhancement). This has allowed them to address three crucial issues: existence, mechanism, and cognitive and social functions of imitation. At the psychological level, the AIM mechanism holds that the perception and production of human acts are mediated by a common code, a "supramodal" framework. Researchers, guided by the behavioral data discovered over the past 30 years on infant imitation, are now uncovering the neural substrates of imitation.

Future work on imitation will rely on techniques in developmental cognitive neuroscience to more fully explicate the mechanisms binding together perception and production. Other future work will focus on robotics. Computer scientists seek to design robots that can learn by observing and imitating others; and they are increasingly turning to developmental science for a "biologically plausible" model of imitative learning. Finally, the bridge to autism is promising, because children with autism have core deficits in social understanding, including dysfunctions in imitation. Cutting-edge interventions aimed at promoting imitation skills in young children with autism may have more general effects of improving their understanding of people.

The capacity for flexible and selective imitation of peers and adults suggests that imitation is a powerful learning mechanism in human children and plays a role in the transmission of human culture. By deepening our understanding of childhood imitation, we will advance not only theories of developmental science, but also spark interdisciplinary insights across a broad array of fields within the cognitive sciences.

## Acknowledgments

Support was provided by grants from the National Institute of Child Health and Human Development (HD-22514 and U54HD083091), the National Science Foundation (SMA-0835854), and the Tamaki Foundation.

## Further Reading

- Heyes, C.M., Galef Jr., B.G., 1996. *Social Learning in Animals: The Roots of Culture*. Academic Press, San Diego.
- Hurley, S., Chater, N. (Eds.), 2005. *Perspectives on Imitation: From Neuroscience to Social Science*, vols. 1 and 2. MIT Press, Cambridge, MA.
- Marshall, P.J., Meltzoff, A.N., 2014. Neural mirroring mechanisms and imitation in human infants. *Philos. Trans. R. Soc. Biol. Sci.* 369, 20130620.
- Meltzoff, A.N., 2007. 'Like me': a foundation for social cognition. *Dev. Sci.* 10, 126–134.
- Meltzoff, A.N., Prinz, W. (Eds.), 2002. *The Imitative Mind: Development, Evolution and Brain Bases*. Cambridge University Press, Cambridge.
- Nadel, J., Butterworth, G. (Eds.), 1999. *Imitation in Infancy*. Cambridge University Press, Cambridge.
- Nehaniv, C.L., Dautenhahn, K. (Eds.), 2007. *Imitation and Social Learning in Robots, Humans, and Animals: Behavioural, Social and Communicative Dimensions*. Cambridge University Press, Cambridge.
- Piaget, J., 1962. *Play, Dreams and Imitation in Childhood* (C. Attengno and F.M. Hodgson, Trans.). Norton, New York.
- Rogers, S.J., Williams, J.H.G., 2006. *Imitation and the Social Mind: Autism and Typical Development*. Guilford, New York.