Learning theories

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Introduction

As human children develop they learn in that they acquire new behaviors and new knowledge, and they do so at a remarkable speed. But how is this learning done? Several psychological theories have been formulated to account for this process. These theories vary with respect to what mechanism(s) they posit as central, but also with respect to what they deem as the substrate and outcome of learning. Some view the young learner as actively participating in the process, others postulate mechanisms which support learning, whether the learner is active or passive. Some focus on universal domain-general processes, others describe mechanisms that are at play specifically in social context, where people learn from one another.

In this entry, we discuss the major learning theories by focusing on the different mechanisms of learning that each of them postulates. We start with two closely related theoretical traditions that to many scholars have been synonymous with *the* learning theory: behaviorism and associationism. Next, we present probabilistic learning theories that recently gained a lot of attention in the field. Finally, we discuss social learning theories with a particular focus on the recent theory of natural pedagogy.

Behaviorism

Behaviorism was the first influential movement in psychology centered on learning as the topic of rigorous experimental investigation and theorizing. The prime objective was to describe laws that govern how tendencies to exhibit particular behaviors are acquired and modified in time through stimulation.

A major influence on behaviorists such as Edward Tolman (1886–1959) was the empirical research of Ivan Pavlov (1849–1936) on a learning principle now widely referred to as "classical conditioning" or "S-S learning" (for stimulus-stimulus, see Table 1). The principle of S-S learning describes how a neutral stimulus which initially does not elicit the studied behavior can acquire the power to do so, after it has been paired for a number of trials with a stimulus which evokes the behavior naturally. In Pavlov's celebrated demonstration the initially neutral sound of a bell became a *conditioned stimulus* invoking dog's salivation (*conditioned response*) after a few trials of being paired with meat, a stimulus that had evoked salivation before the conditioning procedure (thus called *unconditioned stimulus*). In an ethically controversial demonstration of *generalized* S-S learning in human babies, John Watson (1878–1958) and his student Rosalie Rayner (1898–1935) seemingly conditioned a 11-month-old boy, "little Albert," to react with fear toward furry animals (including a rabbit) by presenting to him a rat paired with a startling sound during the learning trials. Thus, a behaviorist principle was shown to guide learning not just in animal models but also in humans. However, the behaviorists' interest in classical conditioning was only the first step in the development of this movement.

A key development in behaviorist learning theory was the work of Edward Thorndike (1874–1949) and Burrhus Skinner (1904–1990) on *operant conditioning*, or R-S learning (for response-stimulus). In this form of learning, the probability of generating a given behavior changes as a function of positive reinforcement (presence of rewards and punishments) and negative reinforcement (cessation of rewards and punishments) that follow the behavior across a number of trials. In other words, this learning principle describes how an organism learns contingencies between behavior and its desirable or undesirable consequences, and as a result is more or less likely to repeat the behavior. For instance, an infant lying in a crib can readily learn that kicking results in the movement of a mobile toy hanging over the crib and connected to the infant's leg by a ribbon, as evidenced by increased kicking rates. More recently, this simple operant-conditioning procedure became the basis of a successful line of research on early development of infant long-term memory, conducted by Carolyn Rovee-Collier (1942–2014) and colleagues

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Table 1. S-S learning: passing pre-existing power by classical conditioning.

Time	*Learning progression*
t1	Sound of bell has no power to cause dog's salivation. Meat has power to cause dog's salivation.
t2	Dog exposed to meat contingent on prior sound of bell for some number of conditioning trials.
t3	Sound of bell now has power to cause salivation.

Table 2. S-(R-S) learning: making new power by discriminative operant conditioning.

Time	*Learning progression*
t1	Sound of bell has no power to cause dog to sit. Food has no power to cause dog to sit.
t2	Dog receives food contingent on sitting within five seconds of sound of bell for some number of conditioning trials.
t3	Sound of bell now has power to cause dog to sit.

(see Giles & Rovee-Collier, 2011). Finally, operant conditioning may result in *discriminative learning*, S-(R-S) learning, in which a neutral stimulus acquires power to elicit behavior, if its presence discriminates trials in which the behavior is reinforced from those in which it is not (Table 2).

Behaviorism is often remembered as a radical philosophy of psychological science, championed by Watson and Skinner: criticism of introspection-based psychology and insistence on ruling out any explanatory notions that refer to mental phenomena and sticking to a narrow set of objectively measurable factors, namely, stimulus, response, and time. Another notable feature, famously criticized by Noam Chomsky in his review of Skinner's book *Verbal behavior*, was the expectation that a combination of behaviorist learning principles can account for even complex human behaviors, such as language development. The radical behaviorist project of human learning collapsed with the advent of the "cognitive revolution," which promoted an information-processing model of the mind, and with mounting evidence of learning phenomena that could not be accounted for by simple conditioning principles (e.g., see Bandura's social learning theory later in this entry). Nevertheless, the behaviorist legacy is lasting, with, for example, some behavioral principles shaping the psychotherapeutic practices of cognitive behavioral therapy, and the focus on describing and explaining behavioral change over time being a major tenet of modern dynamical system approaches to behavior. Last, but not least, the notion that learning arises from exposure to temporal couplings of primitive elements, the same general idea that inspired Pavlov and behaviorists, is at the heart of another hugely influential pedigree of learning theories, namely associationism.

Associationism

Associationism is a long-standing theoretical tradition in both psychology and philosophy. It proposes learning as a process of forming associative links between mental primitives (historically called sensations and ideas). For instance, learning the concept of bird consists of associating sensations of feathers, wings, beaks, etc. The initial tenets of the theory go back to Plato and Aristotle, but associationism gained prominence through the philosophical theories of British empiricists: George Berkeley (1685–1753), John Locke (1632–1704), David Hume (1711–1776), and later through the works of Alexander Bain (1818–1903) and Ivan Pavlov (1849–1936). The core of associationism is the notion that repeated exposure allows the mind to organize mental primitives by forming associations between them according to few simple principles. The most notable of these is the principle of contiguity: Sensations become associatively linked if they frequently occur close in time or space. Just how effective learning by simple associations can be from early on in human development has been demonstrated by empirical studies on infant capacity for statistical learning and formation of perceptual categories. We will discuss these in the next two sub-sections.

Statistical learning

Modern associative learning theories posit a powerful domain-general *statistical learning* mechanism that maps regularities of the environment by extracting statistical correlations present in any corpus of structured input. This proposal got a boost when a series of studies made it evident that even young infants are proficient in such statistical learning in the domain of

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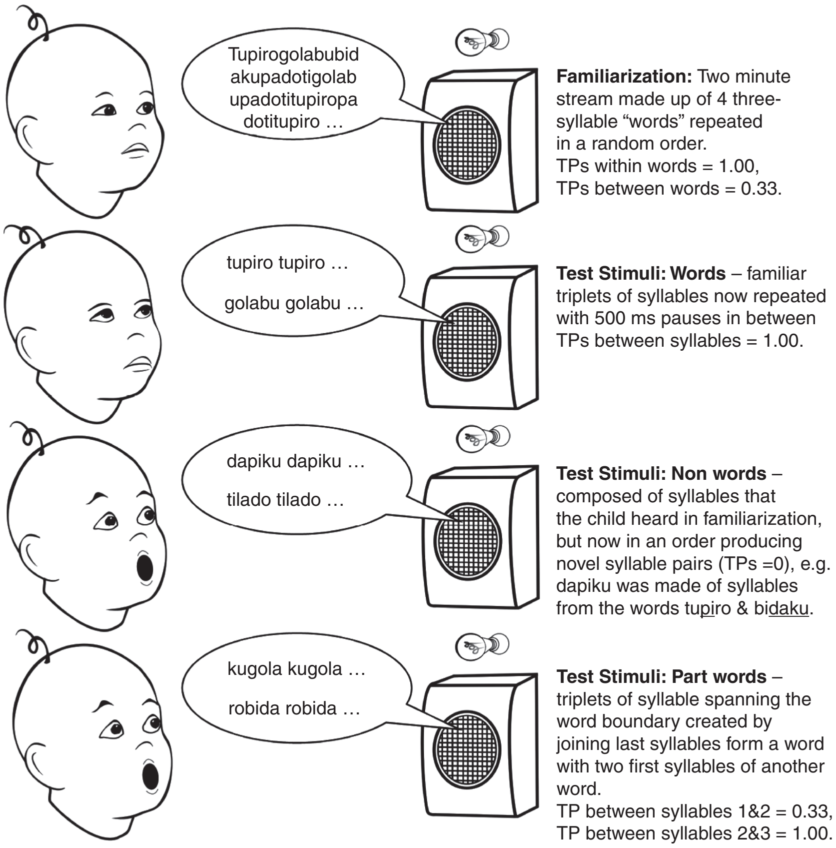

Figure 1 Demonstration of statistical learning in infancy. Transitional probability (TP) refers to the probability of a syllable occurring given that another syllable has occurred. TPs of syllables within words are higher than TPs of syllables between words. Parsing a stream of synthesized speech, where usual cues to boundaries between words (e.g., pauses, stress, and prosodic patterns) were missing, could be done only by attending to TPs. After infants listened to an uninterrupted stream of syllables they heard test stimuli: syllable triplets (words, non-words or part-words) repeated with a 500 ms interval between the triplets. Infants showed longer listening times to both non-words and part-words than to words, thus showing that they had parsed the uninterrupted stream on the basis of TPs. Source: Saffran, Aslin, & Newport, 1996). See original paper for details of design and actual stimuli.

language. Saffran, Aslin, and Newport (1996) found that after listening for two minutes to a continuous stream of synthesized syllables (e.g., "bidakupado…"), 8-month-old infants parsed component "words" merely on the basis of the perceived transitional probability between the consecutive syllables (see Figure 1). Aslin and colleagues obtained similar effects with cotton-top tamarin monkeys, and further showed that human infants extract statistical regularities from streams of tones, as well as from co-occurring patterns of shapes, consistent with the claim that the mechanism of statistical learning is domain general and may have long evolutionary history. Intriguingly, the developmental course of statistical learning skills across the lifetime remains a matter of debate (see Krogh, Vlach, & Johnson, 2013 for review).

Acquisition of perceptual categories

By many associative learning accounts, detection of feature correlations is central to acquisition of categories and eventually concepts. Objects that fall into the same category tend to exhibit clusters of correlated features. For instance, things that are animate tend to be self-propelled and also to have facial features, and birds tend to have feathers and beaks, etc. Category acquisition is considered to be the process of extracting the underlying structure of feature correlations that exists in the external environment and can be detected as statistical regularity in the perceptual input. Younger and Cohen (1983) demonstrated that 10-month-old infants form distinct categories by attending specifically to the features that co-varied within a set of stimuli. Furthermore, variability of features among the encountered individual items determines the breadth of the learned category and how easily it can be differentiated from perceptually similar categories. This was demonstrated in 3-month-olds, who can learn a category of cats (low feature variability) that excludes dogs, but not a category of dogs (high feature variability) that excludes cats (French, Mareschal, Mermillod, & Quinn, 2004).

Importantly, correlated features can span domains and modalities. For example, learning the functions of tools can be thought of as learning multiple correlations between the tool's appearance, the movements of the hand that operates it, and the changes of environment that accompany its use. Word acquisition can be thought of as a process of learning correlations between object appearances and patterns of linguistic sound uttered in their presence. Development of action-interpretation skills can be thought of as rooted in a process of learning correlations between one's own motor codes and their sensory effects. Whether associative learning alone can account for all the effects observed in children in each of these developmental domains is a matter of considerable debate. In addition to empirical experiments, associative learning accounts often bring up the results of computational models (*connectionist models*, also known as *artificial neural networks*), which serve mostly as proof of concept that a particular developmental outcome can be obtained by simple associative processes.

Constraints on learning

One challenge for the associative account recognized by those working both outside and within this theoretical tradition is the so-called learnability problem: how a general associative mechanism alone can zero in on these co-occurrences and their statistical properties that reflect the causal structure of the environment, and refrain from forming indiscriminate associative links, the processing of which would inevitably lead to a computational explosion. One *nativist* answer is that infants' minds are not blank slates. Rather, infant learning is from the beginning constrained and supported by adaptations in the form of dedicated input-analyzers and innate concepts specific to core systems dealing with objects, agents and actions, numbers, and space (see Carey, 2009 for review).

However, proponents of general associative learning mechanisms often argue for a general constraining principle in the form of attentional weighting. Some elements in the input may receive higher attentional weight than others because their low-level perceptual characteristics (e.g., movement, high luminance contrast) make them salient to the human perceptual system. Correlated features may also receive higher attention weights then the uncorrelated ones. As the associative links between correlated features strengthen, their weights increase, while the weights of uncorrelated features decrease and they begin to be ignored. Thus, even if initially associations are indeed formed indiscriminately, the irrelevant ones can be pruned and the already learned associations can constrain the future ones. One example of this process is the emergence of the so-called shape bias, a tendency observed in young children to extend labels to objects that are similarly shaped.

On associationist accounts of shape bias, children are thought to observe that common labels frequently co-occur with particular shapes, such as when utterances of "ball" co-occur with spherical objects. Balls come in different colors and sizes, they are acted upon in different ways and appear in different situations, but (almost) all are of the same spherical shape. Associative links between the label "ball" and the spherical shape strengthen, while links to other features that might have co-occurred (e.g., color) weaken, leading to a first-order generalization, namely, "objects labeled 'ball' are spherical." Over multiple experiences in learning to map different kinds of nouns to categories, children may abstract a second-order generalization that category labels and shapes are correlated. By a similar token, children may learn that while shape and labels go together for solid objects, it is often texture and labels that do so for non-solid materials such as sand or sponge (Colunga & Smith, 2005). These learned biases then provide constraints on detecting correlations in future contexts.

The issues of the learnability problem and the constraints needed to overcome it are a recurrent theme in modern learning theories. We will come back to them later. In developmental science, associative accounts of learning have been historically accompanied by a *tabula rasa* empiricism, which posits that the human child's mind is initially a "blank slate," and that *all* knowledge emerges from sensory primitives by means of associative learning. It is worth noting that claims about the capacity for statistical learning and its role in acquiring particular types of knowledge can be seen as independent from the claims about the mind's initial state and about the conditions that enable learning to start. This is well illustrated by probabilistic learning theories discussed in the next section.

Probabilistic learning theories

There is a long tradition in cognitive developmental psychology to see children as active learners, who construct and modify mental models or schema about the world through an interaction of their existing knowledge and the evidence coming through experience. Jean Piaget (1896–1980) described this process as the interplay of *assimilation* (the use of existing schema to understand new experiences) and *accommodation* (the modification of existing schema to better accommodate new evidence). Cognitive psychologists working under an umbrella label "theory theory" proposed that even young children are capable of testing their hypotheses and revising their naïve theories in the light of mounting evidence (akin to a paradigm shift in science). However, neither Piaget, nor the theory theorists, envisaged a clear mechanism underlying the revision of knowledge.

Recently, a new theoretical framework, sometimes called rational constructivism, posits that the mechanism of updating knowledge is probabilistic inference (e.g., Xu & Kushnir, 2013). An ideal rational probabilistic learner would be one who represents his or her knowledge as a set of hypotheses (each of them with a different perceived probability), and for each of them knows how likely it is that a particular piece of evidence will be observed if the hypothesis is indeed true. When faced with evidence, he or she can then for each hypothesis combine these two probabilities (i.e., *prior* probability of the hypothesis and the *likelihood* of the evidence given the hypothesis) to update his or her certainty about the hypothesis (i.e., to generate a new distribution of *posterior* probabilities among the hypotheses). The formalism according to which this form of belief updating can be done is known as Bayes' rule, hence this rational probabilistic learning is also known as Bayesian learning. Rational constructivism holds that Bayesian learning is indeed a good model of how children learn and update their beliefs.

The empirical evidence for this claim comes from a rapidly growing body of experimental studies that show that young children and infants have probabilistic intuitions that may influence what they learn. For instance, infants seem to expect a correspondence between the composition of the sample and the composition of the population from which the sample is drawn: They react with increased looking to unlikely sampling outcomes (e.g., a blue ball falling out of the container where yellow balls were in the majority). Moreover, infants form different inductive inferences depending on whether they deem the available sample likely or not. After observing that three blue toys drawn out from a box containing mostly blue toys (a likely random sample) could squeak on being squeezed, infants tended to generalize squeaking to a toy that was not blue. However, if the three blue squeaking toys were drawn from a box containing mostly yellow toys (what may be called a "suspicious coincidence"), they generalized this property to only blue toys (Gweon, Tenenbaum, & Schulz, 2010). Other studies by Fei Xu and colleagues showed that a similar sensitivity to likelihood of samples influences early word learning (Xu & Tenenbaum, 2007) and attribution of preferences to agents (Kushnir, Xu, & Wellman, 2010).

Performance of young human learners in experimental tasks is often compared to that of an ideal Bayesian learner, instantiated in the companion computational model (e.g., Gweon *et al.*, 2010). A major challenge for a theory that postulates psychological processes by analogy with a formal model is to explain how these are possible within the limitations of a developing cognitive system. This again leads to the question: How is learning constrained? Rational constructivism is compatible with a nativist position that some constraints on learning (in the form of prior probabilities discussed above) are themselves not learned. However, Xu and colleagues also argue that probabilistic inferences (spelled out by Bayesian hierarchical models) can support rapid acquisition of biases that constrain the space of hypotheses for the naïve Bayesian learner. This happens through formation of over-hypotheses (a term used originally by philosopher Nelson Goodman [1906–1998]). For instance, the shape bias discussed in the previous section is considered on this account an over-hypothesis in that categories always consist of similarly shaped objects. However, this bias is not constructed through a laborious process of forming first- and second-order generalizations (as argued by associationist accounts), but rather through Bayesian learning. Recent evidence from studies with infants (Dewar & Xu, 2010) and formal hierarchical Bayesian models suggests that over-hypotheses can emerge even before first-order generalizations and from relatively little experience. In this sense, rational constructivism takes the middle ground between the nativist position that inferential learning is constrained by innate domain-specific core knowledge and the associationist position that both knowledge and constraints are acquired through statistical learning.

Social learning theories

Human learning is often an intrinsically social affair. Children learn from others by observing them, by participating in joint activities, and, last but not least, by being taught. As we already saw, many influential theories consider the mechanisms of learning in isolation from social context. Here, we review those that consider the social and cultural factors central to what and how children learn. A recurrent question these theories address is what learning mechanisms support acquisition of cultural knowledge and its transfer across generations.

Vygotsky's theory

Lev Vygotsky (1896–1934) stressed how children acquire and exercise their developing mental skills in interactions with the specific sociocultural environment, which includes parents, siblings, teachers, and peers, as well as cultural artifacts such as toys and books.

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Table 3. Observational learning processes.

Process	*Description*	*Example*
Local and stimulus enhancement	Demonstrator's behavior attracts the observer's attention to a particular location or stimulus, allowing the observer to learn about its properties.	After following others to a room, the child discovers that it contains toys. After seeing a peer engage with a toy, the child plays with the toy as well, and discovers its function.
Observational conditioning	Demonstrator's behavior exposes an observer to a relationship between stimuli, allowing the observer to form an association between them.	After overhearing another person's fearful reaction to a novel object, the child is wary of the object.
Emulation	Demonstrator's goal-directed actions allow the observer to learn about the desirable outcome. The observer consequently reproduces the observed outcome, but not the observed actions themselves.	After watching a model turn on the lamp with her forehead, while her hands were occupied, infants tend to turn on the lamp as well, but using their hands rather than the forehead.
Imitation	Demonstrator's goal-directed actions allow the observer to learn about the desirable outcome and about the particular means to achieve it. The observer consequently reproduces both the observed outcome and the observed actions.	After watching a model perform a series of actions in order to get a toy from a novel apparatus, children tend to copy both relevant and irrelevant action steps, even if this way of retrieving the toy is not the most efficient.

Vygotsky recognized that these activities are particularly effective in helping the child to develop skills that are on the verge of emergence but in which the child could not yet succeed on her own, without the "scaffolding" provided by the sociocultural environment. In a similar vein, the role of scaffolding interactions with knowledgeable and helpful adults was also highlighted in the writings of Jerome Bruner.

Imitation and observational learning

The social learning theory of Albert Bandura (see Bandura, 1996) played a major role in introducing cognitive focus to a psychology dominated by behaviorist thinking. Bandura argued that when a child imitates a novel behavior of an observed model for the first time, a new response is acquired without ever being directly reinforced. For behaviorism, this posits a puzzle of "no-trial" learning. In a series of studies known as "Bobo doll" experiments, Bandura and others showed that preschool-aged children imitated aggressive behaviors of the model toward the doll. This constituted an example of social observational learning. Even though children were less likely to imitate aggressive behaviors of a model who they saw being verbally scolded, they were still able to reenact his behaviors when asked to do what the model had done. This further demonstrated that imitation itself is not a necessary condition of social observational learning.

The study of social observational learning proved to be a fertile ground for comparative research. This literature provides a typology of social learning processes and explores their evolutionary history across the animal kingdom (Table 3). It brings to the fore the question of in what respects human social learning is different from that seen in non-human animals and what learning mechanisms allow human cultures to be transmitted from one generation to the next ensuring accumulative traditions. According to Michael Tomasello, human cultural transmission is characterized by the "ratchet effect," whereby each new generation of learners readily absorbs the innovations and cultural knowledge of their predecessors instead of having to discover them anew. Tomasello and colleagues argued that the underlying mechanism lies in the propensity for *imitative learning* documented in human children, but not in our closest evolutionary cousin – the chimpanzee. Consistent with this claim, Horner and Whiten (2005) found that, after observing a model operate an apparatus in order to retrieve a snack from inside, chimpanzees emulated the goal (see Table 3) and got the snack using the most efficient means and ignoring all the irrelevant actions of the model. However, human preschool-aged children tended to *imitate* the model's actions, even if they clearly were causally unrelated to the desired outcome. This strong predilection in children (and in some cases even in adults) to reenact the exact means demonstrated to them, despite their inefficiency, is more recently often referred to as *over-imitation*.

Learning from generic language

Children, of course, learn when others *communicate* new information to them. A striking feature of this way of learning becomes evident when the format of verbal communication directed to children is examined more closely. Very often it contains generic labels (e.g., “dog,” “chair”), which refer to kinds rather than to specific individuals, as well as generic statements (e.g., “A dog barks,” “Girls like dolls”), sweeping generalizations that highlight attributes understood as non-accidental to the kind of object that they describe. Research conducted over the last decade documents young children’s competence in understanding and producing generic labels and statements, suggesting that exposure to linguistic communication provides children with a rich resource that can boost acquisition of generic, kind-based knowledge.

Based on recent evidence, Marjory Rhodes, Sarah-Jane Leslie and others argue that generic language may be a vehicle for cultural transmission of social stereotypes (Rhodes, Leslie, & Tworek, 2012). Hearing generic statements about a novel social category (“Zarpies”) induces in preschool-aged children *essentialist* beliefs, in which the attributes of individuals within the social category are seen as stemming from an intrinsic, enduring, unchangeable *essence* that underlies their kind (Zarpies are afraid of ladybugs, because that’s how Zarpies are). In turn, having such beliefs results in using generic statements to describe the social categories.

Natural pedagogy theory

Gergely Csibra and György Gergely argue that certain aspects of human communication may enable transfer of generic knowledge to young learners even before they have language. Their argument also addresses the question of what learning mechanism secures the fast and veridical transfer of human cultural knowledge across generations. According to Csibra and Gergely, observational learning and imitation alone are not sufficient in this role, since they do not provide the means to overcome the learnability problem, which arises whenever a naïve learner merely observes a cognitively opaque cultural event (e.g., a use of a tool) from which she or he is to extract cultural knowledge generalizable to other events (to other tools and other people, see Table 4). However, Csibra and Gergely argue that human communication provides a mechanism for a unique system of knowledge transmission, which supports learning despite these challenges. They dubbed this “natural pedagogy.”

The theory of natural pedagogy proposes that in humans the transfer of knowledge through communication is supported by a set of cognitive and perceptual adaptations. They enable early sensitivity to communication, not necessarily tied to language. In fact, human children can benefit from such adaptations in infancy and start acquiring generic knowledge from non-linguistic communication directed to them, even before they are able to comprehend generic statements expressed in language. These adaptations allow human children and infants to (a) recognize instances when communication is directed to them, (b) interpret communicative signals such as pointing gestures that help them identify the object of communication, and (c) interpret the communicated information as generic and pertaining to kind. We review these three claims in the following sub-sections.

Table 4. Challenges in acquiring cultural knowledge by observation.

Problem	*Description*	*Example*
Teleological opacity	Cultural practice may be compatible with several goals and/or the final goal may be not apparent.	Preparation of food requires pre-processing the ingredients and it is not obvious that the outcomes of individual steps are desirable.
Causal opacity	Causal relations between the observed action and expected outcome may be not apparent and thus often cannot support learning.	Planting and cultivating a plant involves many actions (with and without tools), of which only some are causally related to the final outcome.
Uncertainty about genericity	The new information may apply merely to the observed token (at the given instance) or it may apply to the kind to which it belongs.	A successful use of a novel tool may reflect either an idiosyncratic purpose (e.g., one can plant a flower in this vessel) or the function for which the tools of its kind are designed (e.g., this vessel is a flowerpot).
Uncertainty about shared-ness	The new information may be specific to the observed model or shared by the cultural group.	Frowning expression may reflect a personal attitude of the expresser or a culturally sanc-tioned norm.

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Sensitivity to ostensive signals

The type of communication of particular interest to this theory is that which is directly addressed to a specified recipient. In such cases, the communicator intends the addressee to recognize that he or she is being targeted by a communicative act. In some contexts, this communicative intention may be apparent, for example when there are only two people in the room and one of them starts to speak. But very often communication is accompanied by signals (e.g., eye contact, calling the addressee by name, or using a special intonation), which manifest the communicative intention of the communicator to the addressee. Such communicative signals are dubbed ostensive signals.

Even human newborns are sensitive to some of ostensive signals. They prefer to look at faces that seem to make direct eye contact with them than to faces with averted gaze. They also prefer to listen to motherese (i.e., utterances with an exaggerated high-pitch intonation typical of infant-directed speech) rather than to speech produced with a regular intonation typical of the way adults speak with each other. The theory of natural pedagogy interprets these findings as evidence that sensitivity to some ostensive cues is innate in humans, allowing infants from early on to attend preferentially to instances when communication is directed to them, and allowing them to start learning other correlated signals of ostension (e.g., being called by one's name, pointing, waving, demonstrating).

Referential expectation

Ostensive signals from the communicator manifest to the addressee not only that she or he is the intended recipient, but also that she or he is a recipient of an act intended to communicate about something, some referent. Thus, if eye contact and motherese indeed serve as ostensive signals to human children and babies, they should elicit in them a referential expectation and consequently a search for the referent. Face-to-face communicative interactions may involve numerous gestures (e.g., pointing, demonstrating, gazing) that help the communicators establish what the communicative act is about. Following seminal demonstration by Michael Scaife and Jerome Bruner (1975), published in the journal *Nature*, numerous studies documented that even infants who cannot yet rely on language can utilize some of these behavioral signals to find a referent. Crucially, whether they do depends on these gestures being preceded by an ostensive signal. For instance, in a study by Senju and Csibra (2008), 6-month-old infants followed the head-turn of a model and gazed at the object that the model had gazed at only if the model's head-turn (a potential referential signal) was preceded either by eye contact or by infant-directed speech. The theory of natural pedagogy interprets this and related findings as evidence that from early on human children are prepared to be the recipients of basic communicative acts, where ostensive signals elicit the search for a referent, guided by directional gestures, such as gazing and orienting, which function as referential signals.

Generic knowledge transmission

The key element of the theory of natural pedagogy is the postulate that children are prone to interpret and encode what is communicated to them as generic knowledge pertaining to kinds and shared among other group members. These claims are backed up by the results of several recent experiments, in which children's and infant's learning was compared across ostensive and non-ostensive conditions. For instance, Yoon, Csibra, and Johnson (2008) showed that ostensive signals biased 9-month-old infants toward encoding object features that might be diagnostic of its kind (such as shape and texture) rather than object location, a transient individual characteristic that rarely generalizes to kind. Location was nevertheless readily encoded by infants who watched the actions without ostensive signals preceding them.

Egyed and colleagues (2013) showed that ostensive signals that accompany a positive or negative emotional expression directed at a novel object changed how 18-month-olds interpreted these expressions. Expressions presented non-ostensively were treated as manifestations of the expresser's individual preference and did not inform toddlers' interactions with another experimenter. But those presented ostensively were treated as manifestations of the object valence more broadly, such that toddlers reliably chose the object that received a positive valence from the ostensive expresser, even if they were to hand it to somebody else.

Notably, what preschoolers and infants learn from communicative demonstrations may be more resilient to counterevidence than what they learn from observing actions presented without ostensive signals. Thus, representations acquired in ostensive contexts may be akin to the beliefs expressed in generic statements, such as "Girls like dolls," which people keep embracing despite a plethora of counterexamples.

For instance, Hernik and Csibra (2015) showed 13-month-olds a series of videos in which one object was repeatedly used to peel a banana and another to "heal" it by bringing the peel back up whole on the banana (see Figure 2). For two separate groups of infants, the videos were accompanied by either infant-directed or adult-directed speech. At test, both groups showed signs of learning. They reacted with longer looking to movie endings showing the peeler

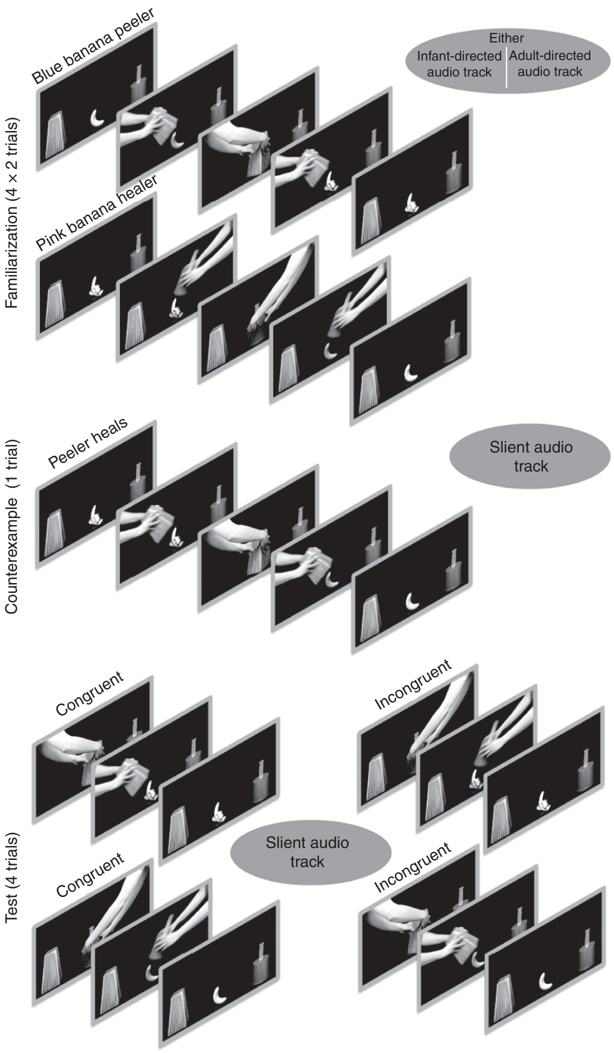

Figure 2. Examples of stimuli from one of the experiments in Hernik and Csibra (2015). 13½-month-old babies who watched familiarization movies accompanied by ostensive infant-directed audio track (but not those who watched familiarization movies accompanied by an adult-directed audio track) reacted with increased looking to test movies that were incongruent with the tool–function mappings presented during familiarization. Previous experiments in which there was no counterevidence trial showed that babies could learn the tool–function mappings from both infant-directed and adult-directed familiarizations. Thus, infant-directed ostension specifically influenced infants' encoding of tool functions in a representational format resilient to counterevidence.

heal and the healer peel (i.e., tool-function pairings opposite to that presented in the original videos). However, babies who learned the functions from adult-directed videos stopped showing surprise at the incongruent movie endings as soon as they observed a single counterevidence to what they had learned by observation. In contrast, only babies who watched infant-directed ostensive demonstrations looked longer at the incongruent movie endings, even after they had been exposed to counterevidence.

Similar resilience to counterevidence was reported by Butler and Markman (2012) in preschoolers, who kept searching for a magnetic block in a pile of them (called "blickets" by the experimenter) despite the fact that every single blicket that they tried failed to be magnetic. However, they showed this pattern of persistent exploration only if the magnetic property of a blicket was demonstrated to them ostensively but not if the demonstration was non-ostensive.

On the whole, the theory of natural pedagogy interprets this set of findings as evidence that ostensive communication licenses children to engage in substantially different types of inference than observational learning. Ostensive communication is thought to facilitate inductive generalization in young learners by inviting a genericity bias. More recently, Csibra and Shamsudheen (2015) proposed that, if the individual object used in the communicative demonstration is interpreted by the recipient as a symbol of the kind rather than only as a token from the kind then the inferences drawn by infants from ostensively demonstrated content can be characterized as deductive rather than inductive.

In a nutshell, natural pedagogy theory argues that one way in which human infants may overcome the learnability problem inherent in acquiring generic knowledge through observation is by being born prepared to acquire generic knowledge through communication.

Conclusions

Despite being the focus of psychological and philosophical theorizing for centuries, learning still remains one of the central topics in developmental science. The learning theories that were historically most influential (behaviorism, associationism) initially showed promise of describing simple universal mechanisms able to account for all learning. However, the grand question "What is the mechanism of learning?" was gradually replaced by questions like "What mechanisms contribute to learning X?" and "Is all about X learned?". Contemporary authors, even when they postulate general-purpose mechanisms such as statistical learning and probabilistic inferences, often appreciate the diversity of learning processes across different cognitive domains (e.g., numerical cognition, language, cultural knowledge), discuss the constraints and biases needed to guide them, and consider the role of innate perceptual and cognitive adaptations. Learning in early ontogeny is currently one of the most vibrant areas of psychological research informed by ingenious experimental designs with human toddlers and infants as well as by computer modeling, comparative studies, and neuroimaging.

See also

Constructivist theories; Dynamical systems approaches; Experimental methods; Bayesian statistics; Connectionist modeling; Cognitive development during infancy; Cognitive development beyond infancy; Imitation; Memory; Language acquisition; Social development; Theory of mind; Behavioral and learning disorders

Further reading

Aslin, S. (2014). Infant learning: Historical, conceptual, and methodological challenges. *Infancy*, 19, 2–27.

Csibra, G. (2010). Recognizing communicative intentions in infancy. *Mind & Language*, 25, 141–168.

Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366, 1149–1157.

Gopnik, A., & Wellman, H.M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological Bulletin*, 138, 1085.

Hoppitt, W., & Laland, K.N. (2013). *Social learning: An introduction to mechanisms, methods, and models*. Princeton, NJ: Princeton University Press.

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References

Bandura, A. (1996). Social cognitive theory of human development. In T. Husen & T.N. Postlethwaite (Eds.), *International encyclopedia of education* (2nd ed., pp. 5513–5518). Oxford, UK: Pergamon Press.

Butler, L.P., & Markman, E.M. (2012). Preschoolers use intentional and pedagogical cues to guide inductive inferences and exploration. *Child Development*, 83, 1416–1428.

Carey, S. (2009). *The origin of concepts*. Oxford, UK: Oxford University Press.

Colunga, E., & Smith, L.B. (2005). From the lexicon to expectations about kinds: A role for associative learning. *Psychological Review*, 112, 347–382.

Csibra, G., & Shamsudheen, R. (2015). Nonverbal generics: Human infants interpret objects as symbols of object kinds. *Annual Review of Psychology*, 66, 689–710.

Dewar, K.M., & Xu, F. (2010). Induction, overhypothesis, and the origin of abstract knowledge evidence from 9-month-old infants. *Psychological Science*, 21, 1871–1877.

Egyed, K., Király, I., & Gergely, G. (2013). Communicating shared knowledge in infancy. *Psychological science*, 24, 1348–1353.

French, R.M., Mareschal, D., Mermillod, M., & Quinn, P.C. (2004). The role of bottom-up processing in perceptual categorization by 3-to 4-month-old infants: Simulations and data. *Journal of Experimental Psychology: General*, 133, 382–397.

Giles, A., & Rovee-Collier, C. (2011). Infant long-term memory for associations formed during mere exposure. *Infant Behavior and Development*, 34, 327–338.

Gweon, H., Tenenbaum, J.B., & Schulz, L.E. (2010). Infants consider both the sample and the sampling process in inductive generalization. *Proceedings of the National Academy of Sciences*, 107, 9066–9071.

Hernik, M., & Csibra, G. (2015). Infants learn enduring functions of novel tools from action demonstrations. *Journal of Experimental Child Psychology*, 130, 176–192.

Horner, V., & Whiten, A. (2005). Causal knowledge and imitation/emulation switching in chimpanzees (Pan troglodytes) and children (Homo sapiens). *Animal Cognition*, 8, 164–181.

Krogh, L., Vlach, H.A., & Johnson, S.P. (2013). Statistical learning across development: Flexible yet constrained. *Frontiers in Psychology*, 3, 598.

Kushnir, T., Xu, F., & Wellman, H.M. (2010). Young children use statistical sampling to infer the preferences of other people. *Psychological Science*, 21, 1134–1140.

Rhodes, M., Leslie, S.J., & Tworek, C.M. (2012). Cultural transmission of social essentialism. *Proceedings of the National Academy of Sciences*, 109, 13526–13531.

Saffran, J.R., Aslin, R.N., & Newport, E.L. (1996). Statistical learning by 8-month-old infants. *Science*, 274, 1926–1928.

Scaife, M., & Bruner, J.S. (1975). The capacity for joint visual attention in the infant. *Nature*, 253, 265–266.

Senju, A., & Csibra, G. (2008). Gaze following in human infants depends on communicative signals. *Current Biology*, 18, 668–671.

Xu, F., & Kushnir, T. (2013). Infants are rational constructivist learners. *Current Directions in Psychological Science*, 22, 28–32.

Xu, F., & Tenenbaum, J.B. (2007). Word learning as Bayesian inference. *Psychological Review*, 114, 245–272.

Yoon, J.M., Johnson, M.H., & Csibra, G. (2008). Communication-induced memory biases in preverbal infants. *Proceedings of the National Academy of Sciences*, 105, 13690–13695.

Younger, B.A., & Cohen, L.B. (1983). Infant perception of correlations among attributes. *Child Development*, 54, 858–867.