Chapter 2
Curious Learners: How Infants' Motivation to Learn Shapes and Is Shaped by Infants' Interactions with the Social World

Katarina Begus and Victoria Southgate

Abstract Most theories of infant social learning focus on how infants learn whatever and whenever the adults decide to teach them. While infants are well equipped to learn from adults, recent research suggests infant social learning is not a passive process but that infants may play an active role in acquiring information and modulating their learning according to their interests. This chapter aims to highlight the importance of investigating young children's intrinsic motivation for learning, particularly in the domain of social learning. It reviews the current research on how infants' curiosity may be expressed through their behaviour while interacting with social partners, and how responding to these expressions of curiosity may affect infants' learning. Finally, through the investigation of the possible neurological underpinnings of the social and motivational aspects of learning, this chapter explores infants' selectivity in social partners and how it can be explained by their motivation to learn.

Introduction

The idea of a child as an active learner, driven by curiosity, is possibly as old as the field of developmental psychology itself, and has been the foundation of some of the most influential theories of early learning (e.g. Piaget, 1952). While children's own independent active exploration could be the principal way of acquiring some skills, others, such as language, for example, could not develop without interaction with the child's social world. It is therefore perhaps not surprising that most research and

K. Begus (✉)
Cognitive Development Center, Department of Cognitive Science, Central European University, Budapest, Hungary

V. Southgate
Department of Psychology, University of Copenhagen, Copenhagen, Denmark

M. M. Saylor, P. A. Ganea (eds.), *Active Learning from Infancy to Childhood*,
https://doi.org/10.1007/978-3-319-77182-3_2

theories of infant social learning focus on infants' ability to receive and encode the information communicated to them. Accordingly, a vast body of research has demonstrated that infants are very well equipped to learn from others, with attentional biases that ensure they detect when a social partner is transmitting information, and cognitive adaptations that ensure the transmission of information is successful (Csibra & Gergely, 2009). However, to ensure rapid transmission of information by communication, both participants ought to be actively involved in the process (Baldwin & Moses, 1996). If the learner is able to take on an active role in gathering information, they need not passively rely on chance that the information will be supplied. Recent research suggests that even in the field of early social learning, infants are not merely passive consumers of information, but may play an active role in soliciting and selecting the information they learn.

> "I think, at a child's birth, if a mother could ask a fairy godmother to endow the child with the most useful gift, that gift would be curiosity". (Eleanor Roosevelt).

Curiosity

Classically, curiosity has been described in terms of drives. Analogous to other drives, such as the drive for reproduction or food, the feeling of curiosity was suggested to be unpleasant, and the reduction of it, achieved by gathering information about the curiosity-eliciting stimuli, was proposed to be rewarding (Berlyne, 1954, 1966). Later theories proposed that curiosity should instead be understood as an interaction between an individual's knowledge state and the current situation (Lowenstein, 1994). According to this knowledge-gap model, curiosity is aroused when a gap in an individual's knowledge becomes apparent, and the individual becomes motivated to close this gap by acquiring information, which results in subsequent reduction of curiosity. However, interpreting the experience of curiosity as aversive fails to explain why much of human behaviour is in fact geared towards actively seeking curiosity-inducing situations. For example, situations with limited stimulation often lead individuals to explore the environment for something new and interesting, which could help them avoid feelings of boredom (Collins, Litman, & Spielberger, 2004). Furthermore, acquiring information on a topic often leads to even more curiosity and information seeking (Hidi & Renninger, 2006), and not necessarily to satiation, as initially proposed by Lowenstein (1994). These considerations lead to new models of curiosity, according to which individuals seek an optimal level of arousal or stimulation, looking for opportunities to have their curiosity piqued, as much as gathering information to relieve it (Spielberger & Starr, 1994). Furthermore, as opposed to knowledge-gap models, more recent theories of curiosity proposed a mechanism by which an individual tracks their local learning progress, without having to define the starting or desired knowledge state (Gottlieb, Oudeyer, Lopes, & Baranes, 2013; Kaplan & Oudeyer, 2007; Moulin-Frier, Nguyen, & Oudeyer, 2013; Oudeyer & Smith, 2006).

According to these theories, the learning progress is proposed to be tracked by monitoring whether the performed actions (or the information gathered) improve the individual's ability to predict (the consequences of) future actions, or the ability to solve problems and master the environment (Nguyen et al., 2013). The activities an individual performs are intrinsically rewarding in proportion to the decrease of prediction error they produce (Gottlieb et al., 2013). As opposed to the theories viewing curiosity as an unpleasant state, these models propose curiosity induction *itself* can be rewarding, involving emotional states, which are positive and not aversive (Fowler, 1966; Litman, 2005, 2008; Litman & Silvia, 2006). This perspective seems to better account for why humans evolved to be curious, despite the fact that exploring and seeking information frequently appears to serve no immediate purpose in terms of survival. Curiosity and information gathering as a rewarding process likely acquired value through long-term evolutionary selection, by maximising evolutionary fitness in rapidly changing environmental conditions through continuous acquisition of information which, even if not immediately valuable, could become useful in the future (Gottlieb et al., 2013).

As well as its potential role in human evolution, the role of curiosity has long been appreciated and investigated in studies of learning. It has been proposed that interest impacts individuals' attention, goals and levels of learning (Hidi & Renninger, 2006). Situational interests can determine what individuals will attend to and learn at any given moment (Mitchell, 1993), stable interests can determine individuals' career paths and help them overcome low abilities (Hidi & Harackiewicz, 2000), and general levels of curiosity are one of the main predictors of academic success (von Stumm, Hell, & Chamorro-Premuzic, 2011). However, while the function of curiosity in learning has been emphasised in educational settings for decades, true advances in linking states of heightened motivation and curiosity to knowledge acquisition have only been made in recent years.

Neuroimaging studies in adults have confirmed what has long been hypothesised from behavioural and self-report studies; states of curiosity or heightened interest function as an intrinsic reward mechanism, and directly modulate what information will be encoded (Gruber, Gelman, & Ranganath, 2014; Jepma, Verdonschot, van Steenbergen, Rombouts, & Nieuwenhuis, 2012; Kang et al., 2009). For example, in two separate studies, adult participants were presented with trivia questions and were asked to rate how curious they were to find out the answer. Using fMRI recordings, these studies have found that the induction of epistemic curiosity and not (only) the relief of it elicited activity in reward-related areas of the brain (Gruber et al., 2014; Kang et al., 2009), specifically in structures that are most reliably activated by the anticipation and processing of rewards (Knutson, Adams, Fong, & Hommer, 2001). Furthermore, both studies have also found that the magnitude of self-reported curiosity predicted the degree to which the participants encoded information during these tasks, and provided evidence on how states of curiosity can directly affect what information is encoded, by modulating the activity of memory encoding areas of the brain (Gruber et al., 2014; Kang et al., 2009). Kang et al. (2009) investigated how curiosity interacts with prior knowledge and demonstrated enhanced learning for information that participants were most curious about, and

the positive effect of curiosity on learning was still observed after a two-week delay. The effects of curiosity on learning were replicated in the study by Gruber et al. (2014), demonstrating enhanced memory for information that participants were curious about in immediate and one-day-delay memory tests. In addition, learning was also enhanced for information that was irrelevant to the curiosity-inducing trivia questions but was presented during states of curiosity, thus highlighting the potential enhancing effect that stimulating curiosity prior to knowledge acquisition could have on learning in educational settings (Gruber et al., 2014).

Curiosity in Early Life

While direct assessments of curiosity are not feasible in infants, several aspects of infant learning suggest that curiosity may drive exploration, and modulate learning, even early in life. Several theories of curiosity-driven learning propose that the information individuals should find most interesting is that which matches an optimal level of complexity or unfamiliarity (Fowler, 1966; Piaget, 1952; Spielberger & Starr, 1994). In trying to reconcile the puzzling tendency of infants to pay greater attention to a novel stimulus in some circumstances, and a familiar stimulus in others, several authors have explained these preferences in terms of infants' changing knowledge states. As infants are encoding features of a stimulus, it is the depth of this encoding that determines their subsequent preferences. While a stimulus is not fully encoded, infants may show a familiarity preference. It is only when the depth of their knowledge is sufficient, that a shift to a novelty preference can be observed (Houston-Price & Nakai, 2004). Infants' tendency to attend to stimuli that are neither too familiar (already encoded) nor too novel (too disparate from existing representations) (Kidd & Hayden, 2015) has also been experimentally demonstrated. Studies showed that 7 and 8-month-old infants preferentially look at event sequences which are moderately predictable, as compared to highly predictable or fully unpredictable sequences (Kidd, Piantadosi, & Aslin, 2012). That infants focus their limited cognitive resources on stimuli of medium predictability, ones that provide the most information for the least cognitive effort, is precisely what would be predicted by the learning-progress models of curiosity, which suggest learning activities that would be most intrinsically rewarding are those that promise the fastest learning progress and greatest decrease of prediction error in the future (Gottlieb et al., 2013; Kaplan & Oudeyer, 2007; Moulin-Frier et al., 2013).

According to the alternative knowledge-gap theory of curiosity, interest arises when attention becomes focused on a gap in one's knowledge (Lowenstein, 1994), leading individuals to seek information that would close this gap. The striking findings that infants structure their exploratory play in a way that resolves uncertainty fits well with this theory. In a series of studies by Stahl and Feigenson (2015), infants were shown events in which common objects (such as a ball or a car) violated basic physical laws, such as object solidity (an object passing through a wall), or object support (an object pushed over the edge of a surface without falling). After

demonstrations, infants were allowed to freely explore the objects with the surprising properties, and were found to explore objects qualitatively differently according to which physical law they previously observed the object violate (Stahl & Feigenson, 2015). Following a violation of object solidity, infants engaged in more banging behaviour (presumably testing how the object was able to pass through a solid wall), whereas they spent most of the time dropping objects which have previously violated the expectation of object support (presumably testing the surprising levitation property of the object). While the authors of this study focused on the role of infants' prior knowledge in guiding the acquisition of new information, infants' behaviour in these tasks can be elegantly described in terms of curiosity-driven information seeking. According to the information-gap models, the violation of infants' expectation could be seen as creating or highlighting a knowledge gap, which led to increased curiosity or interest in the surprising object. The interest in turn led to systematic exploration of the objects, aimed at closing the information gap by acquiring more evidence that could explain the surprising properties.

But do these hypothesised states of curiosity or motivation to learn in infants in fact lead to superior learning, as they do in adults (Gruber et al., 2014; Kang et al., 2009)? Indeed, infants in the studies by Stahl and Feigenson (2015) not only systematically explored the objects with surprising properties, but in fact also learned arbitrary additional features of these objects, such as the sounds they produced. In contrast, infants did not learn the same information when its presentation did not follow a surprising event. Nor did they learn the same information when it was presented after a surprising event, but the information was linked to another object, which did not violate infants' expectations. Infants' learning, observed in the studies by Stahl and Feigenson (2015), could therefore be interpreted as the first demonstration of how experimentally inducing infants' curiosity can guide their subsequent information seeking and lead to superior learning. Together, this research suggests that the rewarding mechanisms of information search and consumption may already be in place in infancy and that, like adults', infants' interest or curiosity may directly affect what information they will seek and learn in any given moment.

A question remains as to how infants are able to detect the gaps in their knowledge, or track their own learning progress, which are proposed to be prerequisites to experiencing curiosity and motivating one's learning (Gottlieb et al., 2013; Lowenstein, 1994). In other words, in order to selectively attend to or seek information that one does not yet possess, it is perhaps imperative to possess some level of metacognition—the capacity to reflect upon one's knowledge or uncertainty, and adaptively control one's cognitive processes accordingly (Hampton, 2009). While these computations may seem complex, and the development of metacognitive processes is not fully understood even in older children (see Sobel and Leourneau, this volume), some recent studies arguably provide evidence that suggests infants may already be able to monitor their errors, communicate their uncertainty, and use metacognitive evaluations to regulate subsequent behaviour (Goupil & Kouider, 2016; Goupil, Romand-monnier, & Kouider, 2016, but see Gliga & Southgate, 2016 for a critique, and Carruthers, 2008, for alternative explanations of ostensible metacognitive abilites of non-verbal organisms). Whatever the level of reflection upon

their knowledge states, if a gap in knowledge is what piques infants' curiosity, and if the learnability of information determines whether infants will be motivated to obtain it, then infants may indeed be the best moderators of their own learning. It is their knowledge states, interacting with the available information, that would ultimately determine what information they would be interested in and therefore more likely to learn.

However, while the studies discussed above provide some evidence that curiosity guides what infants explore or attend to (Kidd et al., 2012; Stahl & Feigenson, 2015), the importance of understanding the role of curiosity in infant learning is perhaps most pertinent in the domain of social learning. Much of what infants need to learn, they must learn from those around them, and if there were non-verbal infant behaviours that might be communicating, or at least reflecting, infants' motivation or desire for information, awareness of these behaviours in caregivers would be important as such situations may offer special opportunities for facilitated learning. However, infants' interest and motivation for learning has received little attention in the domain of social transmission of knowledge. Most theories of social learning, and studies investigating it, focus on infants' ability to receive and encode the information communicated to them (Csibra & Gergely, 2009), whereas infants' motivation and active contribution to social transmission of knowledge is often neglected. Given the effect that curiosity may have on infant learning, and the fact that learning from people is one of the most prominent ways in which infants acquire knowledge in everyday life, investigating infants' active involvement in the process of social learning seems of particular importance.

Asking Questions Without Words

When observing an infant, who cannot yet speak and has limited means of responding and interacting with others in their environment, it is not easy to determine what information she is processing, let alone which behaviours may be signalling her motivation to obtain information. Yet, systematic investigations of infant behaviour have shown that, even before they can speak, infants can modulate the amount, the content and the timing of information they receive from others.

Social Referencing

One of the earliest behaviours, hypothesised to serve as an information-seeking tool, is social referencing, defined as looking at a social partner with the expectation of eliciting a response. In infant research, social referencing has been predominantly explored in the context of infants looking at another person's emotional cues in ambiguous situations, and has been proposed to serve infants regulating their own behaviour and emotional responses in accordance with others' (Feinman, 1982).

Classically, social referencing has been associated and investigated in the context of attachment and emotional regulation, suggesting that infants, by looking at caregivers in ambiguous situations, are seeking comfort, reassurance, and checking their caregivers' proximity and availability (Ainsworth, 1992; Dickstein, Thompson, Estes, Malkin, & Lamb, 1984).

However, accumulating evidence has since suggested infants' referencing behaviour might be better interpreted as seeking information. For example, infants as young as 6 months of age use social referencing more frequently during unexpected than expected events (Walden, Kim, McCoy, & Karrass, 2007). By 9 months, in an ambiguous situation, such as encountering a novel object, infants looked at the caregiver as much as at the unfamiliar experimenter (Kutsuki et al., 2007), speaking against the hypothesis of seeking comfort. Using a different measure, infants have also been shown to orient their gaze faster and use the information they received about an object to regulate their behaviour more, when the object was ambiguous than when it was not (Kim & Kwak, 2011). These findings suggest that infants not only seek but also utilise given information selectively, based on the level of uncertainty associated with objects at hand. Similarly, in a study where infants were given labels for objects, infants looked at the labeller more in the presence of two objects, when the intended referent of the label was ambiguous, than in the presence of a single object (Vaish, Demir, & Baldwin, 2011). These studies suggest uncertainty, or a need for information, rather than anxiety (Zarbatany & Lamb, 1985), plays a role in how much and how quickly infants use social referencing, and suggests the primary function of referencing may in fact be to seek clarifying information, rather than comfort.

The strongest evidence suggesting infants use social referencing as a means of obtaining information comes from findings that infants appear to take into account the informative potential of the available adults when deciding who to reference. In a study where an ambiguous object was presented either by the experimenter or the parent, 10-month-olds looked more to the person, who has presented the object, and (like 12-month-olds in a previous study; Stenberg, 2009) in fact modulated their behaviour more according to the information received by the experimenter than the parent (Schmitow & Stenberg, 2013). This behaviour is consistent with the "expertise" hypothesis of social referencing, by which infants use social referencing behaviour to seek information from the best source available (Feinman, Roberts, Hsieh, Sawyer, & Swanson, 1992). Accordingly, these studies suggest that infants can discriminate between potential informants, based on who has the relevant information (Schmitow & Stenberg, 2013; Stenberg, 2009), and prioritise seeking and following the information given by the adult who should have more information in the given situation (Stenberg, 2009).

Thus, by controlling their gaze alone, infants can already selectively solicit information transfer from the available social partners. But infants are not limited to the use of their eyes when interacting with the social world. Long before the onset of speech, infants begin utilising another powerful means of attracting attention and interacting with people—their voices.

Babbling

Babbling has been proposed to function as a motor exercise, through which infants develop and practice producing speech-like sounds, eventually leading to language production (Kimbrough, Wieman, Doyle, & Ross, 1976; Locke & Pearson, 1990). Studies have indeed found overlap between preferred babbling sounds and first words (Stoel-Gammon, 1992). Furthermore, the number of syllable types in babbling predicts the onset of first words (Stoel-Gammon, 1992), and speech development more broadly (Kimbrough, Eilers, Neal, & Cobo-Lewis, 1998; Kimbrough, Eilers, Neal, & Schwartz, 1999). However, the interpretation of this relationship and the focus of research on infant vocalisations have recently turned from phonological production to investigating infant vocalisations in the context of a social exchange with their caregivers.

Infant vocalising is sensitive and responsive to social contingency (Masataka, 2003). In the classic still-face paradigm, in which an adult suddenly ceases to interact, while continuing to face the infant, infants have been shown to adapt the frequency and length of vocalisations according to whether or not an adult is responsive (Franklin et al., 2013; Goldstein, Schwade, & Bornstein, 2009). Infants increased their vocalisation during unresponsive periods and returned to turn-taking vocalisations when the responsiveness resumed, suggesting they appreciate the social effect of their vocalisations on their caregivers' behaviour (Goldstein et al., 2009). In turn, caregivers have been shown to adapt their responses in accord with infants' vocalisations, providing responses contingent in time and content to the infants' vocalisations (Bornstein, Tamis-Lemonda, Hahn, & Haynes, 2008; Gros-Louis, West, & King, 2014; Tamis-LeMonda, Bornstein, & Baumwell, 2001). Moreover, how both infants and their caregivers adapt their behaviour to each other in a communicative exchange appears to have an effect on infants' learning.

Infants who modulated their vocalisations to a greater extent when facing an unresponsive adult at 5 months of age had better language comprehension at 13 months (Goldstein et al., 2009), suggesting that using vocalisations instrumentally, to elicit a response, may play a role in infants' knowledge acquisition. Likewise, infants' object-directed vocalisations (vocalising while looking at or holding an object) and parents' contingent responses to those sounds at 9 months of age predict vocabulary size at 15 months (Goldstein & Schwade, 2010). Furthermore, when infants' caregivers respond to their babbling contingently, infants produce linguistically more mature vocalisations, than when the caregivers are instructed to delay their responses (Goldstein & Schwade, 2008). Finally, as well as in experimental settings, the degree to which parents respond to infant prelinguistic vocalisations in everyday life is positively correlated with later receptive and productive vocabulary size (Tamis-LeMonda et al., 2001; Tamis-LeMonda & Bornstein, 2002; see Tamis-LaMonda et al. in this volume for review), as well as with the amount of infants' continued use of vocalisations directed at the parent (Gros-Louis et al., 2014).

The selective way in which infants use their vocalisations when interacting with adults suggests infants are aware that their vocalisations can influence the behaviour

of social partners (Goldstein et al., 2009), and speaks against the possibility that vocalisations serve a purely private function of vocal self-stimulation (McCune, 2008). Furthermore, the repeatedly demonstrated effect of parents' responsiveness to babbling on infants' language acquisition provides compelling evidence that, by vocalising, infants can modulate information transfer and consequently their learning from others. However, what motivates infant babbling and what mediates the relationship between responding to babbling and learning remains unclear. It is plausible that infants vocalise because they enjoy interacting with adults and that learning is incidental and merely a result of modulating the amount of verbal input they receive (Hoff, 2003; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Infants may therefore boost their vocabulary through babbling by virtue of hearing more words spoken to them in response, without babbling itself being uttered with a communicative or information-seeking motivation. However, some recent findings suggest the link between infant vocalisations and learning might not be fully explained by mere heightened frequency of opportunities for social learning.

Goldstein and Schwade (2010) investigated object-directed vocalisations, defined as non-cry prelinguistic vocalisations, uttered when the infant is looking at an object being held or within reach. They examined the effect of parental responses to infants' spontaneous object-directed vocalisations in a play situation and, as outlined above, found that responses infants received at 9 months predicted their vocabulary size at 15 months of age (Goldstein & Schwade, 2010). However, this effect was only observed when parents labelled the objects infants were attending to at the time of vocalisation. If the parent, instead of labelling the attended object, said words that bore an acoustic resemblance to the babble (e.g. saying "bottle" after infant vocalised "ba"), an opposite relationship was found; parents' responses were negatively correlated with language outcome (Goldstein & Schwade, 2010). This striking dissociation lead the authors to propose that infant babbling, particularly object-directed babbling, might not only serve the modulation of parental input, but may in fact signal that the infant is in a state of focused attention, a state of readiness to learn about the object towards which the babbling was directed (Goldstein, Schwade, Briesch, & Syal, 2010). If this is the case, it follows that infants should learn the information they receive during these states of heightened attention, signalled by vocalisations, better than at other times.

This hypothesis was tested in two further studies by Goldstein et al. (2010). In the first, the number of infant vocalisations, as a potential measure of focused attention, was recorded as infants freely played with individual objects. If vocalisations reflect states of preparedness for learning, the degree of infants' learning should correlate with the number of vocalisations directed at the object. In the second experiment, the experimenter provided labels for the objects infants were exploring. The labels were given contingently on spontaneous object vocalisations during exploration for one group of infants, and non-contingently (at equivalent time points, but irrespective of vocalisations) for the other. Again, if vocalisations signal preparedness to learn new information, the object labels should be better encoded when given contingent on infant babbling. In both studies, infants' learning outcome was in accordance with predictions of the heightened attention hypothesis.

Infants encoded object features better for those objects that they vocalised most than the ones they babbled about least; and infants who received labels contingent on their vocalisations learned the labels of the objects better than infants who heard the same amount of labels non-contingently on their vocalising (Goldstein et al., 2010). The authors conclude that infants' vocalisations in a social interaction can structure parental responses to align, time and content-wise, with the infants' focus of attention, which in turn facilitates infant learning.

In sum, the reviewed research on infant prelinguistic vocalisations suggests infant babbling affects their learning in a broader way than it was first assumed. Not only do infant vocalisations provide the foundation for future language development from a production point of view (Kimbrough et al., 1976; Locke & Pearson, 1990), but, by vocalising, infants create opportunities for social transfer of information that are tailored to their focus of attention and readiness to learn. Infants appear to babble when they need information (such as while exploring an object of interest) and responding to their vocalisations contingently and with appropriate information can lead to superior learning.

While these studies demonstrate that babbling can serve as a powerful mechanism for eliciting information transfer, it remains unclear whether infant babbling is in fact truly communicative and deployed with the intention to obtain information from others. In contrast, when later in development infants begin to use gestures, they appear to be doing just that— communicating and requesting information.

Pointing

The gesture of pointing becomes a part of infants' behavioural repertoire in the months around their first birthday, when they begin to show both comprehension and production of this unique gesture (Tomasello, Carpenter, & Liszkowski, 2007). Although widely studied, the exact function of pointing and the motives driving infants to point are still a matter of debate.

A pointing gesture can be produced communicatively, in the presence of a social partner and with the intention to solicit a response, or privately, for the pointers themselves. The non-communicative type of pointing was proposed in the first theoretical account of pointing (Bates, Camaioni, & Volterra, 1975) and was suggested to serve the function of focusing one's own attention, much like adults do when faced with complex stimuli (Delgado, Gómez, & Sarriá, 2009). Infants highlighting salient events for themselves, might, in addition to enhancing their attention, serve the function of making the infants' focus of attention publicly available, allowing adults to follow-in on infants' attention (Gómez, 2007). Furthermore, by pointing to salient stimuli initially for themselves, infants ensure that the later emerging communicative pointing is already centred around objects and events that infants find interesting (Bates et al., 1975). Although it has been shown that, contrary to the initial proposal (Bates et al., 1975), private pointing is in fact not replaced by emerging social pointing, but can be observed throughout infancy and childhood (Delgado et al., 2009;

Delgado, Gómez, & Sarriá, 2011; Gómez, 2007), it was communicative pointing that received most attention in infant research.

Classically, infant communicative pointing has been conceptualised as a social tool, and categorised as either imperative or declarative (Bates et al., 1975). Infants were proposed to point imperatively, with the intent to use the adult as a tool of obtaining an object of interest; and point declaratively, with the intent to use the referent of the point as a tool of directing the adults' attention (Bates et al., 1975). What motivates infants to attempt to direct adults' attention to an object or event by so-called 'declarative' pointing has been extensively studied.

According to Tomasello and colleagues, infant pointing is a cooperative communicative act from its onset, motivated by the desire either to share interest and align attitudes about a referent with others, or to help others by informing them about a misplaced object (Tomasello et al., 2007). The idea of an altruistic *informative* motive for infant pointing was based on studies in which infants observed an adult perform actions with an object, which subsequently got accidentally misplaced (Liszkowski, Carpenter, Striano, & Tomasello, 2006). Infants in these situations pointed to the object the adult was searching for, without expressing any desire to obtain the object for themselves, which lead the authors to conclude that pointing was altruistically motivated by a wish to provide information (Liszkowski et al., 2006).

Motivation to *share* interest and attitudes about objects or events, on the other hand, was derived from findings that infants were most satisfied when the adult responded to their pointing by attending to both the infants and the referents of their gestures (Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). Furthermore, infants' satisfaction with adults' response, as measured by absence of repeated points within the same trial and further instances of pointing in subsequent trials, was particularly high when the adult 'aligned' their attitude with infants' interest (Liszkowski, Carpenter, & Tomasello, 2007). According to Tomasello et al. (2007), these results directly support the proposal that it is a desire to share and align an attitude about a referent with another person, and not only to direct attention, that motivates infants to point declaratively.

However, others have expressed reservations about infants' intention to affect others' mental states, such as their attitude towards a referent or knowledge states about objects, and argue that pointing is more likely aimed at eliciting behavioural responses (Gómez, Sarria, & Tamarit, 1993; Southgate, Maanen, & Csibra, 2007). Furthermore, Southgate et al. (2007) propose that the behaviour infants are most likely aiming to elicit in these situations is provision of information about the referent of infants' interest. They argue that real life situations in which an adult requires an infant's help to locate something are rare, and infants' pointing to share interests, simply for the sake of sharing, has no clear function or obvious benefit. It therefore seems unlikely that this gesture would develop for this purpose. Southgate et al. (2007) proposed a re-interpretation of infant pointing as yet another tool infants possess to ensure fast transmission of cultural knowledge from adults. Indeed, several studies suggest infant pointing plays a role in learning.

Adults' most common spontaneous response to infant pointing is verbally responding and naming the objects that infants are pointing to (Kishimoto, Shizawa,

Yasuda, Hinobayashi, & Minami, 2007), suggesting that adults interpret these gestures in a pedagogical framework, teaching infants about the referent in response to their pointing. Goldin-Meadow, Goodrich, Sauer, and Iverson (2007) explored this relationship further and found that it is the referents of infants' points, about which the adults provide information in response, that are the most likely to enter the infants' vocabulary. It is therefore not surprising that the amount of pointing at 10–11 months of age has been shown to be predictive of infants' vocabulary growth (Brooks & Meltzoff, 2008).

This tight relationship between infant pointing, adults' responses, and their impact on infants' knowledge acquisition supports the hypothesis that, as Southgate et al. (2007) suggested, the function of infant pointing is *interrogative* rather than declarative or informative. This account is also more consistent with recent studies on non-communicative pointing, demonstrating that the frequency of private pointing in young children increases when they are engaged in a cognitively demanding task, and that preventing children from pointing (for themselves) has a negative impact on their problem-solving performance (Delgado et al., 2011). Therefore, both communicative and non-communicative pointing potentially reflect infants' cognitive engagement or motivation to learn and, in the same way as private pointing might be used to enhance one's own attention, thereby facilitating one's cognitive processes (Delgado et al., 2011), communicative pointing might serve the function of bringing a referent to the attention of another with the aim of gaining information about it (Southgate et al., 2007). Combined, this would mean that instead of, or in addition to, communicative pointing being used for informing or sharing with others, pointing may serve as a powerful learning tool by which infants request information from knowledgeable adults about the referents they are interested in (Southgate et al., 2007). A series of recent studies has provided strong support for this proposal.

The hypothesis of interrogative pointing was first tested by Begus and Southgate (2012), reasoning that if infants in fact point to request information, then their pointing should be influenced by the potential of an adult to provide information. To test this, two groups of 16-month-olds were faced with either a knowledgeable or an ignorant source of information (the experimenter), in a situation with unfamiliar and non-graspable objects suddenly appearing out of view of the experimenter—a situation which elicits pointing in infants (Liszkowski et al., 2004).

Whether the experimenter was knowledgeable or ignorant was established by the experimenter correctly or incorrectly labelling familiar objects that her and the infant were playing with (e.g. mislabelling a banana a duck) before and during the appearance of unfamiliar objects behind the experimenter. If the infant pointed to the appearing novel object, the experimenter responded by turning to face the object, and labelling it. Based on the hypothesis that pointing serves an information-gathering or *interrogative* function, infants were predicted to point to novel objects less in the presence of someone who is demonstrably ignorant than someone whom they perceive as knowledgeable. In contrast, if infants' motivation for pointing in this study were to obtain the objects (*imperative*), to share interest and excitement (*declarative*), or to inform an experimenter of the presence of an object that she

cannot see (*informative*), there would be no clear reason to predict different rates of pointing between conditions, as the experimenter was responsive, friendly, and demonstrably collaborative in both conditions.

The results revealed that infants pointed to novel objects twice as many times for a knowledgeable than an ignorant informant, despite no other behaviour (infant smiling, willingness to accept objects from the experimenter, etc.) showing any differences between conditions (Begus & Southgate, 2012). These results provide compelling evidence that infants are motivated to share their attention with others because they want to obtain some information about the referent of their gesture, and therefore point more when they perceive that the recipient of their pointing could provide it.

Further supporting evidence for this idea came from a study by Kovács, Tauzin, Téglás, Gergely, and Csibra (2014), in which points, produced by 12-month-old infants, were responded to either with providing information or with sharing the infants' attention. Again, if infants' motivation to share interests through pointing is to merely share attention and align attitudes about the referent with the recipient, then both responses in this study should be equally satisfying. Yet, like in Begus and Southgate (2012), infants were shown to point more frequently when their gestures were responded to with information. The authors concluded that providing information, rather than just sharing attention, was preferred presumably because these responses better matched infants' expectations (Kovács et al., 2014). Both of these studies provide strong evidence that infants indeed point with the motivation and expectation of receiving (reliable) information in response to their gestures, and therefore use the gesture most frequently, when these expectations are met.

The hypothesis of interrogative pointing was then further extended to the prediction that if pointing expresses motivation to learn, it follows that responding to infants' pointing should lead to better assimilation of information. This prediction was first confirmed by Begus, Gliga, and Southgate (2014). In this study, 16-month-olds were introduced to pairs of novel objects and, once they had pointed to one of the objects, were shown a function for either the object they had chosen, or the object they had ignored. Ten minutes later, the objects for which infants had been shown functions were given to the infants, one at a time. Infants replicated the functions of the objects they had pointed to significantly more than those of un-chosen objects. The study provided the first evidence that offering information in response to infants' pointing gestures leads to superior learning, and a control experiment clarified that this difference was due to the learning being *facilitated* when infants' pointing was responded to, and not *hindered* when their pointing was ignored (Begus et al., 2014). A similar paradigm was later also applied to the domain of word learning by Lucca and Wilbourn (2016). In their study, 18-month-olds demonstrated superior mapping of labels to objects when the labels were given to objects that infants had pointed to, compared to ones they did not point to. Furthermore, mapping of labels was more successful when these were provided in response to infant pointing as opposed to other communicative behaviours (Lucca and Wilbourn, 2016).

What drives infants' facilitated learning when information is given in response to their pointing gestures? Regardless of whether infants are pointing communicatively or for themselves, presumably infant pointing reflects their interest in the referent. As reviewed above, it is well established that, in adults, the degree of interest or curiosity for a piece of information is predictive of whether or not this information will be retained (Gruber et al., 2014; Kang et al., 2009) and the findings of Stahl and Feigenson (2015), showing that infants learn more about objects that likely piqued their interest, suggest this relationship may be present early in life. Thus, Begus et al. (2014) proposed that infants direct their points at objects they are interested in, at the time they are prepared to learn about them, and point to them with the intention to solicit information from their social partners. Thus, in addition to infants' pointing modulating their learning by eliciting social interactions (e.g., Petitto, 1988), and by selecting whom to point for (Begus & Southgate, 2012), infant pointing might also facilitate learning directly because it elicits information that is content- and time-contingent to infants' interests and states of preparedness for learning.

Importantly, these findings can have significant implications for infants' learning outside of experimental settings. A closer look at the results of various studies investigating infant pointing behaviour reveals substantial individual variability in how many pointing gestures infants produced under the same circumstances (e.g., Begus & Southgate, 2012). Given the effect that responding to infant (interrogative) pointing has on learning (Begus et al., 2014), and considering that infants' continued deployment of pointing has repeatedly been shown to depend on receiving the desired response (e.g., Begus & Southgate, 2012; Kovács et al., 2014; Liszkowski et al., 2004), variability in the use of, and responsiveness to, this behaviour might have a dramatic effect on infant knowledge acquisition in everyday life.

From Seeking Information to Choosing Social Partners

So far, this chapter outlined how infants' interests and behaviours towards social partners affect when and what information infants learn. But in addition to infants' social interactions affecting their learning and inquisitiveness, infants' drive to acquire information may also directly influence how they perceive social partners, which in turn could influence whom infants prefer to interact with.

Infants selectivity in interactions with other people is well documented. From birth, infants prefer to look at upright, direct-gazing faces (Farroni, Csibra, Simion, & Johnson, 2002; Farroni, Menon, & Johnson, 2006) and faces speaking in infant-compared to adult-directed speech (Cooper & Aslin, 1990). By 6 months of age, infants selectively follow someone's gaze, based on whether or not it was preceded by direct gaze or infant-directed speech (Senju & Csibra, 2008). Later, infants start showing preferences in their behaviour and interactions with social partners based on characteristics such as reliability, conventionality, competence and language. For example, 8-month-olds track how reliably predictive a social partner is when guid-

ing their visual exploration (Tummeltshammer, Wu, Sobel, & Kirkham, 2014); and from infancy to childhood, children consistently copy words produced by a reliable rather than an unreliable labeller (Harris, 2002; Koenig & Echols, 2003; Koenig & Harris, 2007). Furthermore, whether or not infants will imitate a model's actions depends on how competently an adult uses an object (Zmyj, Buttelmann, Carpenter, & Daum, 2010), as well as on the models age (Jaswal & Neely, 2006; Seehagen & Herbert, 2011) and social status (Flynn & Whiten, 2012).

Another widely researched and discussed preference that infants exhibit towards others is their tendency to attend to, imitate, and interact preferentially with social partners that could be described as belonging to the same social group as infants (Buttelmann, Zmyj, Daum, & Carpenter, 2013; Kinzler, Dupoux, & Spelke, 2007; Shutts, Kinzler, McKee, & Spelke, 2009; Soley & Galles, 2015). For example, even before their first birthdays, infants have been shown to exhibit behavioural preferences towards social partners of the same race (Bar-Haim, Ziv, Lamy, & Hodes, 2006), and ones speaking infants' native language (Kinzler et al., 2007).

While infants' selectivity for social partners is well documented, little is known about the role that these preferences play, or whether infants' preferences for different, seemingly unrelated, characteristics of a social partner (e.g. infant-directed speech, competency and native language) might be driven by a common motivation. For example, both infants' preference for direct gaze and for infant-directed speech have been suggested to reflect an adaptation to ensure that infants attend to potential teachers (Csibra & Gergely, 2009, 2011). According to this view, newborns' preference for direct gaze reflects a mechanism dedicated to finding socially relevant information (Farroni et al., 2002). Similarly, infant-directed speech might function as an effective cue for infants to select social partners most likely to provide opportunities for learning (Schachner & Hannon, 2011), and leading infants to expect information from the interlocutor, thus cueing them to attend to the referent of the interlocutor's gaze (Senju & Csibra, 2008).

In contrast, infants' biases towards people speaking the same language or belonging to the same race are usually attributed to highly social motives, such as the desire to affiliate and identify with the chosen social partners (Over & Carpenter, 2012). Because characteristics such as race and language are often seen as indicators of group membership, these early biases have commonly been interpreted as early precursors of our adult tendencies to assign individuals to social groups and, in accordance with the principle of in-group loyalty (Baillargeon et al., 2015), exhibit preferences towards members of one's own group.

It is, however, plausible that both infants' preference for an informative and competent, over an unreliable and incompetent other, and their preference for a native over a non-native speaker, reflect infants' common motivation to focus attention on a social partner who has the most potential to impart useful information. For example, it would seem a sensible learning strategy for infants to attend more to the communication of someone speaking their native language than someone speaking in a foreign tongue. Information communicated in a known language undoubtedly provides more information at lower cognitive effort. A social partner, who demonstrates knowledge of the same language with which infants are already familiar, is

likely to provide information that is less discrepant from infants' existing knowledge (Lowenstein, 1994), and that would be easier to embed into infants' existing knowledge, thus enabling better learning progress (Gottlieb et al., 2013).

In sum, many studies have found that infants are selective in their interactions with social partners. However, behavioural data alone cannot disentangle which interpretations best explain infant selectivity; those assuming it arises from a drive for social affiliation, or those hypothesising an underlying motivation to seek information from optimal informants. To address this question directly, Begus, Gliga, and Southgate (2016) exploited a neural measure to test the hypothesis that infants' social preferences reflect a drive for knowledge rather than for affiliation. The neural measure of interest was EEG oscillatory activity in the theta frequency range.

Research investigating neural underpinnings of learning has identified theta rhythmic activity to be associated with, and predictive of, successful information encoding in both adults and infants. For example, in a task where adult participants were asked to learn pairs of words or faces, the amount of theta activity (4–8 Hz) during trials which subsequently resulted in successful recollection, was higher compared to activity during trials which resulted in poor recall performance (Mölle, Marshall, Fehm, & Born, 2002). Similarly, in a study where 11-month-old infants were free to explore novel objects, the power of theta oscillations (3-5Hz in infants) during their object exploration predicted whether or not the infants later recognised the features of the explored objects (Begus, Southgate, & Gliga, 2015). Importantly, adult studies have shown that theta activity is not only recorded during encoding of information, but can be elicited by an expectation to receive information, and that this anticipatory theta activation likewise leads to better retention of the information presented (Fell et al., 2011; Gruber, Watrous, Ekstrom, Ranganath, & Otten, 2013; Guderian, Schott, Richardson-Klavehn, & Düzel, 2009). Furthermore, these anticipatory theta rhythms have been shown to be modulated by whether or not the participants were motivated to encode information, with higher motivation predicting more anticipatory theta activity, and subsequent superior retention of information (Gruber et al., 2013), suggesting theta activity may be indicative of an active preparatory state for learning.

To investigate if an expectation of information is what drives infants' selectivity in their interactions with social partners, Begus et al. (2016) introduced 11-month-old infants to two social partners, one of whom provided infants with information (labels or function demonstrations on known objects), and another who did not (in this case, the person simply pointed at or handled the object while vocalising, 'Oooh'). In subsequent test trials, infants observed the same two people now interacting with novel objects and theta activity was measured at the beginning of each trial, before the person began interacting with the object. The authors reasoned that differences in theta activity during this anticipation period would be most likely to reflect differences in infants' expectation or preparation for learning the information received (or not) at the end of the trials. Infants indeed exhibited heightened anticipatory theta activity selectively, i.e. only in anticipation periods of trials in which they were facing the informant who had previously provided information. Crucially, the same pattern of activation was also found in a further experiment, in which

infants were faced with a native and a foreign speaker, both labelling novel objects. Theta rhythms revealed that infants were expecting to learn information from the native speakers, whereas they did not have the same expectations of the foreign speaker (Begus et al., 2016; Begus, Gliga, & Southgate, 2017).

Thus, these findings challenge the theories proposing that infants preferentially attend to, and interact with, someone speaking their native language based on a desire to affiliate and identify with social partners (Over & Carpenter, 2012), specifically with members of one's own group (Baillargeon et al., 2015). Instead, in line with the large body of literature that suggests infants selectively attend to, and preferentially learn from, reliable sources of information (e.g. Begus & Southgate, 2012; Tummeltshammer et al., 2014), this study provided the first direct evidence suggesting that what underlies infants' preferences for native over foreign speakers is likewise their motivation to learn. Consistent with theories of curiosity-driven, intrinsically-motivated learning, infants selectively preparing to learn from the knowledgeable and native speakers can be explained by infants' motivation to obtain information that matches an optimal level of discrepancy from their existing knowledge (Lowenstein, 1994), and one that offers the best learning progress (Gottlieb et al., 2013). Therefore, infants' information-seeking motivation affects not only their learning, but can also systematically influence which social partners they perceive as worthy of attending to, and interacting with. Lastly, while older children demonstrate even more complex and sophisticated social learning strategies (see Bonawitz, Bass, and Lapidow, this volume), infants' selectivity in who to attend to, and ask information from, and what information to ask for and learn, suggests efficient active learning mechanisms are in place already in infancy.

Nurturing Young Children's Curiosity

The research reviewed in this chapter focused on investigating infants' active learning experimentally and has shown that responding to infants' expressions of interest can have an immediate impact on their learning. However, given that studies have shown that whether or not infants continue to express inquisitive behaviours depends on them receiving the intended response (e.g. Begus & Southgate, 2012; Kovács et al., 2014), nurturing infants' interest with informative responses may be crucial not only because it affects immediate learning, but because it may also affect the extent to which young children continue to seek information from social partners. As proposed by Hidi and Renninger (2006), while situational interest can lead to short-term information-seeking and learning, sustained inquisitiveness can be seen as a mental resource that contributes to future endeavours, increased personal knowledge and improved cognitive abilities. It is plausible that recognition of infants' early expressions of interest, and responding to these expressions with the right type of information, is important in fostering an inquisitive mind.

Several studies have suggested that curiosity, or a motivation to learn, does indeed predict individuals' cognitive abilities (reflected in academic success),

and that the development of these inquisitive traits may depend on characteristics of a child's early environment. For example, children, whose parents placed more emphasis on academic stimulation and on satisfying children's curiosity (as assessed by interviews and home observations over a period of 2 years), were more likely to develop sustained individual interests, characterised by a relatively enduring predisposition to interact with a target domain (Leibham, Alexander, Johnson, Neitzel, & Reishenrie, 2005). Moreover, other longitudinal studies investigating the relationship between home environment and children's academic motivation have shown that children whose homes had a greater emphasis on learning opportunities and activities were more intrinsically academically motivated (Gottfried, Fleming, & Gottfried, 1998); and that the effect of gene-by-socioeconomic status interaction on academic achievement is mediated by children's learning motivation (Tucker-Drob & Harden, 2013). These studies thus provide strong support for the idea that fostering children's curiosity and interests may have a powerful impact on their learning achievements and might even act as a protective factor against potentially adverse effects of socioeconomic status (Tucker-Drob & Harden, 2013).

But this relationship between home environment and inquisitiveness is likely formed even before children enter formal education. Indeed, characteristics of home environment and parental input have been shown to correlate with frequency of hypothesised inquisitive behaviours even in infancy. For example, the degree to which parents respond to infant prelinguistic vocalisations in everyday life is positively correlated with the amount of infants' continued use of vocalisations directed at the parent (Gros-Louis et al., 2014). Furthermore, aspects of parental responsiveness have been shown to predict the frequency of infant pointing (McGillion et al., 2012), which in turn accounted for the differences in language production between children from families of different socioeconomic status (Rowe & Goldin-meadow, 2009).

In sum, infants' social information seeking, if responded to, could be the cradle of children's curiosity, fostering an inquisitive mind and leading to future academic success. While adults can support their own interests and curiosity by various media, such as literature or inclusion in social networks that involve individuals with similar interests, young children, and especially infants, are dependent on the adult social partners in their environment to provide them with similar types of support (Leibham et al., 2005). Furthermore, as well as nurturing young children's curiosity, it may also be possible to *induce* infants' curiosity. As has been demonstrated in studies exploring effects of violating infants' expectations, highlighting a gap (or inconsistency) in infants' knowledge results in increased theta oscillations (Berger, Tzur, & Posner, 2006), as well as in systematic exploration and facilitated learning (Stahl & Feigenson, 2015). Thus, children's long-term inquisitiveness could plausibly also be encouraged if, for example, formal and informal education included systematically stimulating infants' and young children's curiosity, by exposing gaps in their knowledge or highlighting their learning progress.

Conclusions

Given that our brains appear to be hardwired to experience curiosity and information consumption as rewarding, it seems reasonable to assume every child is born curious. However, as the research reported in this chapter demonstrates, children's expressions of inquisitiveness, as well as its maintenance, can heavily depend on the social environment that children are interacting with. Even before their first birthdays, infants selectively seek and prepare to learn from social partners, who provide them with information that is relevant and learnable. Furthermore, when infants express their interests behaviourally, they appear to expect to receive information in response, and if the appropriate information is conveyed, infants assimilate it better than unsolicited information. Taken together, these studies suggest that even before entering formal education, infants have the motivation and the means to seek information from their environment. Combined with an attentive and responsive social partner, this early inquisitiveness can guide infants' knowledge acquisition and can possibly lay the foundation for life-long curiosity, which is known to be predictive of academic success. Future work on infants' inquisitive behaviours will hopefully lead to better understanding of how the gift of curiosity could be nurtured to ensure it keeps on giving.

References

Ainsworth, M. D. S. (1992). A consideration of social referencing in the context of attachment theory and research. In S. Feinman (Ed.), *Social referencing and the social construction of reality in infancy* (pp. 349–367). New York, NY: Plenum.

Baillargeon, R., Scott, R. M., He, Z., Sloane, S., Setoh, P., Jin, K., … Bian, L. (2015). Psychological and Sociomoral reasoning in infancy. In P. Shaver, M. Mikulincer, J. Borgida, & J. Bargh (Eds.), *APA handbook of personality and social psychology: Vol. 1. Attitudes and social cognition* (Vol. 1, pp. 79–150). Washington, DC: APA. https://doi.org/10.1037/14341-000

Baldwin, D. A., & Moses, L. J. (1996). The ontogeny of social information gathering. *Child Development, 67*(5), 1915. https://doi.org/10.2307/1131601

Bar-Haim, Y., Ziv, T., Lamy, D., & Hodes, R. M. (2006). Nature and nurture in own-race face processing. *Psychological Science, 17*(2), 159–163. https://doi.org/10.1111/j.1467-9280.2006.01679.x

Bates, E., Camaioni, L., & Volterra, V. (1975). The acquisition of performatives prior to speech. *Merrill-Palmer Quarterly of Behavior and Development, 21*(3), 205–226. https://doi.org/10.2307/23084619

Begus, K., Gliga, T., & Southgate, V. (2014). Infants learn what they want to learn: responding to infant pointing leads to superior learning. *PLoS ONE, 9*(10), e108817. https://doi.org/10.1371/journal.pone.0108817

Begus, K., Gliga, T., & Southgate, V. (2016). Infants' preferences for native speakers are associated with an expectation of information. *Proceedings of the National Academy of Sciences, 2016*, 03261. https://doi.org/10.1073/pnas.1603261113

Begus, K., Gliga, T., & Southgate, V. (2017). Reply to Kinzler and Liberman: Neural correlate provides direct evidence that infant's social preferences are about information. *Proceedings of the National Academy of Sciences, 2017*, 03098. https://doi.org/10.1073/pnas.1703098114

Begus, K., & Southgate, V. (2012). Infant pointing serves an interrogative function. *Developmental Science*, 1–8. https://doi.org/10.1111/j.1467-7687.2012.01160.x

Begus, K., Southgate, V., & Gliga, T. (2015). Neural mechanisms of infant learning: Differences in frontal theta activity during object exploration modulate subsequent object recognition. *Biology Letters, 11*(5), 20150041–20150041. https://doi.org/10.1098/rsbl.2015.0041

Berger, A., Tzur, G., & Posner, M. I. (2006). Infant brains detect arithmetic errors. *Proceedings of the National Academy of Sciences of the United States of America, 103*(33), 12649–12653. https://doi.org/10.1073/pnas.0605350103

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology, 45*, 3.

Berlyne, D. E. (1966). Curiosity and exploration. *Science, 153*(3731), 25–33. Retrieved from http://www.sciencemag.org/content/153/3731/25.short

Bornstein, M. H., Tamis-Lemonda, C. S., Hahn, C.-S., & Haynes, O. M. (2008). Maternal responsiveness to young children at three ages: Longitudinal analysis of a multidimensional, modular, and specific parenting construct. *Developmental Psychology, 44*(3), 867–874. https://doi.org/10.1037/0012-1649.44.3.867

Brooks, R., & Meltzoff, A. N. (2008). Infant gaze following and pointing predict accelerated vocabulary growth through two years of age: A longitudinal, growth curve modeling study. *Journal of Child Language, 35*(1), 207–220. https://doi.org/10.1017/S030500090700829X

Buttelmann, D., Zmyj, N., Daum, M., & Carpenter, M. (2013). Selective imitation of in-group over out-group members in 14-month-old infants. *Child Development, 84*(2), 422–428. https://doi.org/10.1111/j.1467-8624.2012.01860.x

Carruthers, P. (2008). Meta-cognition in animals: A skeptical look. *Mind and Language, 23*(1), 58–89. https://doi.org/10.1111/j.1468-0017.2007.00329.x

Collins, R. P., Litman, J. A., & Spielberger, C. D. (2004). The measurement of perceptual curiosity. *Personality and Individual Differences, 36*(5), 1127–1141. https://doi.org/10.1016/S0191-8869(03)00205-8

Cooper, R. P., & Aslin, R. N. (1990). Preferences for infant-directed speech in the first month after birth. *Child Development, 61*(5), 1584–1595.

Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences, 13*(4), 148–153. https://doi.org/10.1016/j.tics.2009.01.005

Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences, 366*(1567), 1149–1157. https://doi.org/10.1098/rstb.2010.0319

Delgado, B., Gómez, J. C., & Sarriá, E. (2009). Private pointing and private speech: Developing parallelisms. In A. Winsler, C. Fernyhough, & I. Montero (Eds.). Private speech, executive function, and the development of verbal self-regulation (pp. 153–162). Cambridge: Cambridge University Press.

Delgado, B., Gómez, J. C., & Sarriá, E. (2011). Pointing gestures as a cognitive tool in young children: Experimental evidence. *Journal of Experimental Child Psychology, 110*(3), 299–312. https://doi.org/10.1016/j.jecp.2011.04.010

Dickstein, S., Thompson, R. A., Estes, D., Malkin, C., & Lamb, M. E. (1984). Social referencing and the security of attachment. *Infant Behavior and Development, 7*(4), 507–516. https://doi.org/10.1016/S0163-6383(84)80009-0

Farroni, T., Csibra, G., Simion, F., & Johnson, M. H. (2002). Eye contact detection in humans from birth. *Proceedings of the National Academy of Sciences of the United States of America, 99*(14), 9602–9605. https://doi.org/10.1073/pnas.152159999

Farroni, T., Menon, E., & Johnson, M. H. (2006). Factors influencing newborns' preference for faces with eye contact. *Journal of Experimental Child Psychology, 95*(4), 298–308. https://doi.org/10.1016/j.jecp.2006.08.001

Feinman, S. (1982). Social referencing in infancy. *Merrill-Palmer Quarterly of Behavior and Development, 24*, 445–470.

Feinman, S., Roberts, D., Hsieh, K.-F., Sawyer, D., & Swanson, D. (1992). A critical review of social referencing in infancy. In *Social referencing and the social construction of reality in infancy* (pp. 15–54). New York, NY: Plenum.

Fell, J., Ludowig, E., Staresina, B. P., Wagner, T., Kranz, T., Elger, C. E., & Axmacher, N. (2011). Medial temporal theta/alpha power enhancement precedes successful memory encoding: Evidence based on intracranial EEG. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 31*(14), 5392–5397. https://doi.org/10.1523/JNEUROSCI.3668-10.2011

Flynn, E. G., & Whiten, A. (2012). Experimental "microcultures" in young children: Identifying biographic, cognitive and social predictors of information transmission. *Child, 83*(3), 911–925. https://doi.org/10.1063/1.2756072

Fowler, H. (1966). *Curiosity and exploratory behavior*. New York, NY: Macmillan.

Franklin, B., Warlaumont, A. S., Messinger, D., Bene, E., Nathani Iyer, S., Lee, C.-C., … Oller, D. K. (2013). Effects of parental interaction on infant vocalization rate, variability and vocal type. *Language Learning and Development, 10*(3), 279–296. https://doi.org/10.1080/15475441.2013.849176

Gliga, T., & Southgate, V. (2016). Metacognition: Pre-verbal infants adapt their behaviour to their knowledge states. *Current Biology, 26*(22), R1191–R1193. https://doi.org/10.1016/j.cub.2016.09.065

Goldin-Meadow, S., Goodrich, W., Sauer, E., & Iverson, J. (2007). Young children use their hands to tell their mothers what to say. *Developmental Science, 10*(6), 778–785. https://doi.org/10.1111/j.1467-7687.2007.00636.x

Goldstein, M. H., & Schwade, J. a. (2008). Social feedback to infants' babbling facilitates rapid phonological learning. *Psychological Science, 19*(5), 515–523. https://doi.org/10.1111/j.1467-9280.2008.02117.x

Goldstein, M. H., & Schwade, J. A. (2010). From birds to words: Perception of structure in social interactions guides vocal development and language learning. In *The oxford handbook of developmental and comparative neuroscience* (pp. 708–729). Oxford, UK: Oxford University Press.

Goldstein, M. H., Schwade, J. A., & Bornstein, M. H. (2009). The value of vocalizing: Five-month-old infants associate their own noncry vocalizations with responses from caregivers. *Child Development, 80*(3), 636–644. https://doi.org/10.1111/j.1467-8624.2009.01287.x

Goldstein, M. H., Schwade, J., Briesch, J., & Syal, S. (2010). Learning while babbling: Prelinguistic object-directed vocalizations indicate a readiness to learn. *Infancy*. https://doi.org/10.1111/j.1532-7078.2009.00020.x

Gómez, J. C. (2007). Pointing behaviors in apes and human infants: A balanced interpretation. *Child Development, 78*(3), 729–734. https://doi.org/10.1111/j.1467-8624.2007.01027.x

Gómez, J. C., Sarria, E., & Tamarit, J. (1993). The comparative study of early communication and theories of mind: Ontogeny, phylogeny, and pathology. In S. Baron-Cohen, H. Tager-Flusberg, & D. Cohen (Eds.), *Understanding other minds: Perspectives from autism* (pp. 397–426). New York, NY: Oxford University Press.

Gottfried, A. E., Fleming, J. S., & Gottfried, A. W. (1998). Role of cognitively stimulating home environment in children's academic intrinsic motivation: A longitudinal study. *Child Development, 69*(5), 1448–1460. Retrieved from http://cat.inist.fr/?aModele=afficheN&cpsidt=1591790

Gottlieb, J., Oudeyer, P.-Y., Lopes, M., & Baranes, A. (2013). Information-seeking, curiosity, and attention: Computational and neural mechanisms. *Trends in Cognitive Sciences, 17*(11), 585–593. https://doi.org/10.1016/j.tics.2013.09.001

Goupil, L., & Kouider, S. (2016). Behavioral and neural indices of metacognitive sensitivity in preverbal infants. *Current Biology, 26*(22), 3038–3045. https://doi.org/10.1016/j.cub.2016.09.004

Goupil, L., Romand-monnier, M., & Kouider, S. (2016). Infants ask for help when they know they don't know. *Proceedings of the National Academy of Sciences of the United States of America*, 2016. https://doi.org/10.1073/pnas.1515129113

Gros-Louis, J., West, M. J., & King, A. P. (2014). Maternal responsiveness and the development of directed vocalizing in social interactions. *Infancy, 19*(4), 385–408. https://doi.org/10.1111/infa.12054

Gruber, M. J., Gelman, B. D., & Ranganath, C. (2014). States of curiosity modulate hippocampus-dependent learning via the dopaminergic circuit. *Neuron, 84*(2), 486–496. https://doi.org/10.1016/j.neuron.2014.08.060

Gruber, M. J., Watrous, A. J., Ekstrom, A. D., Ranganath, C., & Otten, L. J. (2013). Expected reward modulates encoding-related theta activity before an event. *NeuroImage, 64*, 68–74. https://doi.org/10.1016/j.neuroimage.2012.07.064

Guderian, S., Schott, B. H., Richardson-Klavehn, A., & Düzel, E. (2009). Medial temporal theta state before an event predicts episodic encoding success in humans. *Proceedings of the National Academy of Sciences of the United States of America, 106*(13), 5365–5370. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2663999&tool=pmcentrez&rendertype=abstract

Hampton, R. R. (2009). Multiple demonstrations of metacognition in nonhumans: Converging evidence or multiple mechanisms? *Comparative Cognition and Behavior Reviews, 1*(4), 17–28.

Harris, P. (2002). Checking our sources: The origins of trust in testimony. *Studies in History and Philosophy of Science Part A, 33*(2), 315–333. https://doi.org/10.1016/S0039-3681(02)00007-9

Hidi, S., & Harackiewicz, J. M. (2000). Motivating the academically unmotivated: A critical issue for the 21st century. *Review of Educational Research, 70*(2), 151–179. https://doi.org/10.3102/00346543070002151

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development, 74*(5), 1368–1378. https://doi.org/10.1111/1467-8624.00612

Houston-Price, C., & Nakai, S. (2004). Distinguishing novelty and familiarity effects in infant preference procedures. *Infant and Child Development, 348*(September), 341–348. https://doi.org/10.1002/icd.364

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology, 27*(2), 236–248. https://doi.org/10.1037/0012-1649.27.2.236

Jaswal, V. K., & Neely, L. a. (2006). Adults don't always know best: Preschoolers use past reliability over age when learning new words. *Psychological Science, 17*(9), 757–758. https://doi.org/10.1111/j.1467-9280.2006.01778.x

Jepma, M., Verdonschot, R. G., van Steenbergen, H., Rombouts, S. A. R. B., & Nieuwenhuis, S. (2012). Neural mechanisms underlying the induction and relief of perceptual curiosity. *Frontiers in Behavioral Neuroscience, 6*(February), 5. https://doi.org/10.3389/fnbeh.2012.00005

Kang, M. J., Hsu, M., Krajbich, I. M., Loewenstein, G., McClure, S. M., Wang, J. T., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. *Psychological Science, 20*(8), 963–973. https://doi.org/10.1111/j.1467-9280.2009.02402.x

Kaplan, F., & Oudeyer, P.-Y. (2007). In search of the neural circuits of intrinsic motivation. *Frontiers in Neuroscience, 1*(1), 225–236. https://doi.org/10.3389/neuro.01.1.1.017.2007

Kidd, C., & Hayden, B. Y. (2015). The Psychology and Neuroscience of Curiosity. *Neuron, 88*(3), 449–460. https://doi.org/10.1016/j.neuron.2015.09.010

Kidd, C., Piantadosi, S. T., & Aslin, R. N. (2012). The Goldilocks effect: Human infants allocate attention to visual sequences that are neither too simple nor too complex. *PloS One, 7*(5), e36399. https://doi.org/10.1371/journal.pone.0036399

Kim, G., & Kwak, K. (2011). Uncertainty matters: Impact of stimulus ambiguity on infant social referencing. *Infant and Child Development, 20*(5), 449–463. https://doi.org/10.1002/icd.708

Kimbrough, O. D., Wieman, L. A., Doyle, W. J., & Ross, C. (1976). Infant babbling and speech. *Journal of Child Language, 3*(1), 1–11.

Kimbrough, O. D., Eilers, R. E., Neal, A. R., & Cobo-Lewis, A. B. (1998). Late onset canonical babbling: A possible early marker of abnormal development. *American Journal of Mental Retardation, 103*(3), 249–263.

Kimbrough, O. D., Eilers, R. E., Neal, A. R., & Schwartz, H. K. (1999). Precursors to speech in infancy. *Journal of Communication Disorders, 32*(4), 223–245.

Kinzler, K. D., Dupoux, E., & Spelke, E. S. (2007). The native language of social cognition. *Proceedings of the National Academy of Sciences of the United States of America, 104*(30), 12577–12580. https://doi.org/10.1073/pnas.0705345104

Kishimoto, T., Shizawa, Y., Yasuda, J., Hinobayashi, T., & Minami, T. (2007). Do pointing gestures by infants provoke comments from adults? *Infant Behavior and Development, 30*(4), 562–567. https://doi.org/10.1016/j.infbeh.2007.04.001

Knutson, B., Adams, C. M., Fong, G. W., & Hommer, D. (2001). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 21*(16), RC159.

Koenig, M. A., & Echols, C. H. (2003). Infants ' understanding of false labeling events: The referential roles of words and the speakers who use them. *Cognition, 87*, 179–208.

Koenig, M. A., & Harris, P. L. (2007). The basis of epistemic trust: Reliable testimony or reliable sources? *Episteme: A Journal of Social Epistemology, 4*(3), 264–284. https://doi.org/10.1353/epi.0.0017

Kovács, Á. M., Tauzin, T., Téglás, E., Gergely, G., & Csibra, G. (2014). Pointing as epistemic request: 12-month-olds point to receive new information. *Infancy, 19*(6), 543–557. https://doi.org/10.1111/infa.12060

Kutsuki, A., Egami, S., Ogura, T., Nakagawa, K., Kuroki, M., & Itakura, S. (2007). Developmental changes of referential looks in 7- and 9-month-olds: A transition from dyadic to proto-referential looks. *Psychologia, 50*(4), 319–329. https://doi.org/10.2117/psysoc.2007.319

Leibham, M., Alexander, J., Johnson, K., Neitzel, C., & Reishenrie, F. (2005). Parenting behaviors associated with the maintenance of preschoolers' interests: A prospective longitudinal study. *Journal of Applied Developmental Psychology, 26*(4), 397–414. https://doi.org/10.1016/j.appdev.2005.05.001

Liszkowski, U., Carpenter, M., Henning, A., Striano, T., & Tomasello, M. (2004). Twelve-month-olds point to share attention and interest. *Developmental Science, 7*(3), 297–307.

Liszkowski, U., Carpenter, M., Striano, T., & Tomasello, M. (2006). 12- and 18-Month-olds point to provide information for others. *Journal of Cognition and Development, 7*(2), 173–187. https://doi.org/10.1207/s15327647jcd0702

Liszkowski, U., Carpenter, M., & Tomasello, M. (2007). Reference and attitude in infant pointing. *Journal of Child Language, 34*(1), 1–20. https://doi.org/10.1017/S0305000906007689

Litman, J. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. *Cognition & Emotion, 19*(6), 793–814. https://doi.org/10.1080/02699930541000101

Litman, J. a. (2008). Interest and deprivation factors of epistemic curiosity. *Personality and Individual Differences, 44*(7), 1585–1595. https://doi.org/10.1016/j.paid.2008.01.014

Litman, J. A., & Silvia, P. J. (2006). The latent structure of trait curiosity: Evidence for interest and deprivation curiosity dimensions. *Journal of Personality Assessment, 86*(3), 318–328. https://doi.org/10.1207/s15327752jpa8603_07

Locke, J. L., & Pearson, D. M. (1990). Linguistic significance of babbling: Evidence from a tracheostomized infant. *Journal of Child Language, 17*(1), 1–16.

Lowenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. Psychological Bulletin 116, 75–98.

Lucca, K., & Wilbourn, M. P. (2016). Communicating to Learn: Infants' Pointing Gestures Result in Optimal Learning. *Child Development*. http://doi.org/10.1111/cdev.12707

Masataka, N. (2003). *The onset of language*. Cambridge, MA: University Press.

McCune, L. (2008). *How children learn to learn language*. Oxford, UK: Oxford University Press.

McGillion, M. L., Herbert, J. S., Pine, J., Vihman, M. M., DePaolis, R., Keren-Portnoy, T., & Matthews, D. E. (2012). What paves the way to conventional language? The predictive value

of babble, pointing and SES. *Child Development, 15*(6), 817–829. https://doi.org/10.1111/j.1467-7687.2012.01181.x

Mitchell, M. (1993). Situational interest: Its multifaceted structure in the secondary school mathematics classroom. *Journal of Educational Psychology, 3*, 424. https://doi.org/10.1017/CBO9781107415324.004

Mölle, M., Marshall, L., Fehm, H. L., & Born, J. (2002). EEG theta synchronization conjoined with alpha desynchronization indicate intentional encoding. *European Journal of Neuroscience, 15*(5), 923–928. https://doi.org/10.1046/j.1460-9568.2002.01921.x

Moulin-Frier, C., Nguyen, S. M., & Oudeyer, P.-Y. (2013). Self-organization of early vocal development in infants and machines: The role of intrinsic motivation. *Frontiers in Psychology, 4*(1006), 1006. https://doi.org/10.3389/fpsyg.2013.01006

Nguyen, S. M., Ivaldi, S., Lyubova, N., Droniou, A., Gerardeaux-Viret, D., Filliat, D., … Oudeyer, P. Y. (2013). Learning to recognize objects through curiosity-driven manipulation with the iCub humanoid robot. In *Development and Learning and Epigenetic Robotics (ICDL), 2013 IEEE Third Joint International Conference on* (pp. 1–8). https://doi.org/10.1109/DevLrn.2013.6652525

Oudeyer, P.-Y., & Smith, L. B. (2006). How evolution may work through curiosity-driven developmental process. *Topics in Cognitive Science*. https://doi.org/10.1017/CBO9781107415324.004

Over, H., & Carpenter, M. (2012). Putting the social into social learning: Explaining both selectivity and fidelity in children's copying behavior. *Journal of Comparative Psychology, 126*(2), 182–192. https://doi.org/10.1037/a0024555

Petitto, L. A. (1988). "Language" in the pre-linguistic child. In F. Kessel (Ed.), *Development of language and language researchers: Essays in honor of Roger Brown* (pp. 187–221). Hillsdale, NJ: Lawrence Erlbaum.

Piaget, J. (1952). *The origins of intelligence in children*. New York, NY: International University Press.

Rowe, M. L., & Goldin-meadow, S. (2009). *Differences in early gesture explain* (Vol. February, pp. 951–953).

Schachner, A., & Hannon, E. E. (2011). Infant-directed speech drives social preferences in 5-month-old infants. *Developmental Psychology, 47*(1), 19–25. https://doi.org/10.1037/a0020740

Schmitow, C., & Stenberg, G. (2013). Social referencing in 10-month-old infants. *European Journal of Developmental Psychology, 10*(5), 533–545. https://doi.org/10.1080/17405629.2013.763473

Seehagen, S., & Herbert, J. S. (2011). Infant imitation from televised peer and adult models. *Infancy, 16*(2), 113–136. https://doi.org/10.1111/j.1532-7078.2010.00045.x

Senju, A., & Csibra, G. (2008). Gaze following in human infants depends on communicative signals. *Current Biology, 18*(9), 668–671. https://doi.org/10.1016/j.cub.2008.03.059

Shutts, K., Kinzler, K. D., McKee, C. B., & Spelke, E. S. (2009). Social information guides infants' selection of foods. *Journal of Cognitive Development, 10*(1–2), 417–428. https://doi.org/10.1055/s-0029-1237430.Imprinting

Soley, G., & Galles, N. S. (2015). Infants prefer tunes previously introduced by speakers of their native language. *Child Development, 86*(6), 1685–1692.

Southgate, V., van Maanen, C., & Csibra, G. (2007). Infant pointing: Communication to cooperate or communication to learn? *Child Development*, *78*(3), 735–740. https://doi.org/10.1111/j.1467-8624.2007.01028.x

Spielberger, C. D., & Starr, L. M. (1994). Curiosity and exploratory behaviour. In H. F. O'Neil & M. Drillings (Eds.), *Motivation: Theory and research* (pp. 221–243). Hillsdale, NJ: Erlbaum.

Stahl, A. E., & Feigenson, L. (2015). Observing the unexpected enhances infants' learning and exploration. *Science, 348*(6230), 91–94.

Stenberg, G. (2009). Selectivity in infant social referencing. *Infancy, 14*(4), 457–473. https://doi.org/10.1080/15250000902994115

Stoel-Gammon, C. (1992). Prelinguistic vocal development: Measurement and predictions. In C. A. Ferguson, L. Menn, & C. Stoel-Gammon (Eds.), *Phonological Development* (pp. 439–456). Timonium, MD: York Press.

Tamis-LeMonda, C. S., & Bornstein, M. H. (2002). Maternal responsiveness and early language acquisition. *Advances in Child Development and Behavior, 29*, 90–129.

Tamis-LeMonda, C. S., Bornstein, M. H., & Baumwell, L. (2001). Maternal responsiveness and children's achievement of language milestones. *Child Development, 72*(3), 748–767. https://doi.org/10.1111/1467-8624.00313

Tomasello, M., Carpenter, M., & Liszkowski, U. (2007). A new look at infant pointing. *Child Development, 78*(3), 705–722. https://doi.org/10.1111/j.1467-8624.2007.01025.x

Tucker-Drob, E. M., & Harden, K. P. (2013). Learning motivation mediates gene-by-socioeconomic status interaction on mathematics achievemnt in early childhood. *Learning and Individual Differences, 22*(1), 37–45. https://doi.org/10.1016/j.lindif.2011.11.015.Learning

Tummeltshammer, K. S., Wu, R., Sobel, D. M., & Kirkham, N. Z. (2014). Infants track the reliability of potential informants. *Psychological Science*, (July). https://doi.org/10.1177/0956797614540178

Vaish, A., Demir, Ö. E., & Baldwin, D. (2011). Thirteen- and 18-month-old infants recognize when they need referential information. *Social Development, 20*(3), 431–449. https://doi.org/10.1111/j.1467-9507.2010.00601.x

von Stumm, S., Hell, B., & Chamorro-Premuzic, T. (2011). The hungry mind: Intellectual curiosity is the third pillar of academic performance. *Perspectives on Psychological Science, 6*(6), 574–588. https://doi.org/10.1177/1745691611421204

Walden, T., Kim, G., McCoy, C., & Karrass, J. (2007). Do you believe in magic? Infants' social looking during violations of expectations. *Developmental Science, 10*(5), 654–663. https://doi.org/10.1111/j.1467-7687.2007.00607.x

Zarbatany, L., & Lamb, M. E. (1985). Social referencing as a function of information source: Mothers versus strangers. *Infant Behavior and Development, 8*(November), 25–33. https://doi.org/10.1016/S0163-6383(85)80014-X

Zmyj, N., Buttelmann, D., Carpenter, M., & Daum, M. M. (2010). The reliability of a model influences 14-month-olds' imitation. *Journal of Experimental Child Psychology, 106*(4), 208–220. https://doi.org/10.1016/j.jecp.2010.03.002