THE DRIVE FOR KNOWLEDGE

The Science of Human Information Seeking

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CHAPTER 4

Searching for Information, from Infancy to Adolescence

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4.1 Introduction

As adults, we spend a lot of our time seeking and consuming information, reading newspapers and magazines, watching the daily news on TV, browsing the web, scrolling the latest posts on Twitter, and more or less obsessively checking the status updates of our contacts on Facebook or Instagram. Admittedly, this massive, almost compulsive consumption of information is a byproduct of our digital era, characterized by unlimited, overflowing, and often overwhelming availability of ever-accessible, easy-to -ingest information. Yet it is also a reflection – or some might argue, a degeneration – of the intrinsic curiosity and thirst for knowledge that we start displaying in our first months of life, which motivates and drives our learning throughout childhood and beyond. This is evident in the way infants attentively observe and listen to what happens around them, and later in their desire to actively engage with their physical and social environment, tinkering with toys and tools, curiously exploring the space around them, or asking questions. Children's active involvement with the world around them has been considered a crucial component of learning by early developmental psychologists (e.g., Dewey, 1986; Piaget, 1952; Vygotsky, 1987). In particular, Piaget theorized that children's exploration may be triggered and driven by the "discomfort of uncertainty" or by what he refers to as "cognitive disequilibrium" – that is, a mismatch between what is expected and what is observed, which does not fit their existing conceptual structures. This cognitive disequilibrium motivates children to adapt or develop new conceptual structures that better accommodate the new information. Piaget (1952) was probably the first to propose the idea of children as active learners, describing the behavior of his own children as resembling hypothesis testing with self-generated data. Although Piaget and other early constructivists never proposed a full-fledged developmental theory of active learning, as described throughout this chapter, more recent research has not only supported the idea that children are indeed active learners, but has grounded robust evidence that children are efficient and effective information gatherers from a very early age in behavioral, cognitive, and computational work.

In this chapter we review previous developmental literature on active learning, examining the various forms active learning can take across the life span, as well as the novel paradigms and analytical approaches developed to investigate it. In Section 4.2, we review the most recent evidence documenting infants' and toddlers' sensitivity to environmental ambiguity and unexpectedness, triggering increasingly sophisticated forms of information solicitation from others. In Sections 4.3 and 4.4 we draw a developmental trajectory of the effectiveness of children's exploratory and sampling strategies, and of their question asking.

Across sections, we will touch upon three main themes: first, children's *sensitivity* to environmental inputs – that is, their ability to recognize whether a piece of information or observation is novel, and meaningful, and their intrinsic desire to explore it further to make sense of it; second, children's developing *competence* to identify, select, and generate effective active learning strategies from scratch, both on their own and in social contexts; third, children's *adaptiveness* – that is, their ability to tailor their active learning strategies to the specific characteristics of the environment they are presented with. We conclude the chapter by discussing some of the most pressing open questions and promising avenues for future developmental research on active learning and information search.

4.2 Information Search in Infants and Toddlers

Before children develop locomotor and verbal abilities, thereby becoming able to indulge their curiosity through firsthand exploration and question asking, information seeking relies on observations and some rudimentary forms of solicitation of information from their caregivers. Infants' information-seeking strategies are usually investigated by measuring their visual exploration patterns and selective attention, for example, by implementing looking-time paradigms (for critical reviews, see Oakes, 2010, 2017) that observe the direction and duration of participants' eye gaze to infer their degree of interest in stimuli, scenes, or people. A growing body of work has demonstrated that infants tend to look longer at stimuli that are more perceptually salient (e.g., they are more sensitive and pay more attention to changes in color than in speed; Kaldy & Blasser, 2013). In particular, recent work has shown that by 11 months, infants selectively attend to events that violate their expectations and naïve theories across different domains (e.g., emotional, Wu & Gweon, 2019; numerical, McCrinck & Wynn, 2004; social, Henderson & Woodward, 2011; perceptual, Walden et al., 2007). Kidd and colleagues (2012, 2014) demonstrated that this attentional capture can be characterized in terms of information gain, with infants focusing their attention on situations of intermediate visual complexity, thus optimizing their learning by avoiding wasting cognitive resources trying to process overly simple or overly complex events. Along these lines, previous work suggested that at 5 months, infants are already sensitive to the likelihood of a social partner being informative – that is, they look longer at partners who express willingness to convey information, for instance, by making eye contact, calling their name, and using infant-directed speech (e.g., Cooper & Aslin, 1990; Csibra & Gergely, 2009; Kampe et al., 2003; Senju & Csibra, 2008). However, recent evidence suggests that, beyond being selective in deciding what information and information source to attend to (i.e., those most likely to be informative), infants may look at other people to *actively solicit* information, indicating that pretty much the same events and stimuli that trigger infants' perceptual interest may also result in increased references to their social informants (see Dunn & Bremner, 2017). For instance, infants are more likely to direct their gaze to social partners when they encounter novel versus familiar objects (Kutsuki et al., 2007), witness events violating their expectations (e.g., puppets appearing or disappearing from a stage; Dunn & Bremner, 2017; Walden et al., 2007), or are presented with confounded evidence (e.g., they are provided with one label that could refer to any of two novel objects; Hembacher et al., 2017; Vaish et al., 2011). This work offers a brand new perspective on infants' social referencing, which was originally proposed as merely a means for infants to modulate their emotional response to unknown events by seeking reassurance in their caregivers' proximity and reactions to the same event (e.g., Ainsworth, 1992; Dickstein et al., 1984).

Such perspective is further supported by evidence that infants' references to others are *selective*, and emerge only under certain circumstances, such as when they are presented with potentially unknown plants, but not with novel artifacts (Elsner & Wertz, 2019). Infants' selectivity is also evident when they are choosing whom to look at for information. For instance, when confronted with an ambiguous toy, infants prefer to look at unfamiliar individuals who in that specific context are more likely to be knowledgeable (e.g., experimenters in the lab) over caregivers (e.g., Stenberg, 2009). Similarly, when asked to locate which of two novel objects a "pseudoword" refers to, 12-month-olds prefer to look at a knowledgeable informant (one they had previously seen accurately labeling familiar objects) over an ignorant one (Bazhydai et al., 2020).

Around 12 months of age, infants selectively signal their epistemic uncertainty and explicitly solicit information from others through the use of gestures and sounds (i.e., pointing and babbling; see Begus & Southgate, 2018). For instance, 16-month-olds were found to increase their pointing rate in the presence of adults who demonstrated knowledgeability (Begus & Southgate, 2012). Similarly, 24-month-olds showed increased pointing rates when presented with more cognitively demanding tasks (e.g., when asked to remember which of three identical boxes arranged on a rotating table contained a target object; Delgado et al., 2011), and 20-month-olds were found to use pointing strategically to improve their performance by asking adults for help with the location of a hidden toy (Goupil et al., 2016).

Infants' expectation to receive information from others has also been recently associated with neural correlates of information encoding and reward processing (see Begus & Bonawitz, 2020). By complementing the behavioral evidence mentioned above, these findings suggest that the intrinsic drive to seek information is perceived as a rewarding experience, and as such may lead to superior learning outcomes early on. For example, 30-month-old children showed more robust learning of novel word–object associations in categories they were more interested in, as assessed through their pupillary change (Ackermann et al., 2020). More generally, infants' information-seeking behavior has been found to be predictive of superior learning of objects' labels and functions (pointing; Lucca & Wilbourn, 2019), expressive language development (e.g., babbling; Donnellan et al., 2020) and general vocabulary size (pointing; Goldin-Meadow, 2007).

Overall, the evidence reviewed in this section demonstrates that infants' engagement with their physical and social environment is not merely motivated by a general desire for attention, affiliation, or comfort, but is driven by an urge to resolve the discrepancy between what they know and what they encounter (e.g., Loewenstein, 1994). As a result of this drive, systematic patterns of efficient information seeking start emerging during the first months of life and become increasingly explicit and selective between the first and second year of life, when infants can promptly and effectively signal their uncertainty and elicit information from the most informative sources available.

4.3 Developmental Changes in Exploration and Sampling

Recent research on early exploration provides evidence that children are sensitive, competent, and adaptive explorers from a very young age, and that their explorative actions are meaningfully aimed at testing their naïve theories about the environment. Indeed, even 6-month-olds prefer to explore objects that violate their expectations (Stahl & Feigenson, 2015; for a review, see Stahl & Feigenson, 2019), and their willingness to explore decreases when they are provided with explanations for the surprising events they have witnessed (Perez & Feigenson, 2020).

With increasingly fine-grained motor skills and greater familiarity with the environment around them, preschoolers spontaneously engage in systematic hypothesis-testing behavior, looking for the causes underlying observed violations of their expectations (e.g., pushing a button to see if it is connected to a light that was turning on randomly; Muentener & Schulz, 2014) and exploring confounded or ambiguous evidence (i.e., 4- to 9-year-olds exploring why two identical objects had shadows of different sizes; van Schijndel et al., 2015; see also Cook et al., 2011, L. E. Schulz & Bonawitz, 2007). For example, Bonawitz and colleagues found that 4- to 6-year-olds are more likely to explore an asymmetrically weighted block when the asymmetry violated their prior beliefs, compared to when it was consistent with their beliefs. That is, children who believed that objects balance at their geometrical center (i.e., *center theorists)* explored more when the block was balanced on the object's mass, whereas *mass theorists*, who believed that objects balance at their mass center, explored more when the block was balanced on its geometrical center. Moreover, recent work shows that preschoolers tailor their exploring effort (e.g., time) to the complexity, or "degree of discriminability" between two variables, with 4- and 5-year-olds shaking a box for a longer time when tasked to guess whether it contained 8 or 9 marbles, compared to conditions in which the discrimination was easier (e.g., 2 vs. 9; Siegel et al., 2021).

This meaningful exploratory behavior, clearly guided by hypothesis testing, has often been associated with learning, and thus with a general drive to reduce current uncertainty while increasing accuracy to predict future events (for reviews, see Gottlieb et al., 2013; Kidd & Hayden, 2015). Indeed, studies using the "blicket detector" paradigm (Gopnik & Sobel, 2000) – a machine that lights up and plays music when only some objects (blickets) are placed on it – have shown that an increase in preschoolers' successful active exploration supports causal learning (e.g., McCormack et al., 2015), counterfactual reasoning (Nyhout & Ganea, 2019), better, evidence-based verbal arguments to disconfirm false claims (Köksal-Tuncer & Sodian, 2018), and higher-order generalizations of the causal rules learned (Sim & Xu, 2017).

Recent work also showed that preschoolers adapt their exploratory strategies to the characteristics of the task presented to them, demonstrating the *ecological learning* competence previously attributed only to older children and adults. For example, Ruggeri and colleagues (2019) asked 3- to 5-year-olds to choose which of two exploratory actions (open vs. shake) to perform to find an egg shaker hidden in one of four small boxes, contained in two larger boxes. Prior to this game, children learned that the egg was either equally likely to be found in any of the four small boxes (uniform condition) or most likely to be found in one particular small box (skewed condition). The authors found that children successfully tailored their exploratory actions to the different likelihood distributions: They were more likely to shake first in the uniform compared to the skewed condition. These results are in line with those from Domberg et al. (2020) showing that children as young as 4 years can already successfully adapt their predecisional information search to given goals, for instance, deciding to observe the arms of a monster to predict its throwing ability, but to observe their legs when they have to predict the monster's jumping success.

As shown in these studies above, from a developmental perspective, early childhood has been traditionally described as a spike for exploration's breadth and frequency. For instance, a key finding in the psychological literature is that before focusing on smaller subsets of possibilities, children tend to try out far more options than adults, and this has been interpreted as evidence for higher levels of random exploration. This high *temperature* parameter supposedly "cools off" with age, leading to lower levels of random exploration in late childhood and adulthood. However, more contemporary accounts suggest that exploration rather changes in qualitative, complex ways, which could be understood in terms of the resolution of the explore–exploit dilemmas (Gopnik, Frankenhuis and Tomasello, 2020). In particular, changes in exploration may also be associated to *uncertainty-driven sampling* and/or with a more fine-grained ability to *generalize* what is learned beyond observed outcomes. E. Schulz, Wu, and colleagues (2019) demonstrated the individual contribution of these three nonmutually exclusive mechanisms through a spatial search task, wherein 7- to 11-year-olds and adult participants were given a limited number of clicks to explore a grid and acquire as many points as possible. Rewards were spatially correlated across the grid, such that nearby tiles had similar reward values, providing traction for generalization, which could be used to guide search. To maximize rewards, participants had to decide whether to explore (i.e., clicking a new tile) or exploit (i.e., reclick an open tile) a limited number of tiles on a grid. Using a computational model with parameters directly corresponding to the three hypothesized mechanisms of developmental change, the authors found that, compared to adults, children generalized less from observed to unobserved tiles, rarely exploiting and more often showing uncertainty-directed exploration. They did not, however, find differences in random sampling. Using the same paradigm, they also found that although younger children tended to be more random in their search compared to older children and adults, even 4-year-olds showed uncertainty-directed exploratory patterns (Meder et al., 2021). Adding to these findings, Pelz and Kidd (2020) suggest that developmental changes in exploratory behavior may also be explained in terms of response inhibition. In particular, by analyzing 2- to 12-year-old children's free play during an interactive touch-screen game, they found that their exploratory patterns became increasingly efficient and sophisticated with age, as repetitive sampling decreased.

Competence in exploration strategies is reached much later in development if we consider more real-word-like complex scenarios, wherein to make a decision we often have to explore many options, and evaluate multiple, complex causal relations. For example, studies implementing information board paradigms, where participants have to look up information about different available cues for a set of options (e.g., for a set of bikes: the price, number of gears, and color) to make a decision (e.g., which bike to buy), show consistent developmental improvements in search efficiency. On the one hand, younger children tend to search more exhaustively and in a less systematic manner than older children (Betsch et al., 2014, 2016; Gregan-Paxton & John, 1995; Howse et al., 2003). On the other hand, when compared to adults, adolescents' sampling has been found to be characterized by shorter and more superficial predecisional search (see van den Bos & Hertwig, 2017). Similar patterns also emerge from work focusing on teenagers' *information literacy* – that is, their ability to search, navigate, discriminate, and acquire information on the web. Generally, this work converges to suggest that adolescents often do not implement optimal search strategies when navigating the web to make decisions, and this ineffectiveness may be linked to inaccurate judgments (e.g., about health-related risks; see Freeman et al., 2018, for a comprehensive review). For instance, they struggle to formulate efficient and correct queries, (e.g., Gossen et al., 2011), and have trouble filtering the search engines' results page – being, for instance, more likely than adults to click on higher-ranked results, and spend less time on each web address (i.e., URL; Duarte & Weber, 2011). Moreover, they often fail to evaluate the reliability of the sources they are presented with, as well as the accuracy of their content (e.g., Macedo-Rouet and colleagues, 2019), obtaining quite poor learning outcomes (see De Simone et al., 2021).

4.4 Children's Developing Ability to Ask Informative Questions

As soon as they start talking, children ask an impressive number of questions when engaged in conversations with adults – about eighty per hour, according to the verbal transcripts analyzed by Chouinard and colleagues (2007). Asking questions is one of the most powerful learning tools children possess, as it allows young learners to be more precise about the information they want from social partners, select which informants to query, inquire about absent objects or events, address abstract concepts or emotions, target specific attributes of the same object, and, importantly, make queries at different levels of abstraction (e.g., "Do you like apples?" vs. "Do you like fruit?").

Research with 2- to 5-year-olds indicates that children's question asking becomes increasingly more sophisticated throughout the childhood years (see Jones, Swaboda, & Ruggeri, 2020; Ronfard et al., 2018, for reviews). Around age 2, children begin inquiring about causal explanations, besides being just interested in asking about facts or labels, as they do during the first year of life (Callanan & Oakes, 1992; Chouinard et al., 2007; Hickling & Wellman, 2001). By age 3, children have reasonable expectations about what responses count as satisfying answers to their questions: They tend to agree and ask follow-up questions when adults provide explanatory answers, but re-ask their original question or provide their own explanations otherwise (Frazier et al., 2009; Kurkul & Corriveau, 2018).

Preschool-aged children ask domain-appropriate questions; for example, they are more likely to ask about the functions of artifacts but about category membership, food choices, and typical locations of animals (Greif et al., 2006). Previous work has also demonstrated that preschoolers as young as 4 years are competent at generating questions that are mostly informative, as opposed to redundant, uninformative, or irrelevant, and that by age 5 they reliably use the information they receive to solve problems (see Legare et al., 2013).

However, preschoolers still struggle to formulate *the most informative* questions. Analyses of naturalistic and semistructured adult–child conversations have shown that children's questions are usually constrained by their knowledge domains and intuitions (e.g., social and biological phenomena vs. artifacts; Kelemen et al., 2005) and are often unclear with respect to the specific information they would like to acquire. For instance, when presented with novel artifacts, 3- to 5-year-olds often ask ambiguous questions (e.g., "what is it?"), rather than expressing their specific interest in the object's function (and not in the object's name; Kemler Nelson, Egan & Holt, 2004). Yet, preschoolers' difficulty has been also documented in experimental settings, mostly using variations of the twenty-questions game, in which participants have to identify a target object within a given set by asking as few yes–no questions as possible. This work has found that children do not start to implement effective question-asking strategies consistently until age 10 years (Herwig, 1982; Mosher et al., 1966; Ruggeri & Feufel, 2015; Ruggeri & Lombrozo, 2015; Ruggeri et al., 2016).

In particular, this work shows that younger children predominantly, if not exclusively, ask "hypothesis-scanning" questions, which offer tentative solutions by targeting individual hypotheses or objects (e.g., "Is it the dog?"; see Figure 4.1) and typically support a less efficient path to the correct solution. For example, in a traditional version of the game, Herwig (1982) found that about 95 percent of the questions asked by preschoolers, 90 percent of those asked by first graders, and 83 percent of those asked by second graders were hypothesis scanning (see also Ruggeri et al., 2021). In contrast, older children and adults more readily ask "constraint-seeking" questions (see Figure 4.1), which can more efficiently partition the hypothesis space by targeting superordinate categories or features that are shared by multiple hypotheses (e.g., "Is it an animal?" or "Does it have a tail?"; see Herwig, 1982; Mosher et al., 1966; Ruggeri et al., 2016). Moreover, previous research has shown that although even 4- and 5-year-olds are able to spontaneously generate constraint-seeking questions to some extent, these questions are often not the most efficient available (see Legare et al., 2013; Ruggeri et al., 2021).

Why is this the case? To ask constraint-seeking questions from scratch, one needs to identify features that can be used to group hypotheses into different categories, categorize objects correctly according to those features, label those categories, and, finally, formulate the question. That is, generating constraint-seeking questions taps into children's developing vocabulary, categorization skills, and previous experience. Indeed, the developmental change and individual variability in the effectiveness of children's questions has often been explained by an increasing ability to generate object-general features that can be used to cluster similar objects

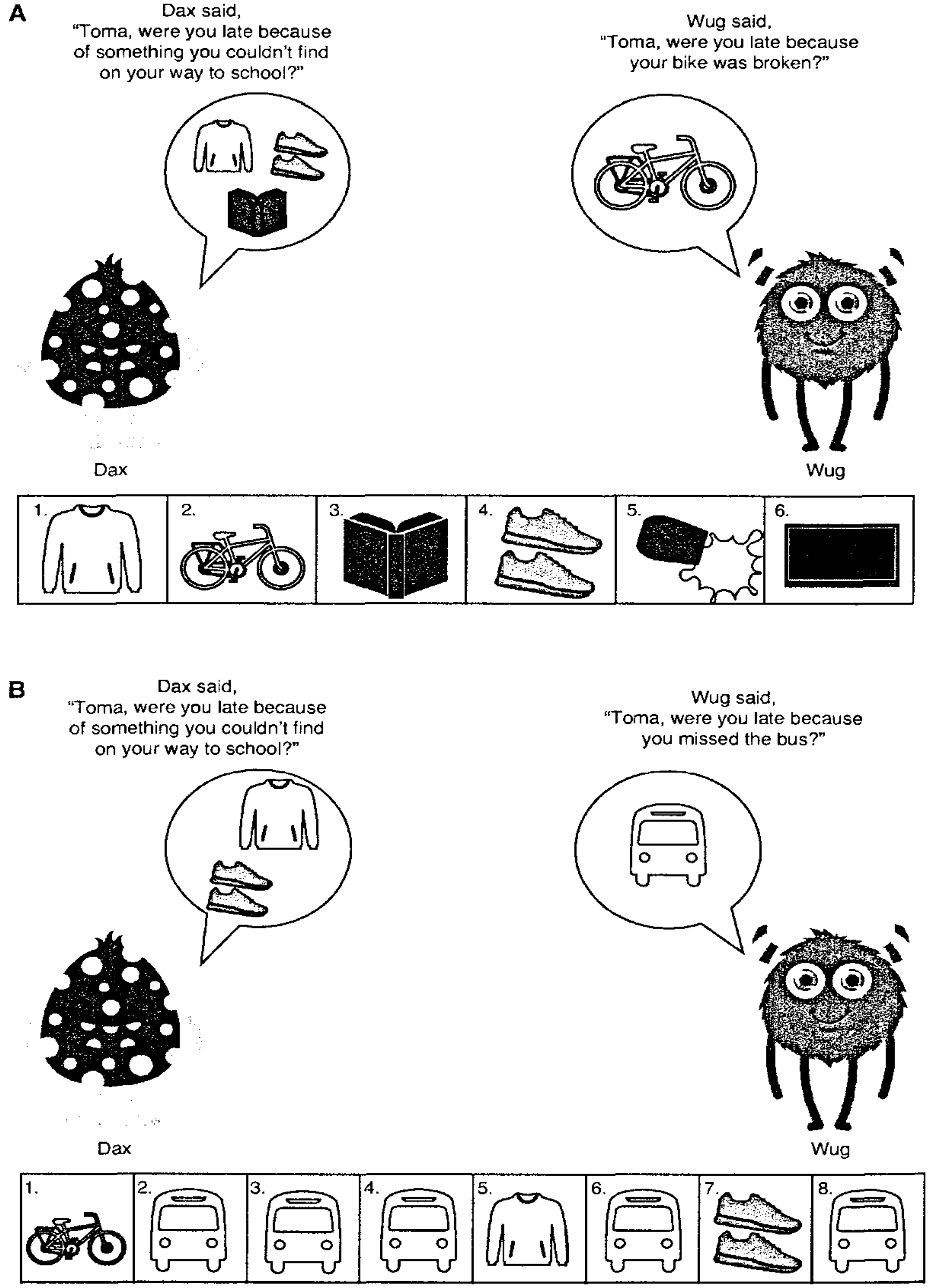

Figure 4.1 Adaptation of the scenarios presented in Ruggeri et al. (2016). Children were asked to select which monster would find out first why *Toma* was late for school. *Dax* asked a *constraint-seeking* question targeting multiple hypothesis, whereas *Wug* asked a *hypothesis-scanning* question targeting a single hypothesis. The icons at the bottom of the page illustrated the reasons why Toma had been late over the previous days (i.e., the hypotheses space). Crucially, in the *Uniform* condition, when the reasons were all equally likely (A), the constraint-seeking question was the most informative. However, in the *Skewed* condition, when one reason was more likely than the others (B), the hypothesis-scanning question was more informative.

into categories (e.g., quadrupeds vs. nonquadrupeds; see Ruggeri & Feufel, 2015), and to identify and flexibly categorize objects on the basis of alternative features (e.g., color and pattern; Legare et al., 2013). Similarly, recent work has found that supporting children's categorization performance, for example, by providing the object-related features needed to ask constraint-seeking questions, helped 4- to 6-year-olds ask more effective questions, target higher category levels, and reach the solution with fewer questions (Ruggeri et al., 2021). Moreover, Swaboda and colleagues (2020) found that 4- to 6-year-olds made more informative queries in a spatial search task, in which they had to find a target monster by tracing a path through a maze, compared to a computationally and structurally analogous twenty-questions game, where they had to identify the monster from a set of eight by asking yes–no questions.

Supporting this further, Ruggeri and colleagues found that even 3-year-olds, when they were not required to verbally *generate* questions from scratch, could reliably identify the most informative between two given questions (Ruggeri et al., 2017), adapting their reliance on the likelihood distribution of the presented hypotheses (see Figure 4.1), showing a capacity for *ecological learning*. Only later, by age 7, were children increasingly able to *generate* different types of queries depending on the likelihood distribution of the hypotheses under consideration, in order to maximize the questions' informativeness (Ruggeri & Lombrozo, 2015). Children's ability to tailor their search to the characteristics of the environment they are presented with is further illustrated by the work of Nelson et al., (2014), showing that, in a variant of the twenty-questions game, children selected more informative queries when the task environment was *representative* of the real-world likelihood distribution (i.e., when gender was uniformly distributed), compared to when the likelihood distribution of the presented features was artificial.

While it is important to know *what* to ask and *how*, and what to expect as an answer, it is also crucial, especially from a developmental perspective, to be able to determine *whom* to ask. A significant body of literature has examined preschoolers' selective trust when discriminating between different sources of information (see Harris et al., 2018; Mills, 2013, for reviews). Results from these studies suggest that children's ability to distinguish reliable from unreliable sources improves over the preschool years for two main reasons. First, there is increasing sophistication in how children interpret the necessary characteristics of a reliable informant. As an example, children younger than 4 years discount claims made by informants who lack relevant episodic knowledge (e.g., Palmquist & Jaswal, 2015), express absolute uncertainty (e.g., Sabbagh & Baldwin, 2001), or show a stable history of inaccuracy (Koenig & Harris, 2005). Yet, only at around age 6 do they take into account the *degree* of inaccuracy, the number of past errors, or even the deceptive intentions that an informant might demonstrate (e.g., Einav & Robinson, 2010). Second, there are developmental improvements in preschoolers' understanding that different individuals may possess different kinds of knowledge. For instance, 3- to 5-year-olds ask their peers when they want to know how to play with a novel toy but refer to adults for information about the nutritional value of foods (VanderBorght & Jaswal, 2009). Three- to 5-year-olds think that doctors know more than car mechanics about how to fix a broken arm, whereas mechanics know more than doctors about how to fix a flat tire. Yet in the same study, 3-year-olds did not make the same judgment about topics that would lie within broader areas of expertise (e.g., who would know more about why plants need sunlight to grow or how to build a treehouse), and without familiar experts as a base for attribution, 4- and 5-year-olds also failed to do so (Lutz & Keil, 2002). Crucially, although by age 5 children focus on the relevant clues when deciding whom to trust, at age 6 they still struggle to use this information to direct their questions or ask the proper experts for help (e.g., De Simone & Ruggeri, 2021; Fitneva et al., 2013).

4.5 Concluding Remarks, Open Questions, and Promising Avenues for Future Research

In this chapter we have reviewed the most recent work to shed light on the developmental trajectory of active learning from infancy to adolescence. In contrast to what Piaget assumed, we now know that infants do not act exclusively on reflexes. Not at all! They intentionally indulge their curiosity about novel and surprising events by actively soliciting information from others through looks, sounds, and gestures. Early information seeking is often driven by perceptually ambiguous or surprising cues and – as a consequence – the ensuing exploratory actions often serve to test and find out about the causes underlying this evidence. Preschoolers can already ask questions and demand explanations in an effective, adaptive fashion, although this ability continues to improve across childhood and until adulthood, in tandem with their increasingly sophisticated verbal and cognitive skills.

Despite its deep roots tracing back to the pioneering work of Piaget and Vygotsky, this field is still fairly young and uncharted, and therefore fertile and wide open to new perspectives and methods. We conclude this chapter by briefly discussing what we deem the most pressing questions and promising directions for future developmental research on active learning.

First, to develop a more fine-grained developmental trajectory of active learning and information search strategies over the life span, it is important to include those age groups that have been generally underrepresented in research on active learning (e.g., adolescent and elderly populations). This broader developmental focus could contribute to the development of more precise computational models and theories, which would shed further light on the *mechanisms* underlying the observed developmental changes at a deeper, process level.

Second, and connected to the previous point, the existing research on active learning reviewed above has mostly focused on identifying key developmental differences in the efficiency and adaptiveness of children's search. However, we do not yet understand why these changes occur or what factors underlie the observed developmental trajectories. More specifically, we do not know what task-related, cultural, environmental, or individual factors (e.g., differences in cognitive abilities, vocabulary, motivation, personality, education, parenting style) drive developmental changes in active learning, how they interact with each other, or how their relative importance changes with age. As a first step in this direction, we developed an exploratory analysis aiming to identify the factors contributing to active learning performance, beyond the broad developmental differences captured in previous research. On the one hand, the project aims to measure different aspects of active learning (e.g., effectiveness, adaptiveness, speed, accuracy) on a wide range of tasks (e.g., question asking, question evaluation, spatial search) to comprehensively assess 6- to 11-year-old children's active learning performance. On the other hand, we will systematically examine the cognitive, social, motivational, cultural, and socioeconomic factors impacting and contributing to active learning performance, to identify the sources of the developmental differences and interpret the individual differences observed.

Third, it is crucial to trace the relative importance of these contributing factors *longitudinally*, in addition to cross-sectionally. This perspective is even more important when considering that it is still unclear, on the one hand, if active learning efficiency or propensity has an impact on later outcomes, such as school achievement, and, on the other, if factors such as parenting and schooling styles impact children's active learning ability or propensity.

Finally, even if the work reviewed in this chapter makes it crystal clear that young children are indeed curious and that this contributes to their impressive learning abilities (see Alvarez & Booth, 2014), it is still unclear what exactly motivates children to explore and learn, and how this can be mathematically modeled. In a recent paper, E. Schulz, Pelz, Gopnik & Ruggeri (2019) showed that the mere opportunity to gain information can serve as an intrinsic reward and suffices to motivate 2- to 4-year-olds to persist in their exploration. This work further highlights the importance of understanding why children explore and what drives their curiosity in the absence of external rewards – a question we believe will keep psychologists, educators, computer scientists, and roboticists busy for a while longer.

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