7 Developmental Changes in Question-Asking

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Introduction

The French philosopher and author Voltaire once said, “Judge a man by his questions rather than by his answers.” Centuries have passed since the Enlightenment, but the idea that a good question may be more valuable than a good answer applies today more than ever. The Internet has made information available at our fingertips at all times: search engines, accessed via our computers, tablets, or smart phones, allow us to look up things whenever and wherever we want – an enhanced encyclopedia of factual knowledge; forums and online communities hold vast nets of human knowledge – from the pragmatic and trivial (“How do I fix my leaking kitchen sink?”) to the scholarly (“How can I create beautiful graphs using R?”). Type any question into Google and you will find an answer somewhere on the Net. This quasi-infinite space of immediately available knowledge has increased the urgency of learning how to navigate this space efficiently – it has become more and more crucial to know how to search for information, that is, to know what kind of questions to ask, how to do this effectively and reliably, how to filter and interpret the results, and how to integrate them into one’s already existent body of knowledge. In this chapter, we examine children’s question-asking strategies, tracing their emergence and developmental trajectory and trying to identify the factors impacting and contributing to their success.

The research we review and discuss has strong potential for informing educational practice and the development of pedagogical tools. For example, the question of how learners approach problems in which they have to figure out how different variables (e.g., water, sunlight, and fertilizer) affect an outcome measure (e.g., health of a plant; Klahr et al., 1993) by actively asking questions or intervening in a causal system has received particular attention in educational research. Over the past decades, the control of variables strategy (CVS) has emerged as a prominently advocated and researched approach and its mastery is considered a benchmark criterion within science, engineering, technology, and mathematics curricula, as part of the more general effort to equip children with the most crucial scientific thinking skills (National Research Council, 2012). The fundamental principle of CVS consists in changing one variable at a time while holding all other variables constant in order to isolate the impact of this variable on the outcome measure (Kuhn & Brannock, 1977). Although considerable effort has been invested in teaching students CVS (e.g., Kuhn & Angelev, 1976; Kuhn & Brannock, 1977; Chen & Klahr, 1999), empirical research shows that its acquisition requires extensive teaching and training (see Schwichow et al., 2016, for a review), and even if children have acquired CVS in one context, they do not readily transfer it to novel problems (e.g., Kuhn & Phelps, 1982; Klahr et al., 1993; Kuhn et al., 1995). There is some evidence that self-directed learning, wherein students explore problems on their own, as opposed to direct instruction, can result in longer-lasting acquisition and transfer of children's use of CVS to solve science-related problems (e.g., Dean & Kuhn, 2007; but see Matlen & Klahr, 2012). However, even adolescents and adults who have mastered CVS do not always rely on it (e.g., Kuhn et al., 1995). There is no doubt that CVS is an effective learning strategy. However, its superiority to alternative strategies may be limited to particular situations. Consider the following scenario: You have to figure out which of twenty switches on a poorly labeled fuse box in the basement turns on the bedroom light. According to CVS, the switches should be turned on one by one until the causally effective switch has been found. However, the optimal strategy in this particular scenario would actually be to turn on half of the switches (ten switches) to find out which subset contains the target switch (i.e., the one controlling the bedroom light), and then to repeat this process, testing half of the remaining switches until only the target switch remains. Recent evidence shows that adults readily adapt their inquiry strategy to the nature of a causal system, relying on CVS when multiple variables affect an outcome (i.e., when it is most effective) but preferring to test multiple variables at once in situations when only one or a few variables affect the outcome (e.g., as in the situation described above; Coenen et al., 2019).

This example reveals a discrepancy between advocated educational interventions, such as those promoting CVS as the hallmark of scientific reasoning, and the most recent results of research in cognitive and developmental psychology investigating how children and adults tackle reasoning problems and spontaneously engage in inquiry processes – a discrepancy that may partly explain why it is so challenging to teach children CVS. As we show in this chapter, although inquiry and question-asking skills emerge very early in childhood, their development continues throughout childhood and is closely connected to children's developing understanding and experience of the world, as well as to the development of general cognitive abilities, such as working memory, executive functions, verbal, and metacognitive skills. Combining insights on the development of children's cognitive processes that support inquiry with educational research may ultimately help in the design of stimulating learning environments and better, more effective interventions.

Developmental Changes in Question Informativeness

It should already be clear from reading the previous chapters that asking questions is a powerful learning tool. Children ask questions about a variety of topics many times per day. Their inquiry behavior is purposeful, intended to fill a knowledge gap, to resolve some inconsistency, or to seek explanations and, more generally, to test and extend their developing understanding of the world (Piaget, 1954; Carey, 1985; Gopnik & Wellman, 1994; Chouinard, 2007; Frazier et al., 2009; Wellman, 2011; Harris, 2012).

Research to date has shown that young children ask domain-appropriate questions (Callanan & Oakes, 1992; Hickling & Wellman, 2001; Greif et al., 2006), have reasonable expectations about what responses count as answers to their questions (Frazier et al., 2009), can use the answers they receive to solve problems (Chouinard, 2007; Legare et al., 2013), and direct their questions to more reliable informants (Koenig & Harris, 2005; Birch et al., 2008; Corriveau et al., 2009; Mills et al., 2010; Mills et al., 2011). But do children ask good questions?

A Qualitative Approach to Capture Question Informativeness

To answer this question, we first need to define what a good question is. There are many different ways to assess the quality of a question, such as its potential to stimulate a discussion or to initiate or maintain social interactions. In this chapter, we focus on questions as goal-directed behaviors intended to obtain new information. In this sense, a good question is one that is "appropriately worded to obtain the information needed to solve a problem" (Mills et al., 2011, p. 3) – that is, one that is *informative*. This definition implies that the quality of a question cannot be determined in absolute terms but depends on the kind of information that is sought, the source of this information, what the information will be used for, prior knowledge of the question asker, and the specific learning situation. For example, if one wants to find out how a new, mysterious machine works, inquiring about its color is unlikely to give useful insight into its mechanism. On the other hand, asking about the function of various buttons is more likely to be informative in this situation because it provides new information about the relevant features of the machine. However, this binary classification of questions into informative or uninformative does not offer a framework with which to assess relative degrees of informativeness – it does not specify *how much* new information a certain question provides.

A more fine-grained classification was suggested by Mosher and Hornsby (1966), who pioneered the study of children's question-asking strategies using the 20-questions game. In this game, children have to identify a target object/cause or a category of objects/causes (e.g., "What kind of objects can be found on Planet Apres?" or "Why was the man late for work today?") within a given set by asking as few yes–no questions as possible. Although the 20-questions game may appear to be very constrained and artificial at first glance, it is a classic example of sequential, binary information search, a problem that is actually a very general one encountered throughout the lifespan. Consider a Boy Scout tasked to identify the species of a wild bird with the help of a *Boy Scouts Handbook*. He may begin by looking at the bird's size (e.g., "Is it larger than a wren?"), then at the location where it was observed (e.g., "Is it high up or on the ground?"), and then at its color ("Is it brown?"). By sequentially querying different features of the bird, the Boy Scout is able to drastically reduce the number of potential alternatives at every step of the search process, converging on the target object in only a few steps. A similar process can be used for medical diagnoses: in emergency medicine, resident physicians learn to check for the presence or absence of certain physiological changes to rule out lethal conditions that can be associated with a particular complaint (e.g., Green & Mehr, 1997; Hamilton et al., 2003). Additional real-world decision-making, categorization, and causal inference tasks have been modeled with fast and frugal trees that involve sequential, binary branching (see Berretty et al., 1997; Berretty et al., 1999; Martignon et al., 2008). Thus, studying children's performance on a 20-questions game is a good compromise between experimental tractability and real-world generalizability.

Mosher and Hornsby (1966) categorized children's questions in this game as hypothesis-scanning or constraint-seeking. Hypothesis-scanning questions are tentative solutions, that is, single objects or hypotheses that are tested directly (e.g., "Is this daisy on Planet Apres?" or "Was the man late because he woke up late?"). Conversely, constraint-seeking questions aim to reduce the space of possible hypotheses by targeting categories or testing features shared by several different hypotheses (e.g., "Are flowers found on Planet Apres?" or "Was he late because of something he forgot at home?"). Constraint-seeking questions are traditionally considered more informative than hypothesis-scanning questions because they allow the question asker to rule out multiple hypotheses (objects, categories of objects, or causes) at once, thus reducing the number of questions needed to identify the solution. Following Mosher and Hornsby (1966), previous research has found that the ability to ask informative questions undergoes a large developmental change from age four to adulthood. Although preschoolers as young as four are already able to generate a majority of informative questions as opposed to redundant or uninformative questions (i.e., questions that target all or none of the hypotheses or that are completely irrelevant to the task; see Legare et al., 2013), their question generation is strongly characterized by a hypothesis-scanning approach. Indeed, preschoolers almost always ask hypothesis-scanning questions in the 20-questions game and still predominantly use this strategy until age seven (Mosher & Hornsby, 1966; Herwig, 1982; Ruggeri & Feufel, 2015; Ruggeri & Lombrozo, 2015). For example, in a traditional version of the 20-questions 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. However, other studies found that 80 percent of the questions asked by fifth graders were constraint seeking and that this strategy increased in prevalence until adulthood (see Ruggeri & Feufel, 2015; Ruggeri & Lombrozo, 2015).

Mosher and Hornsby (1966) replicated these findings in a less constrained version of the 20-questions game, where children aged six to eleven years were prompted to identify the cause of an event (e.g., "A man is driving down the road in his car; the car goes off the road and hits a tree.") by asking yes–no questions without being presented with a predefined set of possible hypotheses. Just like in the more constrained version of the task, younger children tended to ask mainly hypothesis-scanning questions (e.g., "Did an animal run across the road and the man tried to avoid it?"). When prompted to describe their strategies, only a few of the younger children mentioned the idea of a "general" question or of narrowing down the hypothesis space. In contrast, almost all the older children were able to articulate a more systematic strategy, with half of them mentioning the principle of asking broad questions. These results suggest that with increasing age children also develop a more explicit metacognitive understanding of the features determining a question's informativeness. We return to the role of metacognition in the development of children's question-asking strategies later in this chapter.

Limitations of the Qualitative Approach

With their qualitative distinction between hypothesis-scanning and constraint-seeking questions, Mosher and Hornsby (1966) initiated the investigation of children's active learning through question-asking. As mentioned in the previous section, within this qualitative framework, constraint-seeking questions are more informative than hypothesis-scanning questions. However, this is not always the case. The informativeness of constraint-seeking and hypothesis-scanning questions varies depending on the characteristics of the problem under consideration, such as the number of hypotheses available and their likelihoods, as well as on the learner's prior knowledge and experiences (Todd et al., 2012; Ruggeri & Lombrozo, 2015). Imagine a scenario in which there are three equally likely candidate hypotheses. For example, you might want to find out whether mangoes, strawberries, or cherries are your best friend's favorite kind of fruit. Using a constraint-seeking approach, you could ask if her favorite fruit is red. This question would split the hypothesis space 2:1: strawberries or cherries versus mangoes. If she answers "yes," then you have eliminated mangoes and only strawberries or cherries remain. Conversely, if the answer is "no," then you have eliminated both red fruits and are left with only one possibility: mangoes must be her favorite fruit. However, in this context, a hypothesis-scanning question (e.g., "Are strawberries your favorite kind of fruit?") would also induce a 2:1 split, targeting one of three hypotheses. Therefore, in this particular situation both questions are equally informative. Moreover, if one hypothesis is much more likely to be correct than the others, then a hypothesis-scanning question that targets that single high-probability hypothesis (e.g., one that has a 70 percent probability of being correct) can be more informative than a constraint-seeking question that targets several hypotheses with a smaller summed probability (e.g., 30 percent).

Going back to our previous example, you may have seen your friend eat strawberries more often than either mangoes or cherries. From this first-hand experience, you may infer that she strongly prefers strawberries over the other two kinds of fruit. Asking directly whether strawberries are her favorite fruits with a hypothesis-scanning question is therefore likely to result in a quick win. Finally, and crucially, not all constraint-seeking questions are equally informative. Imagine that instead of three "favorite fruit" options, you have eight: red apples, cherries, strawberries, raspberries, oranges, apricots, blueberries, and melons. In this case, there are several possible constraint-seeking questions you could ask. For instance, you might again ask if her favorite fruit is red, which would target half of the available options (i.e., red apples, cherries, strawberries, and raspberries).

This question is very informative because it allows you to narrow down the hypothesis space to four options, irrespective of whether her answer is yes or no, which means you will need no more than two subsequent questions to find the answer. However, you might also ask if her favorite fruit is round. This question targets six of the eight hypotheses available (i.e., apples, cherries, oranges, apricots, blueberries, and melons). In this case, the number of subsequent questions needed to find her favorite fruit depends on whether the answer is yes or no. If she says "yes," then you are left with six options; if she replies "no," then only two options remain. Assuming that all eight fruits were initially equally likely to be her favorite, getting a "yes" answer to this question is more likely than getting a "no." In this sense, this question is not as effective as the previous one (i.e., red fruit) because it does not guarantee the fastest route to the right answer. These examples also highlight the crucial role of prior knowledge for determining the range of considered hypotheses and estimating their respective likelihoods and therefore its potential to impact question-asking efficiency.

The divergence between a constraint-seeking approach and actual question informativeness is further illustrated by two other kinds of questions that children ask: pseudo-constraint-seeking questions and confirmatory questions. Pseudo-constraint-seeking questions take the *form* of a constraint-seeking question (e.g., "Is it blue?") but target only a single object in the set (i.e., the only blue object in the set). They are as informative as the corresponding hypothesis-scanning question. Previous research with traditional 20-questions games (i.e., involving equally likely hypotheses) has found that the rate of pseudo-constraint-seeking questions increases with age (Mosher & Hornsby, 1966; Ruggeri & Lombrozo, 2015), suggesting that older children understand the form that efficient questions should take but that they sometimes fail to generate such questions in a way that actually improves informativeness. Confirmatory questions, by contrast, are redundant based on the information already gathered. Although they do not provide any new information, about 20 percent of the questions asked by four- to six-year-olds in a question-asking task were found to be confirmatory (Legare et al., 2013), and the prevalence of confirmatory questions partially explains why seven- and ten-year-olds fall short of adult levels of efficiency (Ruggeri et al., 2016).

Quantitative Approach: Using Information Gain to Measure Question Quality

The examples above illustrate how the qualitative distinction between different question types does not necessarily map onto their actual informativeness. Given this consideration, instead of exclusively relying on the qualitative distinction between question types, previous studies have introduced a formal approach that quantifies more precisely the information gathered by children's questions (Eimas, 1970; Nelson et al., 2014; Ruggeri et al., 2016; Ruggeri et al., 2017). Although several possible measures have been used to compute how informative different questions are (e.g., probability gain, impact, expected savings, path length; see Nelson, 2005), the most commonly employed is *expected stepwise information gain*. Expected stepwise information gain (EIG; see Oaksford & Chater, 1994; Steyvers et al., 2003; Nelson et al., 2010; Chin et al., 2015) measures the reduction of entropy – that is, the uncertainty as to which hypothesis is correct – upon asking a certain question (see Lindley, 1956). Within this framework, the best questions are those that maximize the reduction of entropy, allowing the learner to move from a state of uncertainty (e.g., "What kind of objects are on Planet Apres?") closer to a state of certainty (e.g., "Only birds are found on Planet Apres"). More information about the expected information gain framework, the formulas used to calculate EIG, and detailed examples can be found in Ruggeri et al. (2016, pp. 2162–3), and Ruggeri et al. (2017, pp. 3 and 12).

Generally, studies employing quantitative measures of question informativeness have confirmed earlier qualitative findings, namely, that the informativeness of children's question-asking strategies increases with age (Ruggeri & Feufel, 2015; Ruggeri & Lombrozo, 2015; Ruggeri et al., 2016). In particular, studies with preschoolers (four- to six-year-olds) have shown to what extent they have difficulties generating the most informative questions from scratch (Ruggeri et al., unpublished data).

Moreover, using a formal, quantitative approach, we can study the efficiency of children's questions in a much more fine-grained way than with a purely qualitative approach. For example, by being able to calculate the expected information gain associated with every conceivable (task-related) question, researchers can assess the quality of children's and adults' question-asking strategies in absolute terms. Indeed, within this quantitative framework, the informativeness of children's questions can be compared to an "optimal" strategy that selects the most informative question to ask at each step of the search process, or to a strategy that "randomly" selects a question among all those that could be asked. This analysis revealed that even seven-year-olds ask questions that are more informative than those generated by a computer-simulated learner that asks random questions, but that even adults tend to fall short of optimality (Ruggeri et al., 2016). Apart from the fact that even adults do not necessarily possess the cognitive resources required to perform complex computations, a likely explanation for this failure is that human decisions are influenced by considerations other than maximization of information gain. For instance, question-asking might be influenced by prior experience with the kinds of questions that are usually efficient, along with any alternative goals they might have in mind during the task (e.g., pleasing the experimenter or rapidly finishing the experiment without investing too much effort). Also, their numeracy skills, motivation, level of tiredness, and level of distraction may all impact their question-asking efficiency.

Adaptiveness and Ecological Learning

As discussed earlier, the informativeness of question-asking strategies depends on children's prior knowledge and expectations, as well as on the task's characteristics, such as the number of hypotheses available and their likelihood. Therefore, the best question can be defined as the match between task characteristics on the one hand and the knowledge, abilities, and biases of the learner on the other (e.g., Gigerenzer et al., 1999; Ruggeri & Lombrozo, 2015). This implies that asking informative questions requires the ability to recognize, select, and generate those questions that are most informative in the particular situation. This ability to flexibly adapt active learning strategies to different situations has been referred to as *ecological learning* (Ruggeri & Lombrozo, 2015).

Ruggeri and Lombrozo (2015) investigated whether children of seven and ten years of age and adults flexibly adapt their question-asking strategies to the characteristics of a 20-questions game in which they had to find out why a man was late for work. Participants were introduced to ten candidate hypotheses, possible solutions for the game. In one condition, all hypotheses were presented as equally likely to constitute the correct solution (Uniform condition). In the other condition, a few hypotheses were presented as much more likely than the others to constitute the correct solution (Mixed condition). Confirming the results of previous studies, the authors found a steady developmental increase in children's reliance on constraint-seeking questions. However, all age groups, including seven-year-olds, asked more hypothesis-scanning questions that targeted the most likely hypothesis in the Mixed condition. These results were the first to demonstrate that children as young as seven years old are ecological learners, able to tailor the kinds of questions asked to the characteristics of the task at hand. A more recent study showed that even five-year-olds are able to dynamically reassess the informativeness of different question types depending on the situation encountered when they are allowed to select one of two preformulated questions (Ruggeri et al., 2017). In this study, Ruggeri and colleagues (2017) presented five-year-old children with a storybook describing the reasons why the monster Toma had been late for school over several days. In the Uniform condition, Toma had been late equally often for six different reasons: once he had been late because he could not find his jacket, once because he could not find his shoes, once because he could not find his books, once because his bike was broken, once because he spilled his drink, and once because he was watching television. In the Skewed condition, Toma had been late multiple times for one particular reason (i.e., on five of eight days he was late because he woke up late). On the remaining three days, he had been late because he could not find his jacket, could not find his shoes, and because his bike was broken. Children then learned that Toma was late yet again and that two of his monster friends wanted to find out why. In the Uniform condition, one monster friend asked the constraint-seeking question "Were you late because you could not find something?" (EIG: 1.0), whereas the other friend asked the hypothesis-scanning question "Were you late because your bike was broken?" (EIG: 0.66). Because in this condition all reasons were equally likely (i.e., occurred exactly once), the constraint-seeking question targeting three of the six candidate solutions (i.e., "Were you late because you could not find something?") was the most informative question. In contrast, in the Skewed condition, one friend wanted to know whether Toma had been late because he woke up late (hypothesis-scanning question, EIG: 0.94) and the other friend wanted to know whether Toma had been late because he could not find something (constraint-seeking question, EIG: 0.81). In this condition, the hypothesis-scanning question targeting the single most likely hypothesis (i.e., "Were you late because you woke up late?") was the most informative.

Children then had to indicate which of Toma's friends would find out first why Toma had been late – that is, which friend asked the more informative question. In both conditions, the majority of children selected the monster asking the question with the higher expected information gain, regardless of the question type: in the Uniform condition, 70 percent of the children selected the friend who asked the constraint-seeking question ("Were you late because you could not find something?"), whereas in the Skewed condition, 73 percent of the children selected the friend who asked the hypothesis-scanning question ("Were you late because you woke up late?"). These results, replicated across several versions of the same task, suggest that preschoolers have the computational foundations for developing successful question-asking strategies, although they do not yet rely on these when generating questions from scratch.

Further research is required to better understand why this is the case. It may be possible that, despite their early emergence, the computational and probabilistic skills underpinning efficient question-asking continue to develop and improve across childhood, thereby allowing children to ask better questions as they grow older. It may also be that these computational foundations are fully present from an early age but that children fail to integrate them with other cognitive processes, such as generating questions; possibly because of age-related limitations in cognitive processing resources. The second part of this chapter looks more closely at what is known so far about potential factors driving improvements in children's question-asking strategies, such as enhanced executive functions and cognitive processing, metacognition, and improving verbal skills.

Interestingly, despite the general developmental increase in performance observed in the 20-questions game, previous research shows that adults do not adapt their active learning strategies more promptly than children do (Ruggeri et al., 2015). On the contrary, some preliminary results seem to suggest that children can sometimes be even more sensitive to the information structure of a task than adults. For example, Ruggeri and Lombrozo (2015) presented adults and nine-year-old children with an open causal inference task, in which the goal was again to find out why a man had been late for work. However, instead of providing participants with a set of possible solutions, they told them that the solution was either *very likely* or *very unlikely*. Trying to obtain a seemingly possible quick win, children tended to start by asking a hypothesis-scanning question in the Very Likely condition, targeting hypotheses they thought had high likelihood (e.g., "Was the man late because he got stuck in a traffic jam?"), but they preferred to ask constraint-seeking questions in the Very Unlikely condition where the potential for a quick win was much lower. In contrast, adults mostly asked constraint-seeking questions in both conditions. A possible explanation for adults' overreliance on constraint-seeking questions may be that they have more frequently experienced situations where this type of question is more informative and therefore resort to constraint-seeking questions as a default strategy, knowing it would eventually, reliably lead to the solution.

Boosting Children's Question-Asking Efficiency

Efforts to boost children's learning have resulted in the elaboration of a wide variety of pedagogical tools and educational programs, ranging from computer-assisted learning apps (e.g., Lego Education, which is designed to teach computational reasoning, or Alien Assignment, which promotes problem-solving skills and literacy; see Hirsch-Pasek et al., 2015) to teaching curricula (e.g., Young Scientist Series, Science Start, Preschool Pathways to Science, reviewed in Klahr et al., 2011). These interventions often aim to improve skills that are fundamental to general problem-solving (e.g., reasoning about individual variables and forming testable hypotheses about their relationships). Is it possible to teach children to ask better questions?

Attempts to improve children's question-asking strategies have met with only moderate success so far (e.g., Courage, 1989; Denney, 1972; Denney et al., 1973; Denney & Turner, 1979). For instance, Courage (1989) tested four-, five-, and seven-year-old children on a 20-questions game and on a Listener game, which is very similar to the 20-questions game except the experimenter first provides a verbal clue about which object she is thinking about. Following this pretest phase, children were trained on either one or both tasks again, with the experimenter providing explicit instructions about how to ask constraint-seeking questions, which were more informative in these tasks. Only five-year-olds showed significant improvements after training (Courage, 1989). In an earlier study, Denney (1972) trained six-, eight-, and ten-year-olds by providing them with explicit examples of adult models asking either hypothesis-scanning or constraint-seeking questions while playing a short 20-questions game. Six-year-olds' rate of hypothesis-scanning versus constraint-seeking questions was unaffected at posttest, while eight-year-olds were susceptible to both training models: children who observed adults asking hypothesis-scanning questions asked fewer constraint-seeking questions at posttest (a decline of 46.8 percent) and vice versa (an increase of 18 percent). Ten-year-olds were unaffected by the hypothesis-scanning model, but those who viewed the constraint-seeking model asked more constraint-seeking questions at posttest (an increase of 26.4 percent; Denney, 1972). However, these benefits of training were short-lived and were not apparent a week after the posttest. Considering the greater success of pedagogical interventions for teaching more complex inquiry skills such as CVS (e.g., Davenport et al., 2008; Klahr et al., 2011; Matlen & Klahr, 2012; Siler et al., 2012; Chase & Klahr, 2017), it is surprising that it should be so difficult to improve children's question-asking strategies.

However, some recent interventions have proven to be partially successful. For instance, reducing demands on vocabulary and categorization in a hierarchical 20-questions game through scaffolding (i.e., telling children which object features could be used to categorize the objects at different hierarchical levels) led six-year-olds to ask more informative questions (Ruggeri et al., unpublished data). These results also provide evidence for the importance of both verbal and categorization skills in the development of children's questions and also show that a simple change to task instructions can potentially improve performance without extensive training. Likewise, in another study, prompting five- to seven-year-olds to provide explanations about evidence observed in a training phase increased the informativeness of their questions in a test phase (Ruggeri et al., 2019b).

More generally, it would be interesting to investigate how and whether attendance at preschools focusing on free or guided play (e.g., Montessori schools) or schools with an emphasis on inquiry learning (e.g., Socratic schools) has a long-lasting boosting effect on children's active learning and question-asking strategies. Training children's active inquiry skills at an early age may improve or accelerate the development of effective question-asking and information search strategies and may make learning more fun. This, in turn, may also increase curiosity and motivation as well as perseverance in the face of setbacks in the short or long term (for a review of the impact of preschool and primary school on child development, see Sylva, 1994).

Factors Impacting Question Efficiency and Adaptiveness

As documented earlier in this chapter, a large body of work has shown that question-asking strategies undergo significant shifts around the ages of five, seven, and ten years, but it is not yet fully understood why these changes occur, why some interventions do not work, and why some are beneficial only for particular age groups. More specifically, it is not known precisely which factors drive developmental changes in question-asking, how they interact with each other, or how their relative importance changes at different developmental stages. These factors include verbal skills, categorization skills, executive functions, metacognition, probabilistic reasoning, attention, motivation, education, and socioeconomic status (SES). For instance, verbal ability has been shown to be generally associated with question informativeness in a 20-questions game played with four-, five- and six-year-olds, but this effect disappeared after controlling for age (Ruggeri et al., unpublished data). In the following sections, we focus here on some of the other contributing factors.

Categorization Skills

Why do younger children tend to ask hypothesis-scanning questions in a 20-questions game, despite their typical inefficiency? A dominant explanation is that constraint-seeking questions require advanced categorization abilities, in particular the ability to represent, and therefore target, more abstract categories or features. Consistent with this idea, Ruggeri and Feufel (2015) found that scaffolding higher-level representations facilitated children's ability to ask constraint-seeking questions. In their study, seven- and ten-year-old children, as well as adults, were presented with twenty cards on a computer screen, each of which contained a word label (e.g., "dog" or "sheep"). Participants were randomly assigned to one of two experimental conditions based on the specificity of the label: a basic-level condition (e.g., "Dog") or a subordinate-level condition (e.g., "Dalmatian"). The authors found that participants were more likely to ask constraint-seeking questions in the former condition than in the latter, suggesting that more abstract labels facilitated a shift away from object-based reasoning when generating questions. They also found that the ability to generate more abstract features (e.g., "a dog is a mammal" or "a dog has four legs") is one factor that affects performance and that it develops within this age range (see also Herwig, 1982). It remains to be seen exactly to what extent improvements in children's categorization skills drive changes in question-asking efficiency, at which stages, and how these skills interact with verbal abilities more generally.

Executive Functions

Although there is no direct or definitive evidence of how executive functions drive changes in the informativeness of children's questions, recent work strongly suggests that they play a crucial role. For instance, Legare and colleagues (2013) examined how cognitive flexibility correlated with question-asking strategies in four- to six-year-olds. They presented children with a 20-questions game in which they had to find out which card of a given set turned on a magic machine, and a cognitive flexibility game in which they had to sort twelve object cards twice, once according to color and once according to their category. Higher cognitive flexibility scores were correlated with a higher proportion of constraint-seeking questions and better performance in the 20-questions game for all children, regardless of age (Legare et al., 2013). However, overall accuracy, which necessitated not only gathering information but also remembering and coordinating it in working memory, was low on this task. The authors interpreted this as evidence that young children can strategically use constraint-seeking questions to acquire relevant information before they are able to successfully coordinate and maintain that information in working memory. Along these lines, a recent study found a positive correlation between active learning performance and working memory capacity in a word-learning game (Ruggeri et al., 2019a). This points to the development of executive functions as an important factor influencing not only the formulation of effective questions but also the ability to successfully represent and use the information acquired during questioning.

Another component of executive functions that may impact question-asking ability is inhibitory control. This ability develops rapidly between the ages of four and eight (e.g., Romine & Reynolds, 2005; reviewed in Best & Miller, 2010) but continues to improve well into adolescence and adulthood, with documented refinements occurring until twenty-one years of age (Huizinga et al., 2006). The impact of inhibitory control on children's questions has not been directly investigated to date. However, since it enables goal-oriented behavior (e.g., by suppressing task-irrelevant or incorrect behaviors) and control of attention (e.g., inhibiting attention to irrelevant stimuli), it seems likely that having good inhibitory control should help children ask effective questions by keeping them focused on the task and by allowing them to inhibit less effective question-asking strategies. For instance, hypothesis-scanning questions may be a strong default strategy in early childhood, and improvements in inhibitory control may enable children who realize that this is not always the most appropriate question type to inhibit this strategy with increasing success in favor of a constraint-seeking strategy.

Metacognition

One reason why children's information search is generally less efficient than adults' is that they search much more exhaustively, making unnecessary queries. For example, in information board procedures, younger children (seven- to eight-year-olds) tend to search more of the available options and in a less systematic manner than older children (ten- to fourteen-year-olds; Davidson, 1991a, 1991b, 1996). This may be partly explained by children's difficulty attending to or identifying the most relevant information for a particular task (Mata et al., 2011). In addition, results of a study by Ruggeri et al. (2016) suggest that a crucial source of developmental changes in question-asking efficiency is a difference in stopping rules. In this study, children (seven- and ten-year-olds) and adults played a hierarchical version of the 20-questions game. Children asked more confirmatory questions than adults, thus continuing their search for information past the point where all the required information had been gathered, suggesting that they had more conservative stopping rules. Therefore, uncertainty monitoring may contribute to driving improvements in question-asking efficiency. Uncertainty monitoring develops during the preschool years (Lyons & Ghetti, 2011), continues to improve throughout middle childhood (Koriat & Ackermann, 2010), and predicts strategic performance (e.g., withholding a response when you are not sure about it) even in three- to five-year-olds (Lyons & Ghetti, 2013). Because having a good understanding of the state of one's own knowledge is a key requirement for knowing what information to ask about, changes in uncertainty monitoring and other components of metacognition may also impact question informativeness. For example, being better able to keep track of how certain they are about the correct solution in a 20-questions game may enable children to realize, consciously or not, that some questions lead to greater reductions in uncertainty than others. Therefore, one could speculate that greater reductions in uncertainty following a more informative (e.g., constraint-seeking) question may encourage children to continue asking these kinds of questions, thereby increasing their information search efficiency.

Probabilistic Reasoning

As discussed previously, the informativeness of different questions crucially depends on the relative likelihoods of the candidate solutions. This also means that in order to ask the most informative questions, one must be able to understand and reason with frequencies and probabilities. Recent research suggests that young children, and even infants, are remarkably skilled at tracking frequencies in the environment and are capable of rudimentary probabilistic reasoning (Téglas et al., 2007; Xu & Garcia, 2008; Xu & Denison, 2009; Denison & Xu, 2010a, 2010b, 2014; Téglas et al., 2011; Denison et al., 2013). Moreover, a growing body of research suggests that infants and preschoolers use probabilistic information to form judgments, to make predictions and generalizations, and to guide information search (Kushnir & Gopnik, 2005; Gweon et al., 2010; Denison & Xu, 2014). The early emergence of this skill may explain why the ability to select the most informative questions manifests earlier than the ability to generate them from scratch (Ruggeri et al., 2017). However, although this skill emerges early in life, it requires lifelong refinement, as adolescents and even adults can struggle with certain forms of probabilistic reasoning, such as comparing fractions (e.g., Schneider & Siegler, 2010). Despite its early emergence, it is unclear how much probabilistic reasoning constrains or boosts developmental shifts in question-asking effectiveness because of this lifelong development.

Socioeconomic Status

The propensity to ask questions in the first place should also be considered. Individual and situational variations in attention, motivation, and loquaciousness aside, social and educational factors are likely to influence how readily children ask questions and therefore how many opportunities they have to refine their strategies over time. One such factor is SES, which is a known predictor of widely used outcome measures such as IQ (Liaw & Brooks-Gunn, 1994; Smith et al., 1997; Gottfried et al., 2003). SES was found to disproportionately impact language and executive function development in preschoolers compared to other neurocognitive systems (e.g., visuomotor skills), with low-SES children performing significantly worse than mid-SES children (Noble et al., 2005). Given the influence of SES on cognition, it is also reasonable to expect that children's questions may be affected. Indeed, studies of children's interactions with parents show that children from mid-SES backgrounds ask almost double the number of questions than those from low-SES backgrounds (Kurkul & Corriveau, 2018), although the content of these questions does not differ between groups (e.g., fact-based "what-" and "where-" vs. causal "why-questions"). The responses of caregivers to causal questions also differ between socioeconomic groups, with low-SES caregivers providing lower quality answers (e.g., more circular or off-topic explanations; Kurkul & Corriveau, 2018). Because children are sensitive to the quality of responses to questions and use this as a cue to decide how many and what kind of questions to direct to an informant from a young age (Frazier et al., 2009; Harris & Corriveau, 2011), children from low-SES backgrounds might be driven to ask fewer questions in general. When they do ask questions, this comparative lack of practice may result in less efficient questions than those used by mid-SES children of the same age. To our knowledge, no study has addressed this avenue of investigation, which would provide a useful counterpoint to existing work accounting for low-SES disadvantages in school, particularly in relation to verbal skills (e.g., Walker et al., 1994; Durham et al., 2007; Rowe, 2008).

Open Questions and Future Directions

Research on question-asking is relatively young and there are therefore many unexplored avenues of research. We believe that three questions particularly warrant further investigation. First, as highlighted in the previous section, to make further progress in understanding how and why children's question-asking strategies change, the factors driving these changes must be identified more precisely. In addition, the interactions between these factors and their relative importance at different developmental stages should also be clarified. Along the same lines, it would also be crucial to assess the cross-cultural robustness and universality of active learning strategies more generally, and of these contributing factors specifically.

Second, considering the complexity of the computations that underlie good question-asking strategies, children may evaluate the informativeness of others' questions and use this, consciously or not, as a cue to assess another person's learning ability and to identify good role models from whom to *learn how to learn*. For example, recent work with preschoolers has shown that by three years of age children infer an agent's competence from how this agent has learned (Bridgers et al., 2018) and selectively seek help from active learners. This line of inquiry would help bridge the gap between research on question efficiency and research on question-asking in its social contexts (e.g., interactions with peers, parents, and teachers).

Third, exploring novel research methods may open new perspectives on answering these questions. Complementing the earlier qualitative work with computational methods has helped researchers gain insight into the processes that underlie good question-asking strategies. However, this quantitative framework is still limited in its ecological validity: we are only able to measure question informativeness in an environment where only yes–no questions can be asked and where the hypothesis space is both constrained and predetermined. This setup is not particularly representative of naturalistic conversations, where much richer questions can be asked and where the hypotheses actually considered, as well as their likelihoods, are shaped by the question asker's prior experience and beliefs. One way to address this limitation is to elaborate a more flexible mathematical framework, as well as a behavioral paradigm in which this framework can be used. Another way would be to integrate techniques such as eye tracking, pupillometry, or electroencephalography (EEG) into the study of question-asking efficiency. This would allow researchers to investigate developmental trajectories and individual differences in more detail. For instance, increased attention to features of visual cues that aid in categorization may occur before children are able to use strategies that capitalize on categorization abilities (i.e., constraint-seeking questions). In addition, pupillometry can provide further detail by tracking changes in cognitive load associated with specific task features (Kahneman & Beatty, 1966; Wierda et al., 2012).

EEG is an even more direct measure of neural activity that would enable researchers to investigate the neural substrates of the subjective perception of question informativeness. Theta oscillations are of particular interest because they are associated with increased memory retention and anticipation of information in both adults (Guderian et al., 2009; Gruber et al., 2013) and infants (Begus et al., 2015), suggesting that prestimulus increases in theta power signal a neural state of "readiness to learn." In other words, theta power can potentially be used as a graded marker of expectation of information gain, and therefore of people's subjective assessment of question informativeness. Being able to track how this changes between individuals and across the lifespan, as well as to investigate whether this measure correlates with cognitive abilities, would greatly improve our understanding of the cognitive mechanisms underlying question-asking strategies and how they develop.

Conclusions

In this chapter, we have reviewed much of the literature concerning how the efficiency and adaptiveness of children's questions develop. In sum, studies using both qualitative and quantitative methods have so far established three milestones in the developmental trajectory of children's question-asking strategies: at five, seven, and ten years of age. Children's question-asking abilities evolve from being able to identify good questions but not being able to spontaneously generate them at the age of five, to beginning to generate them spontaneously at age seven, and implementing efficient and adaptive question-asking strategies by the age of ten, echoing adult-level patterns of performance.

Further research is needed to gain a more complete and nuanced understanding of the processes underlying the development of question-asking. Achieving this goal will enable educators and scientists to design targeted training interventions and educational curricula to effectively support the development of these skills and provide children with a toolbox of strategies and concepts they can use to navigate the world.

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