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Active and Ecological Learning to Navigate the Social World

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Abstract

Children are equipped to infer the reliability of their social informants very early on, as other people represent a crucial source from which to learn important skills like language or moral behaviour throughout development. In this respect, previous research shows that children as young as 3 already have an idea of what makes a *good teacher*, and strategically choose to rely on people's demonstrated expertise or knowledgeability rather than ignorance. Yet, as in daily life children are not always surrounded by experts, they may alternatively take into account their informants' ability to actively solve novel problems or find out things. The main aim of this doctoral project was to assess children's developing ability to reason about the informativeness of their sources. In particular, it examined the extent to which children rely on such inferences to learn new information across two projects, reflecting information search at different stages of development: question asking in childhood and web search in adolescence. Results from these projects suggest that children's search for information is indeed influenced by the informativeness of their sources' question-asking strategies. Yet, this kind of reasoning seems to improve in tandem with the ability to *generate* informative inquiries. Adolescents are quite successful at identifying informative and accurate web sources, but their ability to learn, critically reflect on, and put together the information these sources provide is rather scarce. Considering the ever-increasing abundance of opinions or insights one may gather or simply absorb from social and digital environments, it is crucial to train children to critically reflect on the reliability and informativeness of the sources they consult or encounter. In this respect, by tracing the inferences underlying children's ability to reason about sources' informativeness, and by isolating the factors contributing to adolescents' ability to learn from web sources and mold informed opinions, this work highlights promising educational avenues.

Zusammenfassung

Kinder sind schon sehr früh in der Lage, die Zuverlässigkeit ihrer sozialen Informanten einzuschätzen, da andere Menschen im Laufe ihrer Entwicklung eine entscheidende Rolle in ihrer Sprach-und Moralentwicklung einnehmen. Frühere Forschungen zeigen, dass Kinder bereits im Alter von drei Jahren eine Vorstellung davon haben, was einen guten Lehrer ausmacht, und sich strategisch eher auf die nachgewiesene Expertise oder dem Wissensstand von Menschen verlassen als auf deren Unwissenheit. Da Kinder im täglichen Leben jedoch nicht immer von Experten umgeben sind, können sie alternativ auch die Fähigkeit ihrer Informanten berücksichtigen, aktiv neue Probleme zu lösen oder Dinge herauszufinden. Ziel dieses Promotionsprojekts war es, nachzuvollziehen, wie sich bei Kindern die Fähigkeit entwickelt, ihre Informationsquellen zu beurteilen und einzuschätzen. Insbesondere wurde untersucht, inwieweit sich Kinder auf Schlussfolgerungen verlassen, um neue Informationen zu erlernen. Dies geschah in zwei Projekten, die die Informationssuche in unterschiedlichen Entwicklungsstadien untersuchen: das Fragenstellen in der Kindheit und die Websuche in der Adoleszenz. Die Ergebnisse dieser Projekte deuten darauf hin, dass die Informationssuche von Kindern in der Tat von dem Informationsgehalt der Fragestrategien ihrer Quellen beeinflusst wird. Allerdings scheint sich diese Art des Denkens mit der Fähigkeit, informative Anfragen zu generieren, zu verbessern. Jugendliche sind recht erfolgreich darin, informative und akkurate Webquellen zu identifizieren. Allerdings haben sie Schwierigkeiten die Informationen, die diese Quellen liefern, zu evaluieren, kritisch zu reflektieren und mit einander ins Verhältnis zu setzen. In Anbetracht der immer größer werdenden Fülle an Meinungen oder Erkenntnissen, die man in sozialen und digitalen Umgebungen sammelt oder einfach aufnimmt, ist es entscheidend, Kinder darin zu schulen, wie sie die Zuverlässigkeit und den Informationsgehalt der Quellen, die sie konsultieren oder denen sie begegnen, kritisch reflektieren können. In dieser

Hinsicht zeigt diese Arbeit vielversprechende Bildungswege auf, indem sie verdeutlicht, welche Schlüsse Kinder ziehen, wenn sie den Informationsgehalt von Quellen beurteilen, und indem sie die Faktoren herausstellt, die Jugendliche befähigt, aus Webquellen zu lernen und informierte Meinungen zu bilden.

Contents

Introduction

In daily life we often gather new information from others. We might ask a doctor whether we should get rid of a mole, we might passively stumble upon news on TV and on our social media feed, or ask Google nearly everything we would like to know, ranging from tasty recipes to the risks associated with flu vaccinations. Across all these situations, we are constantly faced with the challenge of evaluating the reliability of both information and informants: Should I really get rid of the mole? Are these fake news? Is Google suggesting a reliable source to learn about vaccinations?

Although it may be surprising in light of the fake news spread during the pandemic highlighting people's gullibility and poor common sense, broadly speaking, humans are well equipped to face this challenge. This is because we have got a long time to train, as other people represent a much needed source of information throughout children's development. For instance, toddlers can autonomously explore the complex laws of physics and the mechanics underlying causal relationships just by observing that when throwing an object, it falls, and that the same object cannot go through a wall, no matter how hard and how much they bang it against it. Yet, without social informants they would never learn that that object is called "ball," and that it's not nice to throw it in someone's face. Likewise, later on in childhood they could never indulge their curiosity by asking the most outlandish questions.

Children's active involvement with their physical and social world was considered a crucial component of learning already by early developmental psychologists (e.g., Dewey, 1986; Piaget, 1952; Vygotsky, 1997). In particular, Piaget theorized that children's exploration may be triggered and driven by the discomfort of uncertainty or by a 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 would motivate children to adapt or develop new conceptual structures that better accommodate the new information. Although Piaget and other early constructivists never proposed a fully fledged developmental theory of active learning, more recent research has not only grounded the idea that children are indeed active learners but has also provided robust evidence that both through physical interventions and social interactions children are meaningful, selective, adaptive, systematic, efficient, and effective information gatherers from a very early age. In particular, children as young as three monitor the relevant informants' and information's characteristics to infer the reliability of their information sources, and strategically choose to learn from people who demonstrate expertise and knowledgeability. For instance, they prefer to ask a doctor how to get rid of a runny nose, but refer to car mechanics to know how a yoyo works (Lutz & Keil, 2002).

Yet, in the real social world children are not always surrounded by knowledgeable experts whom to ask their questions to. In these situations, the best bet might be to refer to someone who is resourceful, ingenious, good at finding out things, asking questions or solving problems. Do children make this inference ?

As children grow into adolescents, information gathering is mostly carried out on the web (Eurostat, 2020), where all kind of human expertise is promptly available at one's fingertips. In this respect, the internet represents a very appealing learning resource as information have often an interactive and engaging connotation. Although appealing and omniscient, the web does not make information search necessarily simpler. In this context, the abundance, richness, and often contradictory nature of the data and sources available can easily be overwhelming, drastically challenging the sophisticated ability to successfully infer informants' reliability and trustworthiness that children display already at a very young age. Generally, considering the ever-increasing presence of informants accessible to children in daily life (e.g., people, Siri, Alexa, Google), understanding how they evaluate their reliability as potential teachers may offer educational insights on how to support their critical reasoning when choosing which sources to consult.

This doctoral work aimed to address these important research gaps and provide novel insights into children's developing ability to make inferences about the informativeness and reliability of their information sources. Across two projects, I explored whether and how inferences about sources' informativeness at different developmental stages: What do preschoolers and older children think of effective question askers, and to what extent their inferences guide their learning from others? How do adolescents filter and discriminate sources and information on the web, and how far does their efficiency impact learning outcomes?

In this monograph, I review previous developmental, cognitive, computational, and educational work to draw a developmental trajectory of children's active and social learning, also examining the various forms they can take across the lifespan. Chapter 1 traces back active learning to its roots, examining and discussing what drives infants' and toddlers' to seek new information and the benefits of this nudge. In Chapter 2 I will describe work on preschoolers' autonomous and collaborative exploration, providing a brief overview of relevant empirical findings from a project I co-authored. In Chapter 3 I offer an outline of children's developing ability to ask informative questions, as well as on their selectivity when choosing whom to ask questions to. In this context, I will detail relevant empirical findings from a project I recently submitted as first author (Project 1). Chapter 4 will review previous work on adolescents' ability to search and filter the web for information, discussing the implications of these abilities for their learning. I will then outline a relevant project I recently submitted (Project 2) and discuss its findings in light of the reviewed literature. Finally, Chapter 5 will offer a general discussion of the state of the art of the active learning research field, integrating my original contribution in the existing, growing body of work, speculating about the factors contributing to children's active learning performance, discussing how previous work can support the development of interventions to support children's learning in the classroom and beyond. I will conclude with a brief discussion of some of the most pressing open questions and promising avenues for future research.

Chapter 1

The roots of active learning

1.1 The drive to seek new information

As adults, we spend a lot of our time seeking and consuming information, reading newspapers and magazines, browsing the web, and scrolling the latest posts on Twitter, Facebook or Instagram. Admittedly, this massive, almost compulsive consumption of information is a byproduct of our digital era, characterized by unlimited and ever-accessible 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 already in our first months of life and that motivate and drive active learning throughout childhood and beyond. As described in detail in the next section, infants' information search is often triggered by encounters with perceptually interesting events. In his pioneering experimental work, the psychologist Daniel Berlyne (1954) characterized this nudge as *perceptual curiosity*, that is the drive to resolve momentarily uncertainty about novel sensory-relevant cues, underlying both nonhumans and humans' exploratory behaviour (particularly during infancy). Later on children manifest *epistemic curiosity*, which predominantly belonging to the human species, is described as the intrinsic desire to access information which is not merely meant to resolve momentarily uncertainty, but to acquire epistemic knowledge and invest therefore greater cognitive resources (Berlyne, 1966). In this sense, having an infinite space of digital knowledge promptly available at our finger tips enables us to indulge both our epistemic and perceptual curiosity instantly. We may learn how to play an instrument from YouTube or the lines of a romantic poem. Likewise, we might feel the urge to click on that weird object advertised on our Facebook feed, obsessively observe our friends' stories on Instagram, or look up for the name of that song airing at the radio.

Contemporary views on curiosity often characterize it as a special form of information-seeking behaviour driven by mere intrinsic motivation, desire or interest to acquire information, rather than by extrinsic incentives like material rewards (Oudeyer & Smith, 2016). From this perspective, curiosity is defined as a cognitive state induced from the perception of having to fill a gap in one's knowledge (Loewenstein, 1994). According to Loewenstein's theory, the willingness to fill a gap in one's knowledge may initially be perceived as a rewarding experience, but this effect ceases to exist once the information is consumed (see Jirout and Klahr, 2012; Kidd and Hayden, 2015 for reviews).

However, intrinsic desires are difficult - if not impossible - to infer for an external viewer, making it quite complicated to trace the presence of such mental state in preverbal children or animals. Therefore, contemporary research has not yet converged on an universally accepted definition of curiosity. Nonetheless, recent neuroscientific evidence supports Lowenstein's theory, showing that intrinsic, epistemic curiosity is indeed experienced as rewarding, and results in activation of the brain's dopaminergic system (like prizes or money incentives do; Jepma et al., 2012; Kang et al., 2009; Redgrave et al., 2008). Greater epistemic curiosity is also associated with increased neural processes that are related to information encoding and retention (Kang et al., 2009; Voss et al., 2011), and has been found to enhance learning performance in cognitive tasks (see Gureckis and Markant, 2012a for a review).

1.2 Active, self-directed learning

The findings mentioned above have contributed to the widespread (and grounded) idea that allowing learners to indulge on their intrinsic curiosity, for instance by allowing them to choose what they want to learn, may be beneficial in educational settings across a variety of domains and subjects. In particular, recent experimental work indicates that even minimal forms of volitional control, such as allowing the learner to control the pace and order of the materials to be studied, enhance memory retention in both adults (e.g., C. Liu et al., 2007; D. Markant et al., 2014; Plancher et al., 2013; Voss et al., 2011) and children (e.g., Fantasia et al., 2020; D. Markant et al., 2016; Partridge et al., 2015; Ruggeri, Markant, et al., 2019) compared to situations in which the learner is merely exposed (i.e., *yoked*) to other participants' study choices. By matching the content experienced during study across conditions, yoked designs isolate the effects of active control on learning. These benefits were proven to persist a week after the initial study session and were robust across different types of tasks and populations (D. Markant et al., 2016).

Self-directed information sampling has been also linked to learning advantages in causal reasoning, where adult participants were asked to intervene—actively or by replicating actions made by someone else—on an unknown system to figure out which sensors turned on which lights (e.g., Sobel and Kushnir, 2006; Steyvers et al., 2003). Moreover, in decision-making tasks children were found to focus on more informative cues when they generated their own questions, as compared to when they were given questions to choose among (Ruggeri & Katsikopoulos, 2013; Ruggeri et al., 2015).

In their review, Gureckis and Markant (2012b) argued that besides the different valences of attention and motivation, just the act of making decisions about the timing, spacing, and order of information that active learners experience can enhance deeper processing. Additionally, because self-directed learners may gather data to specifically test a hypothesis they have in mind, in line with their existing knowledge, their mental state may simply not be matched to the yoked partners' search strategy. In this sense, the advantage of self-directed sampling would emerge only in cases where learners have a proper representation of the information space and are able to successfully monitor their own knowledge gap and uncertainty, sparing them the effort to allocate cognitive resources to redundant information

(D. Markant & Gureckis, 2014). Indeed, self-directed sampling does not always lead to more efficient and successful learning, particularly on very complex tasks (Schwartz, 1966). For example, Enkvist et al. (2006) found that participants who actively experimented on a multiple-cue inference task to predict the binary criterion on which a bug would be considered deadly produced poorer judgments about the criterion values. Along these lines, self-directed sampling can also result in bias-driven strategies in which learners tend to confirm their initial (and potentially wrong) hypothesis (e.g., Denrell, 2005) and perceive illusory correlations (e.g., Fiedler, 2000), which may result in overconfidence about the efficacy of their sampling capabilities (e.g., Juslin et al., 2007).

1.3 The emergence of meaningful information search patterns

Before children develop locomotor and verbal abilities, thereby becoming able to indulge their curiosity through firsthand exploration and question asking, information acquisition 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 and Blaser, 2013). In particular, recent work has shown that by 11 months old, infants selectively attend to events that violate their expectations and naïve theories across different domains (e.g., emotional, Wu and Gweon, 2019; numerical, McCrink and Wynn, 2004; social, A. M. Henderson and Woodward, 2011; perceptual, Walden et al., 2007). Kidd et al. (2012, 2014) demonstrated that this attentional capture can be characterized in terms of information gain, with infants showing the most attention to situations of intermediate visual complexity, supposedly to avoid wasting cognitive resources trying to process overly simple or overly complex events ("Goldilocks effect"). 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 and Aslin, 1990; Csibra and Gergely, 2009; Senju and 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 also result in increased references to their social informants (see Dunn and Bremner, 2017). For instance, they are more likely to direct their gaze to social partners when they encounter novel objects (Kutsuki et al., 2007), witness events violating their expectations (e.g., puppets appearing or disappearing from a stage; Dunn and Bremner, 2017; Walden et al., 2007), or are presented with confounded evidence (i.e., provided with one label in reference to 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). This account 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 (e.g., experimenters in the lab) are more knowledgeable 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). In this sense, looking can be interpreted as the precursor of more sophisticated and explicit solicitations, such as babbling and pointing (for a review, see Begus and Southgate, 2018). With increasingly fine-grained locomotor skills and bodily self-awareness, at 6 months infants can already compensate for their verbal constraints by seeking information on their own, for instance, by manipulating objects. Research on early exploration suggests that infants prefer to explore objects that violate their expectations (Stahl and Feigenson, 2015; for a review, see Stahl and Feigenson, 2019), and that their willingness to explore decreases when they are provided with explanations to the surprising events they have witnessed (Perez & Feigenson, 2020). Interestingly, 16-month-olds are more likely to replicate novel actions they have seen performed on certain objects when they had expressed interest in exploring those objects (Begus et al., 2014). In fact, by 12 months, infants master the use of gestures and sounds to selectively signal their epistemic uncertainty. 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 about 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 and Bonawitz, 2020). By complementing the behavioral evidence mentioned above, these findings suggest that the intrinsic drive to seek information is a rewarding experience and 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 and Wilbourn, 2019), expressive language development (e.g., babbling; Donnellan et al., 2020) and general vocabulary size (pointing; Goldin-Meadow, 2007). This evidence 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 sophisticated between the 1st and 2nd year of life, when infants can promptly signal their uncertainty and elicit information from the most informative sources available.

Chapter 2

Exploration

2.1 Hypothesis testing during play

Children's spontaneous, exploratory play has long been thought to be linked to their learning, by psychologists and educators alike (e.g., Vogt et al., 2018). Contemporary accounts suggest that children's exploratory play is motivated by an epistemic drive to gain information, aimed at reducing the uncertainty of the moment while increasing accuracy in predicting future events (for reviews, see Gottlieb et al., 2013; Kidd and Hayden, 2015). In line with this perspective, research has shown that preschoolers prefer to explore evidence that clearly violates their expectations. For example, 4- to 6-year-olds explored an asymmetrically weighted block more when the asymmetry violated their prior beliefs compared to when it was consistent with their beliefs; that is, center theorists explored more when the block was balanced on the object's mass, whereas mass theorists explored more when it was balanced on its geometrical center (Bonawitz et al., 2012). Moreover, children as young as preschool age engage in spontaneous hypothesis-testing behavior, looking for the causes underlying observed violation (e.g., pushing on a button to see if it is connected to a light that was turning on randomly; Muentener and Schulz, 2014). Young children also try to disambiguate among potential causal variables when they are presented with confounded or ambiguous evidence (i.e., Cook et al., 2011; Schulz and Bonawitz, 2007). Being presented with conflicting evidence was found to prompt both 4- and 9-year-old children to engage in spontaneous, informative experimentation also in more ecologically valid domains, for instance, when they had to disentangle what variables were causing two identical objects to have shadows of different sizes (van Schijndel et al., 2015). 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 (Koksal-Tuncer & Sodian, 2018), and higher order generalizations of the causal rules learned (Sim & Xu, 2017). Recent findings also indicate that the time preschoolers spend exploring is inversely proportional to the "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, in press). Recent work also showed that preschoolers are ecological learners in that they adapt their exploratory strategies to the characteristics of the task presented to them, an ability previously attributed only to older children and adults. For example, Ruggeri, Swaboda, et al. (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. Yet, after all these considerations a question still arises: Are preschoolers' exploration strategies as effective and adaptive when, similarly to the real world, the options to evaluate are many but the opportunities to explore are limited? In order to address this question, Meder et al. (2019) investigated age-related changes in how 4- to 9-year-old children search for rewards in a tablet-based grid. These rewards were revealed by clicking on the grid's tiles, and were either strongly spatially correlated or more spread throughout the grid. To maximize their rewards, children had to decide whether to explore (i.e., clicking a new tile) or exploit (i.e., re-click an open tile) a limited amount of tiles on a grid. Their results show that although general performance increased with age, even 4- and 5-year-olds successfully generalized the observed spatial correlations to guide their search for rewards. However, both younger and older children rarely exploited the grid, with younger children's sampling generally being more random and uncertainty-directed (see also Pelz and Kidd, 2020 for similar exploration trends in absence of explicit rewards). This trend is generally in line with children's navigational style when searching the web for information, which I will detail in Chapter 4.

2.2 Do children rely on effective explorers?

As showed in the previous section, a variety of empirical studies showed that children often engage in independent hypothesis testing during their exploratory play, and indeed there are learning benefits to such autonomous exploration (e.g., Schulz and Bonawitz, 2007), particularly emerging when this is compared to passive exposure to others' actions (Kushnir et al., 2009; Sommerville et al., 2008). Yet, in real life scenarios there may be situations in which a child may gain little or no information by acting. For instance, when trying to figure out the combination of buttons and levers that make a toy light up, young children may struggle to understand that that toy is not turning on because its battery is low. In such cases, the child may seek assistance from others instead of struggling alone. As a matter of fact, even infants make rational decisions about when to explore vs. when to seek help (Gweon & Schulz, 2011), and preschoolers request collaborative assistance from adults when they are tasked to build complicated toys (on which they did not receive any training or when these become increasingly difficult), but act independently when capable to do so (Vredenburgh & Kushnir, 2013). However, children are not only capable of understanding when they need assistance, but also to make selective inferences from others actions, and use these to direct their exploration and learning. For instance, toddlers use the intentionality and efficiency of others' interventions to infer which actions are causally necessary to achieve a goal (Gergely et al., 2002), and preschoolers selectively imitate others' gestures only when these are goal-directed (Bekkering et al., 2000), or done on purpose and not by accident (Carpenter et al., 1998; Carpenter et al., 2002).

Children's sensitivity to the efficiency of others' interventions and their own abilities as active autonomous learners suggest that they might also be sensitive to how other people *learned how* to make such effective or goal-directed interventions. For instance, children may prefer assistance from someone that, in need to figure out how a toy works, demonstrates autonomous exploration over someone who figured it out through passive observation.

In a recent project I collaborated on as second author (see associated publication in section A.1), we investigated across three experiments whether 3- to 8-year-old children are sensitive to the process by which people have learned how to activate a novel toy. In Experiment 1, 3- to 6-year-olds were introduced to 3 videos displaying three learners, who had obtained the same knowledge on how to activate a toy through different ways. One learner acquired the relevant knowledge through active exploration, one by observing another learner's discovery of the solution and the other by being directly taught the solution. In the test phase children were then presented with tree toys, one was identical to the one that they had seen in the familiarization videos (i.e., *same*), one had few more buttons and levers but shared the same shape, function (i.e., sound) and color with the same toy (i.e., *similar*). The third toy was clearly more complicated, as it had more buttons and levers, but also completely *different* shape, color and function (i.e., light-up toy). Children were then asked to figure out how to activate each of these toy, and given the chance to explore them for 30 seconds. However, by design they always failed to activate them, and were thus given the possibility to ask one of the three learners for help. Because all learners learners eventually knew how to activate the same toy, but only the active learner may have been likely to figure out how the other toys worked, we expected children to seek help from the active learner on the similar or different toy, but not necessarily on the same. However, because the different toy was so different from the problem that the active learner had previously solved, children might have thought that her competence did not extend to this toy, and might have therefore not asked for her help. In this experiment, we found that all children preferentially sought help from the active learner, who had figured out how to solve the problem by herself, over the instructed or passive learner. However, children's appreciation for the learner's autonomous exploration's ability emerged only when the problem to be solved was similar to what they had seen previously seen her solving, that is, they asked the active learner for help only on the similar toy. In two additional experiments, we used a similar paradigm to further disentangle the cues that 3- to 8-year-old children use when evaluating others' active learning competence: Did children prefer active learners because they were alone while learning (Exp. 2) or because of their intentional, goal-directed actions (Exp. 3)? Results from these experiments revealed that around age 6, children's preference to seek help from a successful explorer becomes independent of superficial cues that might correlate with a competence for active learning but are not causally related to it, such as being alone or merely making a novel discovery (even if accidentally).

Taken together, these experiments indicate that children ascribe problem-solving competence to an active learner, but a more abstract understanding of what the process of active learning can tell about a person's competence develops across childhood.

Chapter 3

Question Asking

3.1 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 80 per hour, according to the verbal transcripts analyzed by Chouinard et al. (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 A. Jones et al., 2020; Ronfard et al., 2018 for reviews). Around age 2, children already begin inquiring about causal explanations, besides being just interested in asking about facts or labels, as they do during the 1st 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., 2011). Previous work has also demonstrated that preschoolers as young as 4 years are able to generate 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 (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 et al., 2004). Yet, preschoolers' difficulty has been also documented in experimental settings, mostly using variations of the 20-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?") 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% of the questions asked by preschoolers, 90% of those asked by first graders, and 83% of those asked by second graders were hypothesis scanning. In contrast, older children and adults more readily ask "constraint-seeking" questions, 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 into categories (e.g., quadrupeds vs. nonquadrupeds; see Ruggeri and Feufel, 2015), and to identify and flexibly categorize objects on the basis of alternative features (e.g., color and pattern; Legare et al., 2013). In this respect, Ruggeri et al. (2017) found that when children were not required to generate questions from scratch themselves, they were able to reliably recognize and select the most informative between two given questions already by age 5. 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 5 of 8 days he was late because he woke up late). On the remaining 3 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% 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% 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. Supporting this, Swaboda et al. (2020) found that 4- to 6-year-olds made more informative queries in a spatial search task, in which they had to discover the path through a maze, compared to a computationally and structurally analogous 20-questions game, where they had to identify a target monster from a set of eight monsters by asking yes-no questions.

3.2 Selecting whom to ask

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: Not all people are equally suited at answering children's questions, as individuals might lack the relevant knowledge or be deceitful. A significant body of literature has examined young children's strategies when discriminating between reliable and unreliable sources of information (see Mills, 2013 and Sobel and Kushnir, 2013 for reviews). This research demonstrates that children's trust is driven by a complicated mixture of inferences drawn from the *quality* of the information provided (e.g., accuracy, completeness; see Jaswal et al., 2010; Koenig and Jaswal, 2011; Pasquini et al., 2007) and the characteristics of the *agent* providing the information (e.g., expertise, age, familiarity, culture; see Kinzler and Spelke, 2011; Lutz and Keil, 2002; VanderBorght and Jaswal, 2009). Generally, results from these studies suggest that over the preschool years there are developmental improvements in how children understand the necessary characteristics for being a reliable informant. As an example, children younger than 4 discount claims made by informants that lack relevant episodic knowledge (e.g., Robinson et al., 1999), who possess negative characteristics (e.g., mean; Mascaro and Sperber, 2009), who expressed absolute uncertainity (e.g., Sabbagh and Baldwin, 2001) and showed a stable history of inaccuracy (Koenig & Harris, 2005). Yet, only 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 and Robinson, 2010).

Most of the paradigms used to investigate selective trust focus on children's selection of informants. However, only few studies have examined the inferences children make about the presented informants, that is, the extent to which children attribute other positive (potentially irrelevant) characteristics to informants who have provided reliable information or demonstrated expertise. These studies have implemented several different paradigms: Some manipulated the informants' characteristics, such as gender (Ma & Woolley, 2013), accent (Kinzler et al., 2011), attractiveness (Bascandziev & Harris, 2016), physical disabilities (Jaffer & Ma, 2015), or honesty (Li et al., 2014), while others varied the type and quality of the information that the informants provided (e.g., claims referring to episodic or semantic knowledge, Esbensen et al., 1997; accurate or inaccurate labels of familiar objects, Brosseau-Liard and Birch, 2011; Rakoczy et al., 2009; Sobel and

Corriveau, 2010). Because of this diversity, and because very few of these studies have considered a broad developmental range, it is difficult to trace a clear developmental trajectory of children's inferences. Nonetheless, some researchers have suggested that the extent of children's generalizations depends on the *kind* of knowledge or expertise an informant exhibits or lacks (Mills, 2013). For instance, when an informant lacks situation-specific knowledge, children do not necessarily infer that that the informant also lacks semantic knowledge (Zmyj et al., 2010). On the contrary, when an informant exhibits semantic knowledge, children tend to make broader generalizations, for instance about prosocial behaviour or knowledge of words (Brosseau-Liard & Birch, 2010), episodic information (e.g., object's location; C. M. Palmquist and Jaswal, 2015) or even about her knowledge about the rules of a novel game (Rakoczy et al., 2009). These differences in children's attributions of relevant knowledge might be related to the developmental improvements seen over the preschool years in children's ability to recognize that different individuals possess different kinds of knowledge or expertise. For instance, preschoolers ask their peers when they want to know how to play with a novel toy, but refer to adults to know about the nutritional value of foods (VanderBorght & Jaswal, 2009). Three- to 5-year-olds think that doctors know more than do car mechanics about how to fix a broken arm, whereas mechanics know more than do doctors about how to fix a flat tire. Yet in the same study, 3-year-olds did not make the same judgement 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 tree house), and without familiar experts as a base for attribution, also 4- and 5-year-olds failed to do so (Lutz & Keil, 2002). Furthermore, although already 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 questions to the proper experts (Fitneva et al., 2013; Robinson et al., 2011). Similarly, albeit distinguishing between knowable and unknowable pieces of information (e.g., the number of leaves on all the trees in the world), children still fail to use this information to discount an informant that very confidently claims to know unknowable things before age 7 (Kominsky et al., 2016). When seeking or endorsing information from other people in the real world, it is not always possible or easy to evaluate their expertise and therefore their reliability. In such scenarios, the *safest* and potentially most effective way to learn about the world may be to identify individuals that might be able to provide an accurate and reliable information, regardless of their prior expertise. Someone who is resourceful, ingenious, good at finding out things or solving problems. Indeed, recent work suggests that when making inferences about informants' reliability, young children do also consider how they have achieved their knowledge. For example, Einav and Robinson, 2011 found that, when presented with two accurate informants, 4- and 5-year-olds (but not 3-year-olds) were more likely to seek help about an unfamiliar animal's name from an aidless informant than from an informant who had always relied on help from a third party. Along these lines, results from the study described in Chapter 2 suggest that preschoolers attributed problem-solving competence to informants who learned through independent, active exploration (Bridgers et al., 2018). Do children make this inference also about question asker? Do they think that good question askers are smarter, more knowledgeable, or better at solving problems, and rely on them when relevant experts are not available?

3.3 Project 2: What is a good question asker better at?

This project investigates across three experiments the inferences people make based on other people's active-learning competence (see associated publication in Appendix section .1). In particular, it explores to what extent adults and 3- to 9-year-old children generalize the ability to ask informative questions to more or less-related abilities or characteristics (Study 1a and 1b), and use question-asking competence as a cue to infer other people's reliability as potential teachers on specific vs. broader domains of knowledge (Study 2). One intriguing possibility is that children use the informativeness of other people's questions and strategies as a cue to assess their competence as learners and potential teachers. In this way, they can maximize the opportunity to acquire novel information regardless of the specific knowledge that one informant demonstrates.

3.3.1 Study 1a and 1b

Aim

The goal of Study 1a was to obtain adults' judgements about how strongly question-asking competence relates to 12 different abilities, traits, and characteristics. This was done to ensure that there are selective, meaningful inferences to be draw from the quality of other people's inquiries. Such inferences were then also served as a benchmark to evaluate how and when children start showing adult-like intuitions in Study 1b.

On the one hand, based on the findings discussed above, suggesting that 5-year-olds already possess the computational foundations to develop successful question-asking strategies, we might expect preschoolers to already be able to draw selective and meaningful inferences based on other's question-asking competence. However, it is also possible that this emergent sensitivity, together with their tendency to ask *a lot* of questions (Chouinard et al., 2007), drives children this age to be overenthusiastic about question-asking competence. This could lead to extensive generalizations, that is, to believe that good question askers are better at nearly everything. Furthermore, it is also possible that the ability to make selective, sophisticated inferences requires more advanced active learning competences, for example, mastery of effective question *generation*. In this sense, we might observe that adult-like generalization patterns emerge only from age 7.

Methods

Participants

Participants were recruited and tested at local museums in Berlin, they were mostly white European from diverse social classes and were native German speakers or fluent in German. Institutional Review Board (IRB) approval was obtained by the Max Planck Institute for Human Development in Berlin. Adult participants gave informed consent to participate in the study and parents gave informed consent for their children to participate before the study.

Study 1a Thirty adults (19 female; $M_{age} = 28.09$ years; $SD = 7.63$) participated in this study. All participants were recruited and tested at a local museum in Berlin. One additional participant was excluded from the analyses due to missing data.

Study 1b Participants were forty 3- to 4-year-old children (19 female; $M_{age} = 48.41$ months; $SD = 7.19$), forty 5- to 6-year-olds (21 female; $M_{age} = 70.18$ months; $SD = 6.52$), and forty 7- to 9-year-olds (22 female; $M_{age} = 101.59$ months; $SD = 9.74$). Furthermore, since the procedure used in this study was likely to elicit a less explicit and "objective" association between question asking and the ability chosen, we deemed it necessary, for further comparisons, to have an additional adult sample tested with the children procedure. Therefore, to this study participated also 40 adults (25 female; $M_{age} = 34.56$ years; $SD = 10.60$). Twenty-four additional participants were excluded from the analyses due to technical issues ($n = 2$) or for failing the attention check ($n = 7$), the memory check ($n = 9$), or both ($n = 6$; see below).

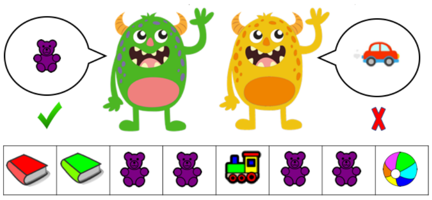
A statistical power analysis was performed to estimate sample size, based on the probability of an event occurring above chance level (>50 % binomial tests). The projected sample size needed to detect a large effect size (g = 0.25) with $\alpha = .04$ and Power ($1 - \beta = .85$) was approximately N = 35 (lower critical N = 11; upper critical N = 24). * Moreover, some findings suggest to use a sample size of 30 as a lower bound for large-sample inference for binary data Agresti and Min, 2002. Thus, our proposed sample size of $N = 40$ per age group is more than adequate.

*Power analysis were performed using *G*Power V3.1.9.6* Faul et al., 2007.

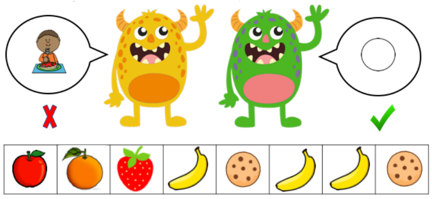
Design and procedure

For both experiments participants were tested individually in a secluded area of the museum. The procedure consisted of two phases: familiarization and test.

Familiarization phase In the familiarization phase, participants were presented with a six-page storybook. The first page introduced two monsters, Bobo and Kila, who wanted to find out what had happened to their friend Toma on her first day of school and so asked her some questions. The following four pages illustrated different episodes (scenarios) taking place on Toma's first day of school (e.g., Toma drew a surprise welcome gift from a bag), together with the questions that Bobo and Kila asked Toma to find out what happened (e.g., "Did you get a teddy bear?" or "Did you get a red toy car?"). On the bottom of the page, eight images, arranged in a row, illustrated the options that the monsters considered (the hypothesis space; e.g., "Bobo and Kila knew what was inside the bag"; see Figure 3.1). Across the four scenarios, one of the monsters (counterbalanced across participants) always asked informative questions, whereas the other always asked uninformative questions. The informative questions targeted half of the hypotheses considered, either by referring to a single hypothesis presented four times (hypothesis-scanning question; e.g., "Did you get a teddy bear?", when four out of the eight objects in the gift bag were teddy bears; see Figure 3.1a), or by addressing a feature shared by four of the hypotheses (constraint-seeking question; e.g., "Did you get a round-shaped snack?", when four out of the eight snacks in the bag were round-shaped; see Figure 3.1b). The uninformative questions targeted either an object that was not included in the hypothesis space (e.g., the red toy car; hypothesis-scanning question; see Figure 3.1a) or a feature shared by all the objects (e.g., something to eat; constraint-seeking question; see Figure 3.1b). A sixth page presented the two monsters again and summarized the lesson to be learned from the familiarization phase, reminding participants that "Bobo/Kila always asks good/bad questions, because they are very informative/not informative at all. She is a good/bad question asker!".



(a) Scenario 1. Hypothesis-scanning questions



(b) Scenario 2. Constraint-seeking questions

Figure 3.1: Two different scenarios of the familiarization phase: Bobo, the green monster, asks informative questions that either target a single hypothesis (a: "Did you get a teddy bear?") or features shared by half of the hypotheses (b: "Did you get a round-shaped snack?"), whereas Kila, the yellow monster, asks uninformative questions that either target a hypothesis that is not part of the hypothesis space (a: "Did you get a toy car?") or a feature shared by all the hypotheses (b: "Did you get something to eat ?").

Test phase In the test phase, participants were asked to complete a paper-and-pencil survey consisting of 12 questions, asking participants to rate how much the 12 abilities, traits, or characteristics listed in Table 3.1 related to the ability to ask informative questions, as exemplified by the familiarization scenarios, on a scale of 0 (*not related at all*) to 10 (*strongly related*). Questions were presented in random order. Given the exploratory character of this study, the questions presented had been selected to include a broad range of abilities, traits, and characteristics (i.e., intellectual skills, physical abilities, individual preferences) that, according to pilot data ($n = 13$), were more or less related to the ability to ask informative questions, involving a stronger or weaker strategic component. As a memory check, at the end of the survey participants were asked to indicate again which monster was best at asking questions.

Study 1b The design and procedure of Study 1b were identical to those in Study 1a, with the following exceptions: First, the task was implemented on a 10-inch tablet, and the script was read aloud to participants by an experimenter, who also reminded them, at the end of each scenario, which monster was a "good" and which one was a "bad" question asker. Second, instead of being asked to rate the strength of the association between the given abilities, traits, and characteristics and question-asking effectiveness as in Study 1a, participants were asked to select the one monster they thought was more likely to possess or was better at the presented abilities, traits, and characteristics. Two cards illustrating the monsters were used to help participants indicate their selection. Finally, participants were asked both at the beginning (attention check) and at the end (memory check) of the test phase to indicate which monster was best at asking questions.

Results and Discussion

Study 1a

All participants ($N = 30$) answered the memory check question correctly and were included in the analysis. We used a hierarchical clustering algorithm to assess how participants' ratings about the relatedness of question-asking competence to the 12 different kinds of abilities, traits and characteristics cluster together. The similarity between ratings was calculated using the Minkowski distance measure (see Table A1). Clusters were created with the between-group average linkage method (UPGMA), which calculates the mean Minkowski distance between all possible intra - and inter-cluster object pairs and define the clusters to minimize the average distance between the included objects. The optimal number of clusters to retain was determined with the "elbow criterion", that is, the point on a scree plot where the marginal gain of variance explained by the first clusters drops (see also Figures A1 and A2). If further examination of the cluster characteristics revealed no meaningful differences between two clusters, the clusters were combined. As a result, participants' ratings clustered across 4 dimensions, each including a subset of those traits, characteristics and abilities sharing similar ratings (i.e., judged as similarly related to question-asking competence). Participants rated intellectual abilities such as being clever and being good at school as the *strong* related to the ability to ask informative questions ($n = 2$, $M_{rating} = 8.33$). Abilities with a strategic component (i.e., being good at treasure hunting and being fast at completing jigsaw puzzles) were rated as having a *moderately strong* association with question-asking ability (n = 2, M_{rating} = 6.26). The association with semantic knowledge (i.e., knowing many animal names) and with being friendly was judged as *moderately weak* ($n = 2$, $M_{rating} = 3.88$), although this latter social trait had the highest between-subjects variability (see Table 3.1). This seems to suggest that a person who is good at asking questions might be considered socially smart, sociable, or just generally more likely to interact with others and have more friends. Physical abilities, independent of whether they were more likely to involve a strategic component (being good at playing soccer) or not (i.e., kicking a ball the farthest), individual preferences (e.g., liking ice cream) and irrelevant characteristics (e.g., seeing the farthest, having siblings) were clustered together and judged as not at all related to the ability to ask informative questions (*weak*: $n = 6$, $M_{rating} = 1.37$). Taken together, these results suggest that the adults made distinct, graded, meaningful, and fairly consistent inferences and generalizations based on the ability to ask good questions.

Study 1b

Did participants attributions of abilities, traits and characteristics reflect their relatedness to question-asking competence? Participants' selections were coded as "1" when they indicated the learner that asked informative questions or "0" when they indicated the learner that asked uninformative questions. We fit a mixed-effects logistic regression model predicting participants' learner choice in this study (Informative vs. Uninformative) with fixed effects of age (continuous) and mean ratings (continuous) of the association's strength between question-asking competence and the 12 abilities traits and characteristics (obtained in Study 1a), and their interaction, including a random intercept for subject [†]. The model revealed that the strength of the relatedness between question-asking competence and the different abilities, traits and characteristics significantly predicted participants' choices in this study (β = 0.29, SE = 0.09, z = 5.53, $p < .01$). Furthermore, whereas this model revealed that age did not

[†]All GLMER models were run using the *lme4* package, version v1.1-23.

Table 3.1: Study 1a: Mean Adults' Ratings of the Strength of the Association Between Question-Asking Competence and 12 Abilities, Traits, and Characteristics. Horizontal lines delimit groups that according to hierarchical clustering results have the closest mean values.

Ability/trait/characteristic	Mean	*SD*
Being good at school	8.36	1.83
Being clever	8.30	1.91
Being good at treasure hunting	6.76	2.21
Being fast at completing jigsaw puzzles	5.76	2.67
Knowing lots of animal names	4.20	2.68
Being friendly	3.56	3.16
Having siblings	2.13	2.53
Being good at playing soccer	1.63	2.08
Seeing the farthest	1.37	2.35
Scoring lots of goals in soccer	1.33	2.22
Kicking a ball the farthest	1.10	2.19
Liking ice cream	0.67	1.39

have a main effect ($\beta = -0.13$, $SE = 0.07$, $z = -1.83$, $p = .07$), it showed a positive interaction between participants' age and the mean association's strength ($\beta = 0.11$, $SE = 0.05$, $z = 2.11$, $p = .04$). To further examine this interaction, the same logistic regression models were fitted again for each age group separately. These models showed that the association strength was reflected only in the selections of adults ($\beta = 0.39$, $SE = 0.10$, $z = 3.98$, $p < .001$) and 5- to 9-year-olds (5- to 6-year-olds: $\beta = 0.30$, $SE = 0.12$, $z = 2.60$, $p = .01$; 7- to 9-year-olds: $\beta = 0.36$, $SE = 0.11$, $z = 3.32$, $p < .001$), but not in those made by 3- to 4-year-old children ($\beta = 0.13$, $SE = 0.10$, $z = 1.28$, $p = .20$; see also Figure 3.2).

To what extent did participants attribute each trait, ability and characteristic to the learners? We performed a two-way repeated measures analysis

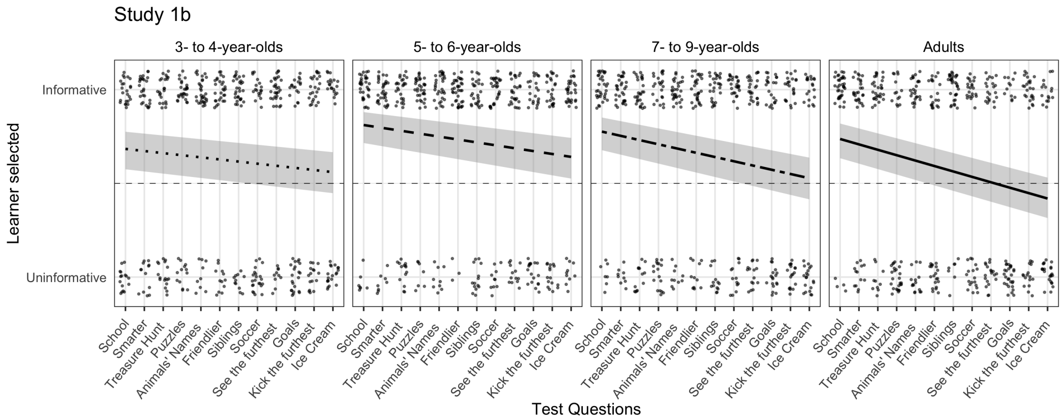


Figure 3.2: Participants' learner choice by age group on each of the 12 abilities, traits and characteristics, arranged in descending order (from strongest to weakest), and color coded based on their association's strength to question asking, as indicated by the independent adult sample in Study 1a. Dashed horizontal lines represent chance level (50%). The grey areas represent 95% bootstrapped confidence intervals.

of variance to assess whether participants' attributions of traits, characteristics and abilities to the learners differed across test trials (i.e., across 12 traits, abilities and characteristics) and interacted with age (dummy coded as factor with 8 levels: 3- to 9 and 18). The analysis revealed that the different traits, abilities and characteristics had a significant effect on participant's learner choice $F(11, 160) = 3.16$, $p < .001$ and significantly interacted with age $F(77, 160) = 1.27$, $p = .05$. To follow up on these developmental differences a series of mixed-effects logistic regression models were run to predict learner's choice on each cluster separately, with fixed effect of age group (factor with 4 levels) and with a random intercept for subject. These models, in combination with series of binomial tests (reported in Table3.2) were run to assess the consistency with which participants of different age groups associate question-asking competence to more or less related abilities, traits and characteristics, and the extent to which their attributions were above chance level. In particular, as illustrated in Figure 3.2, 3- to 4-year-olds were generally conservative in the extent of their generalizations (only 25% attributions were above chance level)[‡], but also unsystematic with respect to the actual relatedness of the abilities to question-asking competence provided by adults in this study and in the pilot. Indeed, logistic regression models predicting participants' choices on each cluster separately by age group, revealed that 3- to 4-year-olds were the only children's age group, that when compared to adults in this study, was less likely to choose the question asker on the characteristics rated as strongly related to question-asking competence ($\beta = -0.86$, $SE = 0.44$, $z = -1.95$, $p = .05$). Along these lines, similarly to other children, they were also more likely than adults to generalize question-asking ability to characteristics with moderately weak association ($\beta = 0.78$, $SE = 0.34$, $z = 2.30$, $p = .02$). Five- to 6-year-olds deemed question-asking competence as related to most of the abilities traits and characteristics (58%), regardless of their actual relevance to question-asking competence. In fact, they were more likely than adults to attribute to the question asker abilities that were judged as moderately strong ($\beta = 0.96$, $SE = 0.42$, $z = 2.30$, $p = .02$), moderately weak ($\beta = 1.48$, $SE = 0.39$, $z = -3.84$, $p < .001$) and weakly ($\beta = 0.60$, $SE = 0.25$, $z = -2.46$, $p = .01$) related to question asking. Seven- to 9-year-old children made more selective attributions above chance (33%), generalizing question-asking competence only to the strong related intellectual traits and abilities, but also to abilities that had moderately weak association with question asking to a greater, significant extent than adults ($\beta = 0.78$, $SE = 0.34$, $z = 2.30$, $p = .02$; see also Table A2 to see the models conducted on questions and not clusters).

Taken together, our results suggest that the attributions made by 5- to 9-year-old children and adults (not 3- to 4-year-olds) reflected the association strength of question-asking competence to relevant abilities, traits and characteristics. However, the extent of participants' generalizations on each of these skills separately undergoes an interesting developmental trend. Three- to 4-year-olds drew unsystematic inferences from the learners' question-asking competence, showing no preference for the good question asker when evaluating abilities, traits, and char-

[‡]The significance level for all binomial tests against chance (50%) was set to $g = 0.25$ ($\bar{X} > .75$) and $\alpha = .01$ to adjust to power analysis' results.

Table 3.2: Study 1b: Mean Proportion of Participants Who Indicated the Best Question Asker as More Likely to Possess Each Ability, Trait and Characteristic

	3-to 4-year-olds			5-to 6-year-olds			7-to 9-year-olds			Adults		
Abilities/traits/characteristics	Mean	95% CI	p	Mean	95% CI	p	Mean	95% CI	p	Mean	95% CI	p
Being good at school	.60	[0.43, 0.75]	.27	.83	[0.67, 0.92]	<.001	.83	0.67 - 0.92	<.001	.90	[0.76, 0.97]	<.001
Being smarter	.68	[0.50, 0.81]	.04	.80	[0.64, 0.90]	<.001	.78	0.61 - 0.89	<.001	.68	[0.51, 0.81]	.04
Being good at treasure hunting	.58	[0.48, 0.73]	.43	.65	[0.48, 0.79]	.08	.68	0.50 - 0.81	.04	.75	[0.59, 0.87]	<.001
Being fast at jigsaw puzzles	.68	[0.50, 0.81]	.04	.83	[0.67, 0.93]	<.001	.58	0.40 - 0.73	.43	.35	[0.21, 0.52]	.08
Knowing lots of animal names	.78	[0.61, 0.89]	<.001	.78	[0.61, 0.89]	<.001	.75	0.58 - 0.87	<.001	.63	[0.46, 0.77]	.15
Being friendly	.70	[0.53, 0.83]	.02	.93	[0.80, 0.98]	<.001	.73	0.56 - 0.85	.01	.50	[0.34, 0.66]	1
Having more siblings	.73	[0.56, 0.85]	.01	.65	[0.48, 0.79]	.08	.68	0.50 - 0.81	.04	.83	[0.67, 0.93]	<.001
Being good at playing soccer	.45	[0.29, 0.62]	.64	.75	[0.59, 0.87]	<.001	.68	0.50 - 0.81	.04	.55	[0.38, 0.71]	.64
Seeing the furthest	.75	[0.58, 0.86]	<.001	.68	[0.50, 0.81]	.04	.63	0.45 - 0.77	.15	.53	[0.36, 0.68]	.87
Scoring lots of goals at soccer	.45	[0.29, 0.62]	.64	.55	[0.39, 0.71]	.64	.55	0.38 - 0.70	.64	.30	[0.17, 0.47]	.02
Kicking a ball the furthest	.60	[0.43, 0.75]	.27	.60	[0.43, 0.75]	.27	.55	0.38 - 0.70	.64	.60	[0.43, 0.75]	.27
Liking Ice Cream	.50	[0.33, 0.66]	1	.75	[0.58, 0.87]	<.001	.50	0.33 - 0.66	1	.40	[0.25, 0.57]	.27

P values refer to binomial tests against chance level (50%). CI = confidence interval.

acteristics that both adults and older children deemed strongly related to question asking (i.e., “being good at school”, “being clever”, “being good at treasure hunting”). At the same time, they showed a strong preference for the competent question asker on some weakly-related abilities like seeing the farthest, and characteristics related to the social character of the learner, such as being friendly or having siblings. On the one hand, the unsystematic trend we found with 3- to 4-year-olds might also just reflect their underdeveloped question-asking abilities, so that it might have just been hard for them to grasp what it means to be good at asking questions and as a consequence, how this capability might extend. Indeed, previous studies demonstrated that the ability to ask effective questions matures rather late, between 7-10 years of age (see Ronfard et al., 2018, for a review). On the other hand, we should also consider that children this young might not be familiar yet with some of the abilities, traits, and characteristics we presented them with. For example, they probably do not have yet a clear idea of what “being good at school” means, as they are not in school yet. Also, they might not appreciate the strategic component underlying the ability of being good at treasure hunting. This component seems to be more evident for them in the ability of solving puzzles. Similarly, they might struggle to understand what intelligence means, but interestingly, as suggested by their preference response for “knowing many animal names", they link question-asking competence to semantic knowledge.

Five- to 6-year-olds identified the good question asker as more likely to have 58% of the presented ability, traits, and characteristic, suggesting that they considered effective question asking as an indicator of global expertise and general likability. It is possible that these global attributions reflect a general enthusiasm for question-asking competence, which could indicate their tendency to take them as role models to learn from, an hypothesis that we assess in Study 2. Speculatively, this stage may therefore represent a stepping stone to a more fine-grained mastery of active learning skills and to more nuanced inferences, emerging later in development. In this respect, our results suggest that starting from around age 7, children showed adult-like response patterns, selectively associating question-asking competence with only 33% of the (most relevant) abilities, traits, and characteristics but not others.

In many studies focusing on generalizations, two informants are presented as experts in different domains (e.g., Jaswal et al., 2010; Koenig, 2012; Kushnir et al., 2013; Lutz and Keil, 2002). However, in our studies, the *good* question asker was contrasted with a *bad* question asker, to whom no other positive or neutral features were attributed. In this scenario, children may fall prey to a sort of *halo effect*: Children may attribute all characteristics to the one informant who was presented with a positive feature only to avoid the *bad* one. As this trend was particularly evident in 5- to 6-year-old children, this limitation was addressed in Study 2.

3.3.2 Study 2

Aim

In this study an effective question asker was pitted against a *knowledgeable* informant: When is it more important to know things, and when to know *how to find out* things? This contrast is particularly interesting because results from Study 1b suggest that all children believe that being good at asking questions also implies being more knowledgeable, for example about animal names.

Methods

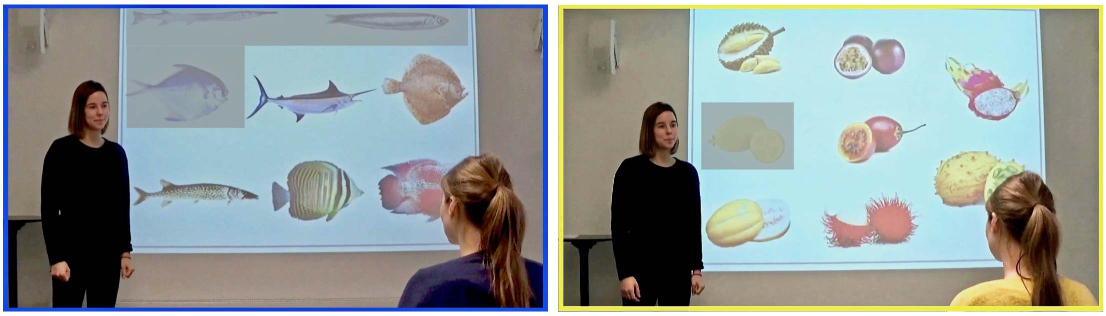
Participants

Pilot testing strongly indicated that the paradigm developed for Study 2 was too demanding for 3- to 4-year-olds, of whom more than half (n = 14, 69%) failed both the attention and the memory check (see Design and procedure section below). We therefore decided to discontinue testing this age group. Participants included in the analysis were twenty-three 5- to 6-year-old children (7 female; M_{age} = 74.71 months; SD = 6.63), thirty-seven 7- to 9-year-old children (16 female; M_{age} = 102.69 months; SD = 10.94), and 20 adults (11 female; M_{age} = 34.50 years; SD = 12.27), recruited and tested at the museum fuer Naturkunde in Berlin. An additional 27 participants were excluded from the analysis for failing the memory check (three 5- to 6-year-olds, one 7- to 9-year-old), both the attention and memory check (thirteen 5- to 6-year-olds, three 7- to 9-year-olds, three adults), for quitting the session prematurely (one 5- to 6-year-old), having a learning disability (one 7- to 9-year-old) or an intellectual disability (one adult) and technical issues (one adult).

Design and procedure

Participants were tested individually in a secluded area of the museum. The procedure consisted of three phases, all implemented on a 10-inch tablet.

Familiarization phase During the familiarization phase, participants were presented with two informants: One was really good at finding out things by asking informative questions (the *question asker*) but did not know anything about fish; the other one was knowledgeable about fish (the *fish expert*) but always asked uninformative questions. Four videos were used to introduce the two female informants (one at the time), who could only be distinguished by the color of their shirt (blue and yellow; counterbalanced order). The videos captured the informants from the back while they were sitting at a desk (see Figure 3.3a and 3.3b), facing an image projected onto a wall. In two of the four videos, a third neutral agent pointed at the images of 8 fishes onto the wall and asked each informant separately "Which one is fastest?" In one video the question asker replies asking three constraint-seeking questions, each ruling out the half of the options left under consideration, and therefore maximally informative (i.e., "Is the fastest fish long?" when there were eight fish and just four of them had an oblong shape, "Is the fastest fish silver?" when two of the four remaining fish were silver and the other two were blue and yellow, and "Is the fastest fish the one with the long nose?" when there were only two options left, consisting of one blue fish with a long nose, the target, and one yellow fish. In the other video the fish expert replies expressing her expertise about the topic (e.g., "I know which one is the fastest. It's the one with the long nose, the black marlin! It's very big and can swim at 129km/h."), without the need to ask any question. In the remaining two videos, both informants were questioned about a neutral topic (unrelated to the informants' expertise). The third neutral agent pointed at the images of 8 exotic fruits onto a wall and asked: "Which one comes from Mexico?" Again, in one video the question asker identified the answer by asking three maximally informative constraint-seeking questions (i.e., "Is it yellow?" when only four of the eight fruits presented were yellow, two were red, and two were pink, "Is it smooth?" when two of the four remaining fruits had a smooth shiny peel and the other two were covered with thorns, and "Is it the pink one?" when the two remaining options were a red and a pink fruit). In the other video, the fish expert asked three hypothesis-scanning questions, each ruling out only one hypothesis at each step (i.e., "Is it the one that looks like a lemon?" then "Is it the one that looks like a melon?" and finally "Is it the pink one?" targeting the right fruit but when there were still five open unexplored options). Animations were used to cover the options that were ruled out (and highlight the ones that were still open), as well as to highlight the target at the end. In all videos both informants eventually identified the target fish and fruit. However, the process they used to find the answer differed according to the domain of knowledge each question targeted. The question asker found out by asking effective questions in two domains she did not have knowledge of (fish and fruit). The fish expert went straight to the solution when she was questioned about her domain of expertise



(a) Question asker asks a constraint-seeking question

(b) Fish expert asks a hypothesis-scanning question

Figure 3.3: The two scenarios of the familiarization phase.

(fish) and guessed the right solution by asking ineffective questions when she was questioned about a domain that was unrelated to her knowledge (fruit).

First test In a first test phase, participants were asked three quiz questions, presented in random order, differently related to the expert's domain of expertise: One of the questions referred to fish (*same-domain question*: "Do you know which of these fish can fly?"); one referred to a related domain (animals; *related-domain question*: "Do you know which of these animals is the pangolin?"); and one referred to an unrelated domain (houses; *unrelated-domain question*: "Do you know which of these houses is in Germany?"). For each question, the options to be considered were presented in a 3 x 4 grid (see Figure 3.4). Two colored frames (blue and yellow, positions counterbalanced across trials) placed below the grid were used to illustrate the two informants to be selected. As expected, most participants did not know the answer to any of the questions. In this case, the experimenter suggested asking one of the informants for help (i.e., "Hmmm, I don't know this either, but we can ask one of my friends for help. Whom do you want to ask?"). Participants were not given any feedback until all questions has been asked. In a few cases participants knew the answers already (Fish: two adults, two 7- to 9-year-olds, five 5- to 6-year-olds; Animals: one adult, one 7-to 9-year-old; Houses: six 7- to 9-year-olds, eight 5- to 6-year-olds). These participants were asked to indicate which of the two informants they would have asked for help if they had

(a) Which of these fish can fly?

(b) Which of these animals is the pangolin?

(c) Which of these houses is in Germany?

Figure 3.4: Stimuli used for the quiz questions, varying in how much the topic related to the domain of expertise (fish) of the expert: (a) same, (b) related, and (c) unrelated.

not known the answer. Both at the beginning (attention check) and at the end (memory check) of the test phase, we also asked participants to indicate which informant was good at asking questions and which was a fish expert, but also which one was *not good* at asking questions and which one *was not* a fish expert.

Second Test In a second test phase, participants were asked to indicate which of the two informants was more likely to possess or be good at some of the abilities, traits, and characteristics presented to participants in Study 1a and 1b. In particular, we selected "being good at treasure hunting", an ability that was rated by both children and adults (Study 1) as strongly related to question-asking competence; "knowing many animal names", to examine whether participants would attribute more factual knowledge to the good question asker (as they did in the previous studies) when contrasted to someone knowledgeable in a related domain; "being clever", to explore whether participants would be more likely to relate intelligence to knowledgeability or effectiveness in search; and finally, "liking ice cream", as a control question. At the end of the session, participants were given the solutions to the quiz questions presented earlier.

Results and Discussion

Whom did participants ask for help? Participants' selections were coded as "1" when they indicated the question-asking expert and as "0" when they indicated the fish expert. To assess developmental differences in participants' learner choice we fit a mixed-effects logistic regression model predicting participants' learner choice on each quiz question separately, with fixed effects of age (continuous), including a random intercept for subject. The models showed that, with increasing age, participants were more likely to ask the question asker for help on the quiz questions targeting the related domain (Animals: $\beta = 1.74$, $SE = 0.81$, $z = 2.13$, $p = .03$), marginally on the unrelated domain (Houses: $\beta = 0.89$, $SE = 0.50$, $z = 1.77$, $p = .06$) but not on the question targeting the same domain (Fish: $\beta = -0.18$, $SE = 0.30$, $z = -0.62$, $p = .53$), on which they preferred instead the fish expert. To further explore this age effect we fit the same models replacing the continuous age with participants' age group (factor with 3 levels) and adults choices as baseline for comparisons (results are reported in Table 3.3 and illustrated in Figure 3.5). These models revealed that the preference for the question asker on the related and unrelated domains found above was driven by 7- to 9-year-old children and adults and not by 5- to 6-year-olds, whose preference was always at chance level (see also binomial tests reported in Table 3.4).

Summarizing, these results are in line with previous literature suggesting that even 3-year-old children impose epistemic boundaries on what they assume an expert knows (e.g., Lutz and Keil, 2002; VanderBorght and Jaswal, 2009). In this study both younger and older children, as adults, preferred to team up with someone possessing specific factual knowledge (i.e., the fish expert) when this knowledge was relevant to the domain of knowledge they wanted to learn about. On the other hand, only older children and adults perceived someone who is good at finding out things as a better informant to learn about more generic domains of knowledge, such as animals or houses. Indeed, although 5- to 6-year-old showed a clear preference for the fish expert when they had to learn about the domain that was related to her expertise, they did not attribute broader generic knowledge neither to the fish expert nor to the question asker. This result confirms previous work's results suggesting that children this age group still fail to attribute knowledge to unfamiliar experts when this would lie within (broader) areas of their expertise (e.g.,

Table 3.3: Study 2: Mixed-effects logistic regression predicting children's learner choice on each question with fixed effects of age group and random intercept for subject. Adults' choices are considered as baseline.

	Same (Fish)				Related (Animals)				Unrelated (Houses)			
Predictors	OR(Beta)	SE	Z	p	OR(Beta)	SE	Z	p	OR(Beta)	SE	Z	p
(Intercept)	0.25 (-1.39)	0.56	-2.47	0.01	19.0 (2.94)	1.03	2.87	.001	9.00 (2.20)	0.75	2.95	.001
5- to 6-year-olds	1.41 (0.34)	0.73	0.47	0.64	0.04 (-3.21)	1.11	-2.89	$<$.001	0.14 (-1.93)	0.86	-2.26	0.02
7- to 9-year-olds	1.10 (0.10)	0.69	0.14	0.89	0.14 (-1.95)	1.09	-1.79	0.07	0.35 (-1.06)	0.84	-1.27	0.21

Table 3.4: Study 2: Mean Proportion of Participants Who Asked The Question Asker For Help On The Same, Related and Unrelated Domain.

	5- to 6-year-olds			7- to 9-year-olds			Adults		
Domain	Mean	95% CI	p	Mean	95% CI	p	Mean	95% CI	p
Same (Fish)	.26	[0.10 - 0.48]	.03	.22	[0.10 - 0.39]	$<$.001	.20	[0.05 - 0.44]	.01
Related (Animal)	.43	[0.23 - 0.66]	.68	.72	[0.54 - 0.85]	.01	.95	[0.75 - 1.00]	$<$.001
Unrelated (Houses)	.52	[0.30 - 0.73]	1	.78	[0.60 - 0.90]	$<$.001	.90	[0.68 - 0.99]	$<$.001

Aguiar et al., 2012; Robinson et al., 2011). In this sense, this might indicate that advanced active learning abilities might be required to perceive a good question asker as a reliable source of information, and to understand that sometimes being a good learner might be more useful than being knowledgeable. Nevertheless, it should be also mentioned that the subtle manipulation of the agents' characteristics in Study 2 might have been challenging to grasp for younger children. Indeed, many of them failed the memory check.

How far do informants' competences generalize? We fit a second mixed-effect logistic regression model predicting participants' attributions of expertise to a subset of the abilities, traits, and characteristics (used in Study 1a and 1b) by age (continuous) and their interactions. The model revealed that overall participants were more likely to indicate the question-asking expert when asked which learner was better at treasure hunting ($\beta = 1.36$, $SE = 0.43$, $z = 3.16$, $p = .001$) or liked ice cream the most ($\beta = 0.83$, $SE = 0.36$, $z = 2.28$, $p = .02$). No main effect of age, nor any interaction effect was found between participants' age and their attributions patterns. Interestingly, participants' generalizations were always at

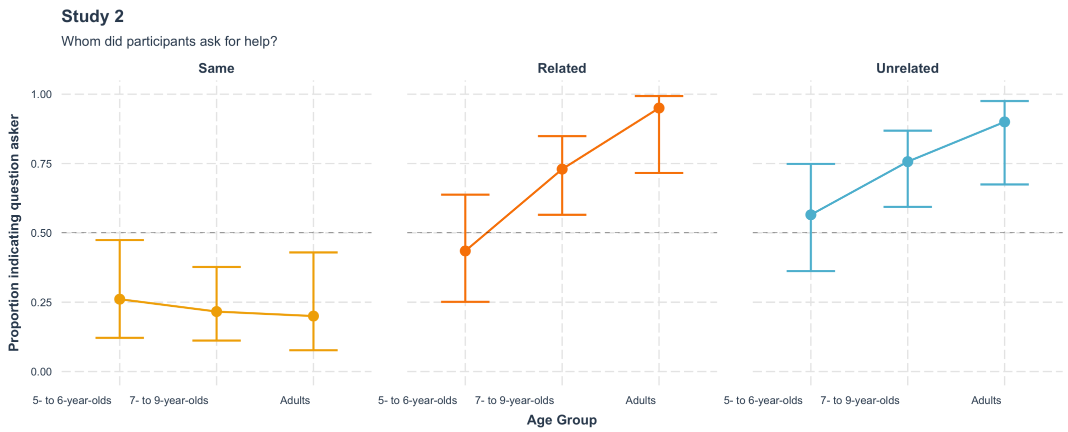


Figure 3.5: Participants' learner choice by age-group, when they had to ask for help on the three quiz questions. Dashed horizontal lines represent chance level (50%). Bars represent 95% bootstrapped confidence intervals.

chance level: When presented with the informants demonstrating different kinds of expertise (e.g., factual-specific vs. strategic-global), neither adults nor children drew systematic inferences. That is, they made no clear distinctions between knowledgeability and potential for learning.

3.3.3 Inferences about questioners and their reliability as teachers

This series of studies revealed that adult-like selective inferences about question-asking competence emerge from age 7 onward.

The unsystematic (3-4 year-olds) or exaggerated (5-6 year-olds) generalization trend found with younger children across these studies seems surprising in light of the literature suggesting that even 4-year-olds are already quite good at evaluating the necessary characteristics for being a reliable source of information (e.g., Koenig and Jaswal, 2011; Kushnir et al., 2013; Sobel and Corriveau, 2010). Yet, results from studies looking at how far do young children generalize informants' traits or knowledge seem to suggest that preschoolers' tendency to draw local rather than global inferences might change depending on several factors, like the nature and salience of the characteristics or competences demonstrated by the informants

Table 3.5: Study 2: Mean Proportion of Participants Who Indicated the Best Question Asker as More Likely to Possess each Ability, Trait and Characteristic

	5-to 6-year-olds			7-to 9-year-olds			Adults		
Abilities/traits/characteristics	Mean	95% CI	p	Mean	CI	p	Mean	95 % CI	p
Being smarter	.56	[0.34, 0.76]	.67	.35	[0.20 - 0.52]	.09	.65	[0.40, 0.84]	.26
Being good at treasure hunting	.65	[0.42, 0.83]	.21	.59	[0.42 - 0.75]	.32	.75	[0.50, 0.91]	.04
Knowing lots of animal names	.43	[0.23, 0.65]	.67	.36	[0.20 - 0.53]	.09	.30	[0.11, 0.54]	.11
Liking Ice Cream	.30	[0.13, 0.52]	.09	.59	[0.42 - 0.75]	.32	.70	[0.45, 0.88]	.11

P values refer to binomial tests against chance level (50%). CI = confidence interval. The significance level for all binomial tests was set to alpha = .01 to adjust for the multiple comparisons.

(e.g., intellectual or physical and episodic or semantic knowledge; see Csibra and Gergely, 2009; Esbensen et al., 1997), or the extent to which these differences are polarized when presented to children (e.g., see Heyman et al., 2003). For example, Fusaro, Corriveau, and Harris (2011) found that 3- and 4-year-olds inferred that a puppet who labeled familiar objects accurately would have been smarter but not stronger or nicer than an inaccurate puppet. They also predicted that the accurate puppet would have been more competent at labeling unknown objects but not at lifting things, sharing cookies, throwing a basketball, or knowing what animals eat, although this last would have been consistent with being smart. Interestingly, when children in this study were presented with two informants differing in physical strength (i.e., successfully or unsuccessfully lifting different items), they made general rather than local attributions. Thus, they inferred that the strong puppet would have been smarter, stronger, and nicer than the weak one, and they also predicted that she would have been more competent in the behaviors listed above (e.g., labeling objects, sharing cookies, or knowing animals' habits; Fusaro et al., 2011). In line with this evidence, we might interpret the trend observed in this study as an indicator of the salience that younger preschoolers gave to question-asking competence. It is plausible that their understanding of this ability is limited to a primarily social function (Graesser et al., 1992), so that a person asking informative questions is only seen as someone who's friendly, generally sociable and therefore is more likely to have grown up with siblings. This hypothesis is supported by the evidence that actually all children participants made the same connection between friendliness and question-asking ability. Brosseau-Liard and Birch (2010) also suggested that the tendency to draw local rather than global attributions might also be an effect of general age-related experience. In their study, children were presented with an individual's brief history of accuracy in labeling common objects and were asked to make explicit judgments about that individual's future word knowledge as well as broader factual knowledge, talents, or prosocial behavior. Their results show that 4-year-olds do not make the type of explicit attributions that 5-year-olds make, or do so only to a very limited extent, within the same domain as the informants' prior accuracy (i.e., word knowledge; Brosseau-Liard and Birch, 2010). In line with these findings, other studies have suggested that 5- and 6 year-old children tend to make broad inferences, sometimes even to unrelated domains, when they observe an informant demonstrating specific knowledge (e.g., labeling familiar objects accurately, Brosseau-Liard and Birch, 2010; knowing causal properties of an object, Sobel and Corriveau, 2010) or showing sociomoral understanding (Cain et al., 1997). For instance, Rakoczy, Warneken, and Tomasello (2009) found that 5-year-olds deemed an accurate informant (i.e., one who had correctly labeled familiar objects) as more likely than an inaccurate informant to know the rules for a novel game Rakoczy et al., 2009. Moreover, when an informant is presented as possessing epistemic knowledge (e.g., Jaswal and Malone, 2007; Lane et al., 2013) and shows prosocial traits (e.g., Heyman and Gelman, 1999; D. Liu et al., 2007), children at this age might be subject to some sort of halo-effect that leads them to make global rather than local attributions. In line of these results, it was unclear whether the trend found with 5- to 6-year-olds, who made broader generalizations compared to the other age groups, was due to the positive connotation of being "good" at asking questions, or to a more generous appreciation for question-asking competence reflecting the emergent ability to *identify* effective inquiries (e.g., Ruggeri et al., 2017).

In Study 2 we assessed this possibility by pitting against one agent who demonstrated question-asking competence to one agent exhibiting specific domain expertise. In this case, all children and adults identified the knowledgeable expert as the most reliable source of information to learn about the domain that was related to her knowledge. However, when asking for help on broader areas of knowledge, only adults and older children preferred the question asker.

The selectivity found with older children in both studies is in line with some of the results obtained in previous studies (e.g., Lane et al., 2013) with this age group. For example, Danovitch and Keil (2007) presented 6-, 8-, and 9-year-olds with four short vignettes illustrating a character facing a moral dilemma (e.g., respecting another's privacy) or involved in a scientific problem (e.g., building a rocket). Following each vignette, participants were asked to choose what characteristics the character would have needed to solve the problem (e.g., if the character needed to be nice to other people or if the character needed to be smart). Their results show that only starting at age 8 did children consistently indicate that scientific skills were necessary to solve scientific problems and that moral characteristics were needed to solve moral dilemmas (Danovitch & Keil, 2007). Generally, it is probably not a coincidence that the ability to make selective, meaningful inferences about question asking seems to emerge at the age when children start becoming more effective at generating questions themselves (Herwig, 1982; Mosher et al., 1966; Ruggeri & Feufel, 2015).

Interestingly, however, we found that neither children nor adults made distinct, consistent inferences from question-asking competence versus knowledgeability. This is not too surprising if one considers that after all, in real life, differentiating the potential for learning from knowledgeability might not always be straightforward. On the one hand, being more knowledgeable might result in developing a high potential for learning. For example, someone who is very knowledgeable might have gained expertise in the process of searching for information, becoming an effective active learner. On the other hand, being an effective active learner might result in being more knowledgeable. Further research is needed to understand whether it is possible to disentangle these two interpretations and their directionality, for example, by exploring whether boosting one aspect will affect the other. Moreover, the impact of motivational factors in such processes should also be addressed, for example, by investigating the possibility that greater motivation to learn might drive the development of active learning strategies, knowledge acquisition, or both.

Chapter 4

Searching the web

4.1 Adolescents' web usage

The protracted developmental trajectory in question-asking efficiency described above is also reflected in the results of process-tracing studies that examined children's information search using information boards, where participants have to look up information about different 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). These studies show consistent developmental improvements in search efficiency between the ages of 7 and 14, with younger children searching more exhaustively and in a less systematic manner than older children (Betsch et al., 2014; Betsch et al., 2016; Gregan-Paxton & John, 1995; Howse et al., 2003). In particular, adolescents' information search has been found to be characterized by shorter and more superficial predecisional search, compared to that of younger children and adults (see Van Den Bos and Hertwig, 2017). Adolescents' propensity to take risks and their superficiality in searching for evidence becomes particularly alarming when considering the implications these behaviors can have in more real-life scenarios, where we all increasingly prefer to refer to the web (over friends, family and professional experts) to gain information before making important decisions (Jiménez-Pernett et al., 2010; Rainie et al., 2019). In particular, seven out of ten European aged 16- to 29 ranked *searching for information* among the most pursued activities on the web, together with emailing, video browsing, and using social networks (Eurostat, 2020). Likewise, evidence from Lenhart et al. (2007) indicates that the majority of 13- to 17-year-old adolescents use the web most often to visit social media platforms (71%), to check websites about movies, TV shows, music groups, or sports stars (81%), but also to look up news and current events (77%). Some studies suggested that older teens (15- to 18-year-olds) also use the web to look up health-related information (66%), particularly about sensitive topics that can cause embarrassment when discussed with other people (e.g., sex or mental health; Robards et al., 2017; Skinner et al., 2003; or see Freeman et al., 2018, for a comprehensive review).

4.2 Information Literacy

Having every kind of information available at our fingertips does not necessarily make information acquisition simpler. Indeed, although the web constitutes an invaluable resource, the abundance, richness, and often contradictory nature of the data available can easily be overwhelming. To acquire new information efficiently and successfully, one has to be able to search, filter, critically evaluate, and compare a virtually infinite list of results and sources, which are not all equally reliable, or reliable at all. This ability to effectively navigate the web, to read and interpret information coming from the media, and to evaluate and apply the knowledge gained from digital environments (often referred to as *information literacy*) has been described as the most important skill for the 21st-century learner (Eisenberg, 2003; Saunders et al., 2017). Information literacy is critical to transition from the *information* society we are living in, which is primarily concerned with collecting and disseminating data, to a *knowledge* society that transforms the available data and information into resources to empower people and improve the human condition (Alkali & Amichai-Hamburger, 2004; Aviram & Eshet-Alkalai, 2006; B. Jones & Flannigan, 2006). As information literacy becomes increasingly relevant for nearly every academic and nonacademic endeavor, research has been conducted from a variety of disciplinary perspectives, from psychology, human–computer interaction and education, to marketing and design, often with diverging goals and distinct methodologies (Livingstone, 2004). Consequently, there is quite some blurriness and ambiguity in the literature, with different terms (e.g., *computer literacy*, *digital literacy*) often used interchangeably despite their overlapping but still fairly distinct definitions (Bawden, 2008; Porat et al., 2018).

Although the ever-rising awareness of the need to provide students with the opportunity to become information literate, evidence shows that there is actually poor implementation of this process in school curricula. Results from the comparative International Computer and Information Literacy Study (Fraillon et al., 2020), conducted in 2013 and 2018 among teachers and students from 2,200 schools across 14 countries, suggest that although in this time frame schools had been increasingly equipped with digital tools such as computers and tablets, this was often not accompanied by the actual *implementation* of such tools in the educational curricula. For example, ILCIS 2018 consisted of a battery of tasks developed to measure students' ability to use computers to collect, manage, produce, and exchange information (computer information literacy). Participants' scores indicated that in most Western countries (e.g., Germany, Finland, and the United States, France, Denmark) the majority of students were at Level 2 of 4, indicating they "needed support." Italian students reached an average score of 461 (of 746), corresponding to the "basic skills" Level 1. Furthermore, only 18% of the Italian students reported regularly using computers during their classes on information technology, programming, and computer science, which is a lower percentage compared to students from other European countries such as Denmark (75%) and Portugal (67%; Fraillon et al., 2020). These findings are in line with other survey studies showing that only 5% of the students credit school for teaching them how to search and process online information (Strom et al., 2009).

Overall, prior work on information literacy outside the school setting has mostly focused on assessing the efficiency and effectiveness of students' online search behavior, and on their ability to identify and target reliable sources of information.

4.2.1 Efficiency in online search strategies

Previous research evaluating students' efficiency when browsing and filtering the web for information (see Covello and Lei, 2010, for a review) focused on different measurements, using questionnaires and self-reports (e.g., Gui and Argentin, 2011; Ng, 2012; Porat et al., 2018; see Hargittai, 2010, for a comparative study of self-reports' efficacy), search engines' transaction logs (e.g., Toms and Latter, 2007; Walhout et al., 2015), verbal protocols (e.g., Greene et al., 2018; Greene et al., 2014; Kammerer and Gerjets, 2014), and video analyses of search patterns in tailored (e.g., modified results' page: Gwizdka and Bilal, 2017) or realistic (e.g., Google: Bilal and Gwizdka, 2018; Rennis et al., 2015) search engines. Notwithstanding these differences, this work converges to suggest that adolescents often do not implement optimal search strategies when navigating the web. For instance, they frequently utilize search engines rather than going straight to websites, often trusting the engines' query suggestions blindly (Gossen et al., 2011). Although this approach might circumvent their lack of relevant knowledge and general difficulty in formulating correct queries on their own, following the algorithm's predictions may lead to results that are popular and trending but not necessarily the most relevant or accurate. This risk becomes even more significant given the evidence suggesting that teenagers heavily rely on the search engines' rankings, tending to select the very first results obtained and rarely looking beyond the first page of results (Gwizdka & Bilal, 2017; Kammerer & Gerjets, 2014). When compared to adults, 10- to 16-year-olds are more likely to click on higher ranked results, spend less time on each web address (i.e., URL), but nevertheless take longer to reach a solution to the task at hand (Duarte Torres & Weber, 2011), which is likely because of a stronger tendency to repeat the same queries and revisit the same result pages and websites (i.e., *loopy browsing*, Gossen et al., 2014). Moreover, when formulating queries to be used on search engines, they seem to prefer natural language to keywords (Bilal & Gwizdka, 2018; Duarte Torres & Weber, 2011), which would lead to more targeted and refined results.

4.2.2 Efficiency in identifying appropriate sources of information

As described in the previous chapter, from a strictly developmental and cognitive standpoint, adolescents should be generally pretty good at telling good from bad sources of information. However, several studies suggested that they often do not take into account or are not able to evaluate the reliability and credibility of the sources of the information they are presented with online (Hautala et al., 2018). For instance, Maitz et al. (2020) found that more than 90% of the web pages visited by 14-year-olds during a health search task (i.e., suggest whether to get rid of a hairy mole) were judged poor or unreliable by independent raters. In particular, adolescents seem to fail to consider those aspects of the websites that would be relevant to appraise their reliability, such as the presence of advertisements (Gossen et al., 2011; McGrew et al., 2018), and do not take into account the website's sponsors or political and industry affiliations (McGrew et al., 2018). Instead, they often focus on more superficial cues, such as the vaunted expertise of the person providing information (e.g., the source of health-related information claiming to be a doctor, Maitz et al., 2020), or the website appearance (Freeman et al., 2018). In this respect, a meta-analysis by Dresang (2005) indicated that young people tend to discard the information coming from text-only websites, preferring more interactive pages, rich with video and visual content. This tendency might make them especially susceptible to false or biased information (Britt & Aglinskas, 2002). For example, McGrew et al. (2018) found that 52% of high-school students wrongfully believed that a grainy video claiming to document ballot stuffing in the 2016 Democratic primaries constituted strong evidence of voter fraud, although the video was actually shot in Russia.

4.3 The impact of information literacy on learning outcomes

Previous literature rarely offers insights on the impact of information literacy on learning outcomes that transcend the boundaries of academic achievements on higher education's specific subjects (e.g., Christ, 2004; Johnston and Webber, 2003; Storksdieck, 2016), with some exceptions. For instance, using verbal protocol analysis, Greene et al. (2018) found that the extent to which university students checked the consistency between different claims found on the web was positively related to their knowledge and comprehension of the topic at hand, although this relationship was not found to be statistically significant. Along these lines, undergraduate students were found to be better at justifying their opinions about unsettled scientific topics (e.g., whether using mobile phones can be a health hazard: Mason et al., 2010) when they had reflected on the extent to which the consulted websites provided actual scientific evidence (see also Çoklar et al., 2017; Kammerer et al., 2021; Zlatkin-Troitschanskaia et al., 2020 for similar work with university students). Moreover, Tu et al. (2008a) analyzed video captures of 14-year-olds' web searches about nuclear energy. In their task, participants were asked to search for answers to both "open-ended" (i.e., among all of the energy resources, what do you think is the best energy resource? Why?) and "close-ended" (i.e., What are the currently used energy resources in Taiwan?) questions. Coding of the video captures focused on several quality indicators such as number of keywords, visited pages, maximum depth of exploration, refinement of keywords, and number of words used in the first query. Their results indicate that some of these parameters (e.g., number of keywords used), along with participants' general web experience, predicted the accuracy of participants' answers, but only when they were searching answers to close-ended questions. Analyzing similar query patterns, Bilal (2000) found a positive correlation between the quality of the search strategies implemented by 12- to 13-year-old students and their success in solving fact-finding tasks (i.e., how long do alligators live in the wild vs. captivity?). In particular, they found that successful children had navigated and examined a higher percentage of hyperlinks and homepages, and looped searches and hyperlinks less frequently than unsuccessful children. However, more recently, Walhout et al. (2017) measured 14-year-olds' perceptual search processes using a combination of log files, eye-tracking data, surveys, and think-aloud protocols when they were asked to complete three tasks of differing complexity (i.e., fact-finding, cause–effect, and a controversial topic task). Their results showed that an increase in task complexity resulted in poorer task performance but in increased interaction with the search engine. In particular, when completing the controversial task (i.e., Does radiation from mobile phones have consequences?), participants made more search queries and used more keywords, longer formulation time, and considered a greater amount of search results (but still higher ranked in the results' page).

4.4 Project2: Adolescents Online Active Learning

Contributing to the rapidly growing literature reviewed above, the present study explored how 14- to 17-year-olds navigate the web when they were tasked with making an informed suggestion about controversial topics (i.e., whether using deodorants containing aluminum compounds or drinking mineral water containing nitrates increase the risk of developing cancer; see associated publication in Appendix section .1).

4.4.1 Aim

In addition to evaluating participants' overall search patterns, the factual knowledge they acquired, the accuracy of their suggestions, the completeness and clarity of their explanations, and interactions between these outcomes, the aim of this study was to explore possible factors driving individual differences in search efficiency and learning outcomes. In particular, it addressed the novel hypothesis that having control over the online search experience, along with having experience with searching the web specifically to obtain relevant factual information, may influence the overall quality of adolescents' online search efficiency and learning. Each hypothesis is detailed below.

Volitional control over the search process. As mentioned above, efficiently controlling the online search process is quite complex and demanding to, tapping into several cognitive skills, such as reasoning, working memory, attention, and perceptual speed (Sharit et al., 2008), as well as vocabulary and cognitive flexibility (Dommes et al., 2011). However, the media landscape also offers a constant stream of information that one does not control—TV news, YouTube channels, video bloggers, and social media feeds collecting and assembling information for consumption, presenting well-packaged stories that one can only absorb, endure, and later try to process, filter, and make sense of. Even though this process might be less costly from a cognitive perspective (Brossard, 2013) compared to situations in which one has to search actively, it may be even more demanding and taxing to evaluate and integrate information one has not put together oneself.

Thus, this study expands previous work by exploring whether having volitional control over the online search experience impacts the accuracy and quality of the search process and of the knowledge acquired. For this purpose, we manipulated within participants whether they were free to search and navigate the web to collect the information they needed to form an opinion and make a suggestion (active condition) or could merely observe and follow another participant's search process (yoked condition).

Experience in searching relevant information. Previous studies suggested that the general experience of using computers (e.g., 5 days a week) was positively associated with students' information literacy (Fraillon et al., 2020). Yet, it seems improbable that using computers to play video games, to chat with friends, or to watch movies would make one a more efficient and conscious web user.

This study contributes to the existing literature by investigating whether the frequency with which adolescents specifically search for factual information on the web (e.g., related to subjects covered in school, current events, or news stories), compared to other kinds of web experience, has a positive impact on their ability to search, filter, and consciously learn from the web.

4.4.2 Methods

Participants

Forty-eight 14- to 17-year-old high-school students (13 female; $M_{age} = 15.2$ years, $SD = 1.03$) recruited from a secondary school in Livorno, Italy, voluntarily participated in the study. Institutional Review Board approval was obtained from the Ethics Committee of the Max Planck Institute for Human Development in Berlin (protocol: "WISE"), and parents gave informed consent for their children to participate before testing took place. Two additional participants were excluded from the analyses because of a certified intellectual disability or missing data.

Design and procedure

Students were tested in groups of 10 to 14 in the computer room at their school and were presented with an online survey consisting of two identically structured blocks, in a 2×2 within-subject design.

Active and yoked research phase. Each block presented a brief text describing a dilemma scenario in which a fictitious character expressed uncertainty about whether to use products containing one of two substances that have recently received controversial media coverage because of their potential carcinogenic effect: aluminum (A) in deodorants and nitrates (N) in water. The text concluded with the fictitious character explicitly asking participants whether the use of products containing those substances was safe and whether there was actual scientific evidence supporting their connection to cancer (see Section .3 in the Appendix for the complete procedure).

The text included four "target" keywords (i.e., cancer, scientific evidence, aluminum/nitrates, deodorants/water), not made explicit as such to participants, which if searched on Google would have led to the most reliable (*target*) website being shown as a snippet (i.e., a box on top of the results page containing a summary of the main content of a website relevant to the user's search).* The target

*Note that omitting the keyword "scientific evidence" would have still resulted in the "target" website belonged to a national association for cancer research (a nongovernmental organization [NGO]) and presented transparent and clear information about the connection of both substances to cancer.[†]

Crucially, both pages on the target website contained all the information needed to make an informed suggestion in reply to the character's question, and to answer knowledge assessment questions correctly. Also, the two pages were comparable in terms of reading time (5 min).

Participants were asked whether they had previous knowledge about the presented topic (i.e., "Do you know anything about nitrates in water/Do you know anything about aluminum in deodorants?") and were then asked to search the web for 10 min (active block) or watch a 10-min video of another participant searching the web (yoked block) to make the informed suggestion. All participants completed the active block before the yoked block, but the two topics (A and N) were pseudorandomly assigned to the blocks, so that half participants started with Topic A in the active block and proceeded to Topic N in the yoked block, whereas the other half started with Topic N in the active block and proceeded to Topic A in the yoked block. Before entering the research phase, participants were explicitly informed about the subsequent tasks and were prompted to be as exhaustive and accurate as possible.

Suggestion and justification. After the 10-min active or yoked research phase, participants were asked to come up with a suggestion (i.e., to avoid/not avoid deodorants containing aluminum; to avoid/not avoid drinking water containing nitrates) as well as a justification for this suggestion (maximum of 150 words).

Source reliability For each block, participants then had to provide a link to the *most reliable* and the *least reliable* source encountered while researching and were asked to select the reason for their choice from an eight-item multiple-choice list (see Table A3).

website being listed first, but not as a snippet.

[†]Link Alumnium; Link Nitrates

Factual knowledge. For each block, participants were then presented with three multiple-choice questions assessing the knowledge gained in the researched topic (see Table A5).

Information search habits. After having completed the active block, participants were asked to report the frequency with which they usually search for information online, which search engines they preferred, and how often search engines were utilized for various purposes, on a Likert scale ranging from 0 (*never*) to 10 (*every day*).

4.4.3 Results

As there was no effect of topic (A or N) on any of the outcomes considered in the study, this variable was excluded for the following analysis (please note that the full data set is available on the OSF platform at this link). This section first reports the overall descriptive statistics of the measures considered (previous knowledge, accuracy of the suggestion and quality of the justification provided, sources selected as most/least reliable), merged across conditions, and interaction effects found between these outcomes. Second, it follows an overview of participants' web habits. Third, the analyses of participants' search patterns in the active blocks. Finally, I present the analyses of the factors we hypothesized might contribute to participants' performance. In particular, these addressed whether being given control over the search process (i.e., active vs. yoked condition), previous knowledge, and web habits as well as efficiency in navigating the web elicited in the active condition had an impact on the learning outcomes considered. Additionally, I explored whether previous knowledge and web information search habits also had an impact on participants' search efficiency.

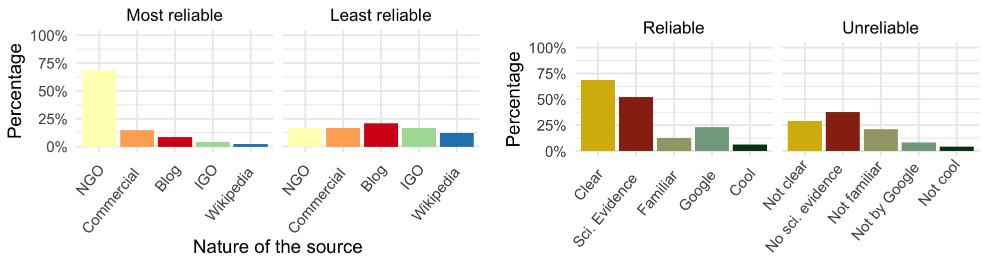
Overall measures

Previous knowledge: Had participants heard about these topics before? Overall, 12.5% of the students indicated that they had heard about one of the presented topics before (Topic A: $n = 6/48$; Topic N: $n = 6/48$), whereas only two of 48 students had heard about both topics, and 70.8% (n = 34/48) had heard about neither.

Suggestion and justification. The Italian Association for Cancer Research (AIRC) has reassured the public that it is safe to use both of these products, as there is no evidence supporting the alleged risks. In particular, epidemiological studies have not shown significant relationships between deodorant use and the occurrence of any cancer, and specific studies on aluminum have not found any relationship between its effect on estrogen receptors and breast cancer. Similarly, the association between nitrates in bottled water and cancer has not been confirmed by any studies demonstrating a cause-effect relationship. However, studies on nitrates have shown that, when ingested, about 20% of these compounds can be transformed into *nitrosamines*, which can be considered carcinogenic if introduced directly and at high doses. Therefore, according to the World Health Organization and the Italian law, nitrates in tap and bottled water must not exceed 50 mg/L.

In total, 58.3% of participants ($n = 28$) gave positive suggestions concerning both products; that is, they thought that the characters could safely continue using deodorants containing aluminum and continue drinking water containing nitrates, whereas 10.4% had the opposite opinion, that is, that the characters should stop using both products ($n = 5/48$). Thirty-one percent of the participants gave a positive suggestion to the fictitious character concerning at least one of the allegedly carcinogenic products (Topic A: $n = 7/48$; Topic N: $n = 8/48$).

Participants were also asked to justify the given suggestions with a short text. Three chemistry experts blind to the research questions rated the accuracy and completeness of the justifications on a scale of 0 (lowest possible score) to 10 (highest possible score). We assessed raters' agreement by computing the intraclass correlation coefficient (ICC) with a one-way random effect model and average unit: ICC = .881; 95% confidence interval (CI) [.83, .91]; $F(86,174) = 8.39$; $p < .001$. As the raters' agreement was very good, an average score was calculated for each participant. On average, the justification score obtained by participants was – = 4.59 (Min = 1, Max = 9, $SD = 2.38$).



(a) Which source was the most or least reliable?

(b) Why was the source the most or least reliable?

Figure 4.1: Percentage of the websites indicated by participants as most and least reliable, coded by source type (Panel a) and the reasons why participants had selected those links as most or least reliable (Panel b). IGO = International governmental organization; NGO = nongovernmental organization; sci = scientific.

Source reliability. The links participants provided as most/least reliable sources of information were coded into different categories: NGO websites, official international governmental organization (IGO) websites, commercial websites, personal blogs, and Wikipedia pages (see Table A4). As illustrated in Figure 4.1a, 68.8% of participants deemed NGO websites as the most reliable (94.5% of the NGO links provided were the target website). Overall, 72.9% of the websites participants indicated as most reliable provided at least two of the three pieces of information required to correctly answer the knowledge assessment questions. Interestingly, we found no systematic trend in attributing unreliability to any of the source types (see Figure 4.1b). Sixty-nine percent of participants perceived sources as reliable because they were clear and provided scientific evidence (52%), but no reason stood out when indicating why the provided sources were the least reliable.

Knowledge assessment. Participants' answers to the three multiple-choice questions were coded as "1" when they were correct and "0" otherwise. On average, participants answered correctly about half of the questions (M = .45, SD = .29).

Interactions between learning outcomes. We ran several mixed-effects regression models to examine potential interactions between the above-mentioned measures and the two conditions.[‡] We found that neither the proportion of correct answers participants gave in the factual knowledge assessment ($p = .27$), nor the suggestions given ($p = .52$) predicted the justifications' scores. Additionally, we ran three models predicting each learning outcome by the probability of providing a fully informative link, that is, a link that contained at least two of the three pieces of information needed to answer the knowledge assessment questions correctly. These models revealed that participants who provided such links were slightly more likely to answer more questions correctly (OR = 0.65, 95% CI [0.23, 1.78], $p = .05$) but not to give different suggestions ($p = .47$) or to get higher justification scores ($p = .28$).

Online information search habits. As can be seen in Table 4.1, adolescents reported they most often searched the web for entertainment content (e.g., video and games). Indeed, this was ranked as the most frequent activity by 37.5% of participants. In total, the percentage of participants who ranked factual information search (i.e., searching for interesting facts, school-related content, or daily news) as the most pursued online research activity amounted to 43.8%.

Information search patterns in the active blocks. Video captures of participants' search during the active blocks were coded by a blind and independent observer using the Datavyu video-coding software (Datavyu-Team, 2014). Five video captures were missing because of technical problems, leaving $n = 43$ participants for the following analyses. The coding focused on two main aspects: the characteristics of the websites consulted and those of the inquiry process. As in the previous analysis of source reliability, the websites participants consulted were coded by type. For each participant, we calculated the percentage of pages consulted and the average time spent on pages by source type. Results are reported

[‡]All generalized linear mixed models were run using the *lme4* package, version v1.1-23. Effect sizes and 95% confidence intervals (CIs) for significant effects of logistic regressions are reported in terms of relative odds ratios (OR), which indicate the multiplicative change in the odds of providing a positive suggestion (binomial) or a fully informative link (binomial), which is associated with a unit change in the given predictor.

Table 4.1: Mean frequency (0 = never; 10 = on a daily basis) of participants' information search activities on the web and percentage of participants who ranked each search activity as the most pursued on the web

Activity	**Mean**	***SD***	**Ranked 1st by**
Entertainment	8.54	2.23	37.5%
Interesting facts	7.85	1.84	33.3%
School-related content	6.56	2.34	8.3%
Products to purchase	6.52	3.26	12.5%
Daily news	4.31	3.03	2.2%
News about celebrities	4.58	3.33	6.2%

in Table 4.2.

In Table 4.3 we report the coding results concerning all the characteristics of the inquiry process that have been previously identified as indicators of web search efficiency (e.g., Tu et al., 2008b). As participants were explicitly instructed to use the Google search engine, we did not include "search engine" among the indicators. Also, note that none of the participants used hyperlinks or typed in a specific link directly.

Overall, only 39.54% (17 of 43) of participants used a keyword-based query, that is, did not use any unnecessary conjunctions or specifications as one would do using natural language. Among them, 5.90% used none of the four target keywords, 11.76% used just one, 58.82% used two, and 23.52% used three. Interestingly, none of the participants used the cue "scientific evidence," although this was explicitly mentioned in the text as the main goal of the research task.

Factors contributing to participants' performance

Active versus yoked: Does volitional control over the search process impact learning outcomes? We fitted three generalized mixed-effects models predicting each learning outcome (i.e., knowledge assessment, justification score, suggestion, and provision of a fully informative link) with fixed effects of condition

Table 4.2: Summary of the sources consulted during the active research blocks: Proportion of participants who visited each source type at least once, average percentage of page visits of the total of all pages consulted by source type, and average time spent on each source type across all queries

	Visited at least once	Total pages visited	Time spent on page (s)	
Source type	**Percentage (participants)**	**Percentage (source type)**	**Mean**	***SD***
NGO	93.02%	52.2%	273.12	162.99
Commercial	65.12%	29.8%	85.6	126.85
Blog	18.60%	4.4%	11.21	34.75
IGO	16.28%	3.4%	16.72	57.63
Magazine	16.28%	6.4%	6.42	20.39
Wikipedia	11.63%	2.6%	11.81	36.53
Scientific journal	2.33%	1.2%	2.28	14.94

Note. NGO = nongovernmental organization; IGO = international governmental organization.

Table 4.3: Summary of the characteristics of the inquiry process: The average of each of the actions listed has been calculated across queries, unless indicated otherwise. Time excludes time spent taking notes

Inquiry characteristic	**Average**	***SD***
Queries	2.18	1.36
Keywords	0.53	0.80
Keywords/query	2.49	0.76
Natural language	1.65	1.11
Reformulations	0.16	0.43
Pages consulted	3.25	2.18
Pages/query	1.86	1.28
Position rank	3.36	1.72
Lowest position rank (of 10)	4.67	3.67
Time (s)	407.16	145.23
Time/page (s)	185.05	146.40

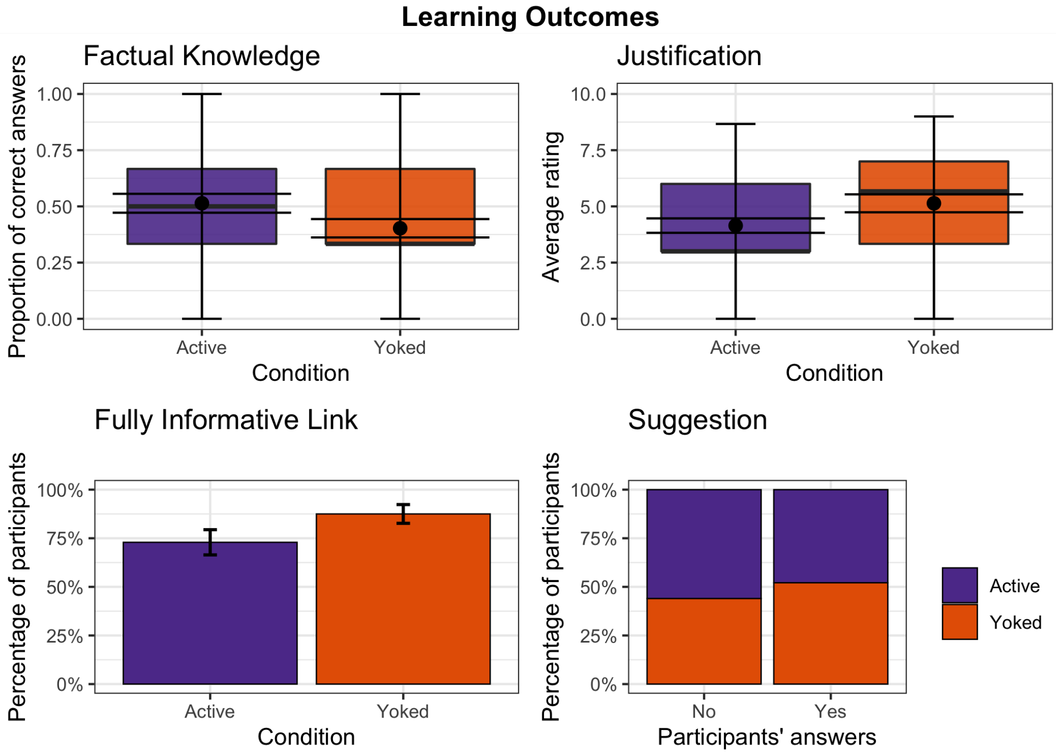


Figure 4.2: Outcome measures used in the study: Knowledge assessment, justification rating, provision of a fully informative link, and suggestion. Bars represent 95% bootstrapped confidence intervals.

(i.e., active and yoked), and their interactions. The models show that participants in the yoked condition were less likely to answer the knowledge questions correctly (β = -0.38, 95% CI [-0.75, -0.01], p = .04) but more likely to get higher justification ratings (β = 0.42, 95% CI [0.00, 0.83], p = .05). Learning condition did not have an effect on the suggestions they gave to the fictitious character (p = .44), or on the likelihood of providing a fully informative link (p = .08).

As illustrated in Figure 4.2, a paired Wilcoxon signed-rank test confirmed that the average of correct answers was significantly higher for the active blocks ($Z = -8.48$, $p < .001$, $r = 1.22$). Yet participants received on average higher ratings for their justifications in the yoked condition ($Z = -7.74$, $p < .001$, $r = 1.11$).

Does previous knowledge predict learning outcomes and search efficiency? Not too surprisingly, previous knowledge about the topics to be researched significantly predicted learning outcomes. Mixed-effects regression models predicting each of the learning outcomes separately by participants' previous knowledge (factor: Yes/No) and their interactions with learning condition revealed that participants who stated at the beginning of the test that they had heard about the topic(s) before were more likely to answer the multiple-choice questions correctly (β = 0.98, 95% CI [0.29, 1.67], $p < .01$) and to get higher justification ratings (β = 0.77, 95% CI [0.06, 1.47], $p = .03$). Interestingly though, knowing about the topics had a negative interaction effect in the yoked condition, indicating that when participants did not exert control over the search process, they were less likely to answer the knowledge questions correctly even if they knew something about the subject before actually gaining the (new) information (β = -0.98, 95% CI [-2.00, 0.04], $p = .05$). On the other hand, previous knowledge did not affect participants' suggestions to the fictitious character in any learning condition ($p =$ .08), nor the likelihood of consulting a fully informative link ($p = .09$), nor any characteristic of the inquiry process (ps $> .11$).

Do web information search habits predict learning outcomes and search efficiency? We ran three regression models, predicting each of the learning outcomes by the overall frequency of online information search, by the habit of searching the web for factual information (factor: Yes/No), and by search activity. The first model showed that the overall frequency did not predict any of the learning outcomes considered (ps $> .12$); the second model showed a nonsignificant effect (p $= .59$). However, by looking at each activity separately, the third model revealed that participants who more frequently searched the web to perform school-related assignments were more likely to achieve higher justification ratings ($\beta = 0.49$, 95% CI [0.17, 0.82], $p < .01$). No further predictors were found to be significant in this case; nor were these predictive of any other learning outcome. Finally, we ran several models predicting different characteristics of the inquiry process by participants' information search habits, which revealed no significant results (ps $>$ .14).

Does online search efficiency impact learning outcomes? We fit several linear mixed-effects models, predicting each learning outcome by the characteristics of the inquiry process and of the websites consulted. The models revealed that participants who visited IGO websites were more likely to answer more questions correctly ($\beta = 0.42$, 95% CI [-0.01, 0.84], $p = .05$). The number of reformulations negatively predicted the quality of the justification provided (OR = -0.31, 95% CI [-0.62, -0.01], $p = .04$). In contrast, participants who spent more time reading blogs ($\beta = 0.36$, 95% CI [0.06, 0.67], $p = .01$) and NGO websites ($\beta = 0.43$, 95% CI [0.02, 0.84], $p = .03$) were more likely to obtain higher justification ratings. Moreover, participants who visited NGO websites were more likely to suggest the fictitious character continue using the products (OR = 0.27, 95% CI [0.02, 1.15], $p = .04$). Somewhat surprisingly, no other aspects of the inquiry process significantly predicted learning outcomes.

4.4.4 How adolescents searched, filtered and learned from Google

This project examined how adolescents search and filter information on the web when they are tasked with making and justifying an informed suggestion about unsettled scientific issues. Beyond assessing the effect of factors that have already been identified as potential influences on adolescents' information literacy (i.e., previous knowledge and search efficiency Corredor, 2006), we were particularly interested in exploring the possibility that having control over the online search experience, along with having experience with searching the web to obtain factual information, would positively contribute to the quality and informativeness with which opinions, such as whether using a certain product might be a health hazard, are formed. Generally, participants' learning performance was rather poor, although a vast majority had indeed identified informative and accurate web sources and provided the right suggestion (i.e., it is indeed safe to use the controversial products).

This study was the first to compare active and yoked information acquisition on the web, within participants, and in a naturalistic Google environment. Notably, its results indicate that having or lacking volitional control over the search process had a differential impact on the learning outcomes considered. In particular, having control over the information flow in the active blocks (i.e., being able to decide what to search, which keywords to use, which source to consult, and for how long) supported participants' retention of specific factual information, as measured by the knowledge assessment task. This is in line with the previous studies with adults and developmental work reviewed in the Introduction, robustly showing that even minimal forms of volitional control tend to result in memory improvements across a variety of tasks when compared to situations in which one lacks this possibility (C. Liu et al., 2007; D. Markant et al., 2014; D. Markant et al., 2016; Murty et al., 2015; Partridge et al., 2015; Pezzulo et al., 2016; Ruggeri, Markant, et al., 2019; Voss et al., 2011). However, our results also indicate that being a passive observer of the search process, in the yoked blocks, resulted in more accurate and elaborate justifications. This apparently contradictory finding can be potentially explained by taking into account the different nature of this task, compared to the knowledge assessment task. Indeed, similar trends have been found in spatial and spatial navigation tasks. For example, Plancher et al. (2013) compared active drivers and yoked passengers in a virtual driving experiment. Active participants were assigned to one of two conditions: an interaction condition, in which they drove a car along a route dictated by the experimenter, and a planning condition, in which they decided which direction to turn at each intersection and their choices were carried out by the experimenter. Compared to a yoked condition in which participants simply watched a video of the driving experience generated by active participants, both active conditions led to better memory for the layout of the virtual environment and the route taken. Moreover, performance in the planning condition was higher than in the interaction condition, suggesting that deciding how to explore enhanced memory independent of the physical act of exploring itself. This is in line with a number of studies showing that certain forms of spatial memory (e.g., memory for the distances between landmarks) are enhanced by active navigation of the environment (see Chrastil and Warren, 2012, for a review).

Interestingly, however, just like in the current work, the same study found the opposite pattern in recognition memory for objects encountered along the route, with passive observers showing better recognition relative to both active conditions (see also Brooks, 1999). Similarly, some studies found that participants who were given volitional control when exploring immersive and complex virtual environments or 3D objects had equal (Foreman et al., 2004; Keehner et al., 2008; Wilson, 1999) or even worse route and survey knowledge (i.e., configural information to take novel shortcuts and detours between locations) than participants who were passively exposed to the same content (Attree et al., 1996; Marchak & Zulager, 1992; Richardson et al., 1981). For instance, Wilson and Peruch, 2002 showed that young adults who explored a virtual environment through a prerecorded tour of similar experiences were significantly more accurate in their judgments of orientation and paths to the target object than active explorers. Generally, in a review of these findings, Chrastil and Warren, 2012 proposed that encoding certain aspects of the environment, such as full route and survey knowledge, requires mental manipulation of such properties but also the allocation of attention and encoding in working memory, which in turn may be constrained when participants are also actively involved in the decision-making process. In this sense, it is plausible that in the current study, saving participants the cognitive effort of deciding how to navigate the web allowed them to pay more attention and focus on the quality of the information provided, allowing them later to formulate more rigorous and conclusive arguments. Yet, why would they fail at the knowledge assessment task? On the one hand, it may be that while the yoked exposure promoted a broader view of the problem considered, enabling participants to allocate their attention in weighting counter-evidence and critically evaluate the information to which they were exposed, the effort of putting together such information somehow hindered the encoding of specific factual information. On the other hand, it is worth considering that this effect could also just be a result of always having participants complete the yoked block after the active block. In particular, this may have affected our results in two ways. First, completing the questionnaires following the active block might have unconsciously prompted participants to focus their attention on different aspects of the video they watched, for instance, on the reliability of the sources and the information. Second, although participants already knew about the justification task at the beginning of both research phases, they might have realized what was really required to succeed at this task only after having done it for the first time. Yet, it is unlikely that such awareness would have affected the knowledge assessment task, as it was practically impossible for participants to predict the specific facts the multiple-choice questions addressed. In support of this interpretation, previous work suggests that providing participants with specific instructions about what to pay attention to might mitigate the differences found within subjects' performance in active and yoked exploration of complex virtual environments (Taylor et al., 1999; Wilson & Peruch, 2002).

Not too surprisingly, and in line with previous work, in the current work that already being familiar with the topic(s) to be researched helped and supported subsequent retention of factual knowledge, resulting in more accurate and evidence-based judgments (Hailikari et al., 2008; Hembrooke et al., 2005). Interestingly, our results suggest that this advantage was absent in the yoked condition. Thus, when participants did not exert control over the search process, they were less likely to answer the questions correctly even if they knew something about the subject before actually gaining novel information. As discussed by Gureckis and Markant (2012b), it is likely that in this study context, participants' previous knowledge about the topics may not have been matched in the yoked partners' search, hindering their chance to directly test their intuitions and eventually confirm their hypotheses and resulting in a potentially frustrating experience.

Contrary to what has been found in previous work (Kelly & Cool, 2002; White et al., 2009; Wildemuth, 2004), previous knowledge did not seem to impact the efficiency of participants' inquiry strategies (e.g., keywords used, reformulations, websites consulted, etc.). However, this inconsistency may also be attributable to the different definition of *familiarity* adopted in the studies mentioned above, where the benefit of having previous knowledge was assessed by comparing search effectiveness of users identified as experts and nonexperts within different domains (e.g., medical doctor vs. nonmedical doctor searching for health-related information).

Notably, these findings show that the majority of participants endorsed the reliability of nonprofit NGO websites, such as the National Association for Cancer Research, which in our case also represented the best source of information needed to succeed on the learning tasks. This finding is consistent with the many studies showing that adolescents deem NGO or IGO websites (i.e., the National Health Service in the United Kingdom: Gray et al., 2005, or the Mayo Clinic in the United States: Malbon et al., 2012) as the most reliable for health-related information (Gray et al., 2002; R. K. Jones & Biddlecom, 2011a, 2011b). In this respect, more than the half of our participants indicated they attributed trust and reliability to web sources based on the quality of the information provided, such as its clarity (Selkie et al., 2011) and the degree to which it provided scientific evidence. However, even if to a lesser extent, participants also inferred reliability from other, less content-related aspects of the web source, such as its familiarity (i.e., whether they had heard of it before) and its position in Google's list of results (Gossen et al., 2014). Surprisingly, participants did not seem to agree on what kind of websites are least reliable, and they did not systematically distrust Wikipedia and similar sources, as found in previous studies (e.g., E. M. Henderson et al., 2013).

Generally, the characteristics of the inquiry process observed in this study resembled the general trends found with adolescents in similar web-research-oriented tasks. For instance, participants in our study formulated queries using natural language rather than keywords, did not use hyperlinks (Bilal & Gwizdka, 2018) and *never* went beyond the first page of Google results (Druin et al., 2009; Gossen et al., 2011; Walhout et al., 2017). They consulted predominantly the first three web pages in the list of results (Kammerer & Gerjets, 2014) and spent a relatively short time (i.e., about 3 min) on each page (Duarte Torres & Weber, 2011). All participants used the Google search function rather than typing in a specific website (Gossen et al., 2011; Kobayashi et al., 2006). Crucially, however, our results suggest that only a few characteristics of the inquiry process were predictive of the quality of the learning outcomes. In particular, spending more time reading information provided by NGO websites resulted in greater—though not *great*—performance on the knowledge assessment task.

Moreover, more frequent use of reformulations led participants to provide lower rated justification; in contrast, Tu et al. (2008b) showed that refinement of keywords predicted the accuracy of participants' answers. Yet this effect was found only when participants were tasked with searching for answers to close-ended questions, like in other studies reporting a relationship between the quality of students' learning and their information search strategies (e.g., Bilal, 2000; Greene et al., 2018; Greene et al., 2014). Taken together, these results suggest that understanding such effects on research-oriented tasks might necessitate more sophisticated classification of the inquiry's characteristics (e.g., Bilal and Gwizdka, 2018; C. Liu et al., 2010), which may better reflect the complexity and amplitude of tasks such as the one used in this project.

Chapter 5

General Discussion

5.1 Factors contributing to active learning effectiveness

5.1.1 Question asking and selective trust

The developmental trajectory of active learning outlined in this monograph upholds the idea that children's question-asking strategies improve concurrently to their executive function skills (e.g., inhibitory control; Huizinga et al., 2006), probabilistic reasoning (e.g., Schneider and Siegler, 2010), categorization skills (Ruggeri & Feufel, 2015), and verbal abilities (e.g., Swaboda et al., 2020). Previous work suggests that, over the preschool years, there might be important development in the ability to monitor and recognize not only a gap in one's own knowledge, but also a lack of confidence about the things one already knows (e.g., Coughlin et al., 2015), as well as a general improvement in integrating this prior knowledge to seek new information strategically (Was & Warneken, 2017). In this sense, the development of meta-cognitive abilities and theory of mind (e.g., Wellman, 1992) might enhance children's awareness of their own knowledge and capabilities, and at the same time support their understanding of other people's knowledge, intentions or actions. In this respect, some work showed that performance on the false belief task correlated with greater success at identifying which of two informants was likely to give accurate information based on informant history (e.g., DiYanni et al., 2012; Lucas et al., 2013). In this sense, enriched executive function skills might facilitate the coordination between theory of mind and meta-cognitive abilities and guide children to direct their selective request for information (Ronfard et al., 2018 for a review). Yet, reasoning about how others came to know what they know (e.g., through question asking or active exploration), and the implications different ways of learning hold for others' knowledge and inquiry abilities is plausibly more complicated than reasoning about the source of one's own knowledge, or being an effective learner oneself. In this respect, results from two of the projects described above (i.e., in sections 2.2 and 3.3), suggest that to make meaningful and selective inferences about other people's ability to actively learn, and know to what extent this skill underlie one's knowledge, children must master these skills themselves.

Besides individual differences in cognitive abilities, a great proportion of variability in individuals' active learning abilities is likely to be rooted in differences in those individuals' non-cognitive factors, such as socio-cultural milieu. In a pioneering study, McCarthy (1930) recorded children ranging in age from 18 to 54 months as they each talked to the same unfamiliar adult. She found that upper class children asked more questions than lower class children. This difference was not simply due to variation in children's overall talkativeness because the number of questions was calculated as a proportion of the first 50 utterances. Nor was it a matter of comprehension. When children from the two social strata were equated for mental age, the proportion of questions asked by upper class children was still double that of lower class children. Finally, the difference was not likely to have been due to class differences in social confidence, notably in questioning a stranger, because Tizard and Hughes (1984) observed a similar social class difference in the U.K. even when 4-year-olds were recorded in conversation with their mothers at home and not with a stranger. As compared to lower class children, middle class children devoted more conversation turns to questions, and were more likely to ask follow-up questions based on the answers they had received. More recently, Kurkul and Corriveau (2018) corroborated these findings, suggesting that children in middle-SES families generate more questions than children in low-SES families because they receive more satisfying responses from their caregivers (see also Callanan and Oakes, 1992).

Moreover, and consistent with the hypothesis that parental value shape children's exploration, Endsley et al. (1979) found that mothers' authoritarianism predicted fewer maternal behaviors that encourage physical exploration (e.g., prohibitions) and this in turn predicted lower physical exploration in the children. Along these lines, children whose parents placed more emphasis on academic stimulation and on satisfying children's curiosity, over a period of 2 years, were found to be more likely to develop sustained individual interests (Leibham et al., 2005).

In summary, depending on their socio-economic status and their level of education, parents bring different goals and values to their children's upbringing. Wealthier and better-educated parents favor independence and the way they speak to their children reflects that. They encourage their children to explore and express themselves by asking them questions and by elaborating on what they say. Poorer and less well-educated parents are more likely to prioritize obedience and respect. The frequency with which they produce prohibitions reflects that priority on which their children appear to pick up. As a result, middle-class children engage in more sustained questioning and exploration than lower class children.

In light of these evidence, one may also expect sociocultural variety in the attributions and values associated with active-learning competence, which may in turn influence the extent to which children may rely on active learners as potential teachers. In this sense, I look forward to extend these projects to non-WEIRD populations (see also section 5.2.1 below).

5.1.2 Information literacy

Several studies have addressed the impact of different personal, social, and motivational factors underlying individual differences in information literacy skills (see also Lewandowski and Kammerer, 2020 for a review of factors influencing viewing behaviour on search engine results pages). Evidence from the comparative ILCIS study (Fraillon et al., 2020) suggests that factors such as parental education, socioeconomic background, and students' expectations of attaining a university education were significant predictors of computer and information literacy across countries. Perceived self-efficacy (Hatlevik et al., 2018), self-regulated inquiries (Lai et al., 2018), as well as epistemological beliefs and previous knowledge about the topics one searches about (e.g., Corredor, 2006; Tu et al., 2008b), also seems to affect students' efficiency in searching, retrieving, and interpreting information from the web. A similar trend was found for participants' gender, with female participants scoring on average 11 points higher than male participants. Gender differences were also found in adolescents' online search efficiency, but generally pointing in the opposite direction, suggesting that boys may be more efficient searchers than girls (e.g., Large et al., 2002). For instance, Roy and Chi (2003) found that 13-year-old boys filtered information at an early stage in the search process, using a predominantly horizontal search pattern, which consists of opening multiple tabs simultaneously to check the veracity of different sources of information. Same-aged girls, on the other hand, were found to implement more vertical, linear search moves and to be generally more thorough than boys. The kind of task presented also has an impact on learning efficiency (e.g., Walhout et al., 2017). For instance, Bilal (2002) found that 12- to 13-year-olds solved fact-finding tasks with greater ease compared to more research-oriented assignments, where participants were asked to learn and report about more complex topics, such as the depletion of the ozone layer (Bilal, 2002).

Results from Project 2 (section 4.4) add to these findings by highlighting that the way one through which adolescents acquire information on the web may have implications on their ability to critically reflect and learn about what they see. Yet, gaining further insights on the social and cognitive mechanisms underlying how people learn and form opinions when gathering (i.e., on Google) vs. receiving (i.e., Social Media) information on the web remains a societal and educational need.

Not too surprisingly, general experience and time spent in navigating web environments also has been found to have a solid impact on adults' navigational style (e.g., R. A. Palmquist and Kim, 2000; Thatcher, 2008) and on children's performance on tasks related to computer and information literacy (e.g., Bilal, 2000; Tu et al., 2008b). Even the frequency of use of information and communications technology applications in the classroom, along with the perception of having learned about computer and information technologies, was found to predict children's information literacy (Fraillon et al., 2020). Along these lines, Project 2 showed that general experience in searching the web for factual information was also a good predictor for information literacy. I will discuss educational implications of this finding in the next chapter.

Finally, the availability of technology applications in the classroom and at home, and in turn the experience children may have with their usage, is strongly dependent on SES and general economical resources, representing an impairment in developing countries (e.g., Dorner and Gorman, 2006). In this sense, further investigations on the factors contributing to information literacy may indirectly help to develop useful tools that obviate the need for economical resources and equip children of more heterogeneous, non-WEIRD population with the right tools to live in the information society.

5.2 Interventions to boost active learning

5.2.1 Question asking and selective trust

Previous studies have attempted to improve children's question asking abilities by exposing them to effective role models (D. R. Denney, 1972), providing them with feedback, or training them with rules and explicit instructions (N. W. Denney et al., 1979). However, these methods showed moderate success. Children did not improve their performance over time, and the modest training benefits, when present, did not generalize to other sets of stimuli or domains. For instance, being exposed to a role model that asked effective questions (i.e., either constraint-seeking or hypothesis-scanning) in a 20-questions game resulted in 10-year-old children asking more effective questions. However, this effect was no longer present after 1 week delay, and did only apply to constraint-seeking questions (N. W.

Denney et al., 1979).

In light of these results, it may seem rather implausible that older children's reliance on the effective question asker found in Project 1 reflected a desire to learn *how to ask*. However, neither the intervention studies mentioned above, nor my project explicitly assessed this hypothesis, leaving it open for future endeavours. Additionally, in the interventions' study mentioned above exposure to questioner models was limited to one occasion. It may be that longer and more frequent exposure to such models may enhance children's question-asking ability, even impacting their general problem-solving skills, possibly in the long-term. For instance, using some specifically-developed digital apps was found to improve children's problem-solving skills in pedagogical context (e.g., improving their ability to reason and test hypothesis about causal relationships; e.g., Hirsh-Pasek et al., 2015; Klahr et al., 2011). In this sense, if children would often be surrounded by informants (or teachers) that are ingenuous, good at finding things or that ask insightful questions, then their learning from them may not only be limited to epistemic knowledge, but may extend to more general problem-solving and reasoning skills. In other words, children may *learn how to learn*.

Recent research has also proved the advantages of boosting those cognitive skills and abilities that underlie children's ability to search for information described in section 5.1.1. For instance, providing children with the labels needed to target categorical features at different levels of abstraction was found to substantially improve children's search efficiency in a 20-questions game already at age 4 (Ruggeri et al., 2021). Along these lines, soliciting the identification of categorical features that applied to multiple objects and hypotheses through explanations improved 6- and 7-year-olds, but not younger children's performance (Ruggeri, Markant, et al., 2019). Additionally, spatial organization of the stimuli was found to ehnance children's categorization skills trough a nonverbal paradigm (Swaboda et al., 2020), and allowing children to explore and decide what objects to visualize was found to improve their recognition memory about those objects across different populations (Fantasia et al., 2020).

Taken together, these evidence and those discussed in 5.1.1 can lay the groundwork for tools aimed at boosting young children's ability to make meaningful inferences about the reliability information sources, for instance, by training their general meta cognitive abilities (e.g., through variations of the false belief tasks; Lucas et al., 2013).

Improving children's active inquiry skills at an early age has the potential to accelerate the development of their general information search strategies and problem-solving skills, boosting their later study and independent learning beyond the classroom. Developing such interventions becomes increasingly relevant for the information society we are living in, where effective knowledge acquisition strongly relies on the ability to search information effectively. I discuss some of these interventions in the following section.

5.2.2 Information Literacy

A variety of tools and interventions—games, tutorials, guidelines, workshops—have been developed over the last few years to help children become information literate. However, their actual efficacy and potential is unclear and hard to assess, as they often stem from different perspectives and focus on diverse methods, outcomes, and goals (see Munn and Small, 2017, for a review). The efficacy of some of these interventions has been proven in higher education settings by introducing information literacy training within school curricula to boost students' ability to search scientific literature from specific databases, generally showing quite good and long-term success (e.g., Hegarty and Carbery, 2010; Kavšek et al., 2016; Wallace et al., 2000; Wegener, 2018). However, the evidence of successful interventions targeting younger students is generally scarce, if not absent. In this respect, the Joint Research Center of the European Commission published a support guide for stakeholders (DigComp; Kluzer and Priego, 2018), including case studies and interventions developed within the European Union with the aim of enabling people to acquire the digital skills they need to be successful in the workplace, at school, or simply as citizens. Within the educational domain, most case studies suggested that interventions and tools were mostly successful when focusing on making students aware of their digital competences rather than boosting them (e.g., see the

Task Project's tool).

By investigating the factors contributing to information literacy in more naturalistic settings, resembling the implications that this may have on more daily-life outcomes, findings from Project 2 (section 4.4) have provided interesting groundwork for future investigations on how to boost information literacy.

First, the cognitive effort of having to search and filter the vast and infinite space of web information may support adolescents' ability to acquire knowledge, while being spared such effort may help them to critically reflect on the quality of the information found, provided that the information sources to which they are exposed are reliable. Creating environments that lighten the cognitive load of active browsing could foster critical thinking and processing ability. Conversely, making children train to actively search the web could impact their retention of information.

Second, adolescents seem to lack expectations about what makes web sources unreliable. As some of the work mentioned above showed moderate success when making adolescents aware of their digital abilities, making them aware of the characteristics underlying unreliable sources (and not only reliable ones) may be an asset to their critical-thinking competence. especially in relation to their ability to detect fake news.

Last but not least, having the habit, that is, having more experience in searching the web to complete school assignments, helped students reflect on the information found on the web, resulting in higher rated justifications for their opinions. This is probably the most encouraging result from the educational point of view, as it seems to suggest that training students to independently perform research tasks may indirectly support the development of critical reasoning, even about topics that are not directly relevant to their academic achievements. Future endeavors should address this possibility more directly, by evaluating the efficacy of such a simple, yet potentially effective training. For the same purpose, as mentioned in section 5.1.2, research should further systematically analyze other factors that may potentially contribute to adolescents' ability to search, filter, and learn from the web, addressing, for instance, the impact of cognitive factors (e.g., meta cognitive skills, working memory, attention) and academic achievement, generally focusing more on individual differences, for example, by implementing longitudinal designs.

5.3 Open questions and future directions

Throughout this monograph, I have outlined a developmental trajectory of children's information search, by reviewing relevant cognitive, computational and educational work on active learning and differentiating between the various forms that this can take throughout the lifespan: From selective attention and pointing in infancy, to physical and spatial exploration during the preschool years, to question asking, to web browsing in adolescence. Despite its deep roots, tracing back to the pioneering work of Piaget and Vygotsky, this field is still fairly young and rapidly growing, expanding in many different directions, and leaving open some important aspects unexplored. Before taking up on concluding remarks, I briefly delve into these open questions and point out to future directions for research on children's information search, social and active learning.

First, although the developmental changes traced above, some age groups (e.g., adolescent and elderly populations) have been generally underrepresented in behavioural and cognitive research. Additionally, because research on selective trust has mostly focused on preschoolers and young children, it is also still unclear how and whether all the selective inferences about sources' reliability that children make at a very young age change later in childhood. In this sense, research is still missing a fine-grained and less fragmented overview of how information search strategies or inferences about sources reliability develop and change over the entire lifespan. This broader developmental focus would also contribute to develop more sophisticated and precise computational models and theories, which, by comparing the behavior and attributions of infants, toddlers, children, adolescents and adults at a deeper process level, would shed further light on the mechanisms underlying the observed developmental changes.

Second, existing research has mostly focused on identifying key developmental differences in the efficiency of children's search, or in their sensitivity to information sources. 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 and environmental, as well as individual factors (e.g., differences in cognitive abilities, vocabulary, motivation, personality, education, parenting style) drive developmental changes in active learning and selective trust, how they interact with each other, or how their relative importance changes with age. In this respect, my future work will focus on analysing cross-cultural data that the iSearch lab has collected in collaboration with scientists and institutions from Cuba, Egypt, India, Germany and the US. This project is conceived as an exploratory analysis with a threefold scope. On the one hand, the project aims to measure different aspects of active learning (e.g., efficiency, adaptiveness, selectivity, speed, learning accuracy) on a wide range of tasks (e.g., question asking, question evaluation, informants' evaluation, spatial search) to comprehensively assess 6- to 11-year-old children's active learning performance. On the other hand, it will systematically examine the cognitive, social, motivational, and socioeconomic factors impacting and contributing to active learning performance, to identify the sources of the developmental differences and interpret the individual differences observed. Finally the cross-cultural design will allow not only to examine a broader range of cultural differences (e.g., type of education) and to assess the robustness of our methods, but also to generalize our results to populations usually not represented in psychological research.

Third, it would be crucial to trace the relative importance of these contributing factors longitudinally. This perspective is even more important when considering that it is still unclear, on the one hand, whether active learning efficiency and general propensity to learn has an impact on later outcomes, such as school achievement; on the other hand, how factors like parenting and schooling styles may impact children's active learning ability, intuitions about active learners or propensity.

Finally, the work presented in throughout this monograph has emphasized the connection between children's intrinsic curiosity and its contribution on their remarkable ability to learn autonomously and from others. However, it is still unclear what drives children's nudge to seek information outside laboratory settings, in absence of intriguing stimuli, extrinsic rewards, or ambiguous and surprising events. This unanswered question will most likely delay the much-needed mission to develop learning environments able to foster children's intrinsic, innate curiosity, while indirectly training their information search skills.

5.4 Concluding remarks

Given the immediacy with which children can access all kinds of information from digital devices, learning nowadays relies more on the ability to make effective and appropriate inquires than on the availability of the answer. However, the abundance, richness, and often contradictory nature of the data and sources available on the web can easily be overwhelming, drastically challenging the sophisticated ability to successfully infer informants' reliability that children display already at at age three.

This doctoral work provided novel insights into children's developing ability to reason about the informativeness and reliability of their information sources, addressing important research gaps in cognitive, psychological and educational research. In particular, these projects addressed these gaps by tracing the inferences underlying children's ability to reason about sources' informativeness, and by isolating the factors contributing to adolescents' ability to learn from web sources and mold informed opinions.

Ideally, by relying on people in their social world who are competent, independent learners and good at asking questions themselves children might not only effectively learn about the world, but also learn *how* to learn about the world on their own. Likewise, identifying and appraising informative and accurate web sources can better inform adolescents' opinions as well as their learning about controversial and complex issues.

In the digital era, where there is the ever-increasing power to shape political and social discourse with just one click, the ability critically reflect on the insights and opinions we gather, or often just get bombarded with, is becoming the necessary foundation for conscientious citizenship.

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Appendix

.1 Associated Publications

1. De Simone, C., & Ruggeri, A. Searching for information, from infancy to adolescence. In I. Cogliati-Dezza, E. Schulz, C. M. Wu (Eds.). *The Drive for Knowledge: the Science of Human Information-Seeking*. Cambridge University Press. *Under review.* (applied to sections 1.1, 1.3, 2.1)

   Authors' contribution:

   - De Simone, C., 70 %
   - Ruggeri, A., 30 %

2. Bridgers, S., De Simone, C., Gweon, H., & Ruggeri, A. Children consider how others learn to decide whom to ask for help. *Under review.* (Child Development, initial submission November 2020; reported in section 2.2).

   Authors' contribution:

   - Bridges, S., 50 %
   - De Simone, C., 25 %
   - Gweon, H., 10 %
   - Ruggeri, A., 15 %

3. De Simone, C. & Ruggeri, A. What is a good question asker better at? From unsystematic generalization to adult-like selectivity across childhood.

Under revision. (Cognitive Development, initial submission November 2020; reported in 3.3 as Project 1)*.

A short version of this manuscript, including only Study 1a and 1b, has been published in the Proceedings of the Cognitive Science Society in 2019:

4. De Simone, C. & Ruggeri, A. (2019). What is a good question asker better at? In A.K. Goel, C. M. Seifert, & C. Freksa (Eds.), Proceedings of the 41st Annual Conference of the Cognitive Science Society (pp. 1613-1619). Austin, TX: Cognitive Science Society.

   Authors' contribution:

   - De Simone, C., 75 %
   - Ruggeri, A., 25 %

5. De Simone, C., Battisti, A., & Ruggeri, A. (2021). Differential impact of web habits and active navigation on adolescents' online learning. *Under review.* (Computers & Human Behaviour Reports, initial submission in March 2021; reported in section 4.4 as Project 2)†

   Authors' contribution:

   - De Simone, C., 65 %
   - Battisti, A., 15 %
   - Ruggeri, A., 20 %

*Preprint available at the following link

†Preprint available at the following link

.2 Project 1

Table A1: Distance matrix used in the hierarchal clustering process to evaluate the dissimilarity between the 12 abilities, traits and characteristics ratings. Distance was measured with the Minkowski metric, which can be considered as a generalization of both the Euclidean distance and the Manhattan distance.

	Smart	School	Treasure Hunt	Puzzles	Animal	Friendly	Goals	Soccer	Siblings	Kick	Ice Cream	See far
Smart	0	0.07	1.51	2.61	3.84	4.76	6.81	6.54	6.01	7.04	7.55	6.81
School	0.07	0	1.58	2.68	3.91	4.83	6.88	6.61	6.08	7.11	7.62	6.88
Treasure Hunt	1.51	1.58	0	1.1	2.33	3.25	5.3	5.03	4.5	5.53	6.04	5.3
Puzzles	2.61	2.68	1.1	0	1.23	2.15	4.2	3.93	3.4	4.43	4.94	4.2
Animal	3.84	3.91	2.33	1.23	0	0.92	2.97	2.7	2.17	3.2	3.71	2.97
Friendly	4.76	4.83	3.25	2.15	0.92	0	2.05	1.78	1.25	2.28	2.79	2.05
Goals	6.81	6.88	5.3	4.2	2.97	2.05	0	0.27	0.8	0.23	0.74	0
Soccer	6.54	6.61	5.03	3.93	2.7	1.78	0.27	0	0.53	0.5	1.01	0.27
Siblings	6.01	6.08	4.5	3.4	2.17	1.25	0.8	0.53	0	1.03	1.54	0.8
Kick	7.04	7.11	5.53	4.43	3.2	2.28	0.23	0.5	1.03	0	0.51	0.23
Ice Cream	7.55	7.62	6.04	4.94	3.71	2.79	0.74	1.01	1.54	0.51	0	0.74
See far	6.81	6.88	5.3	4.2	2.97	2.05	0	0.27	0.8	0.23	0.74	0

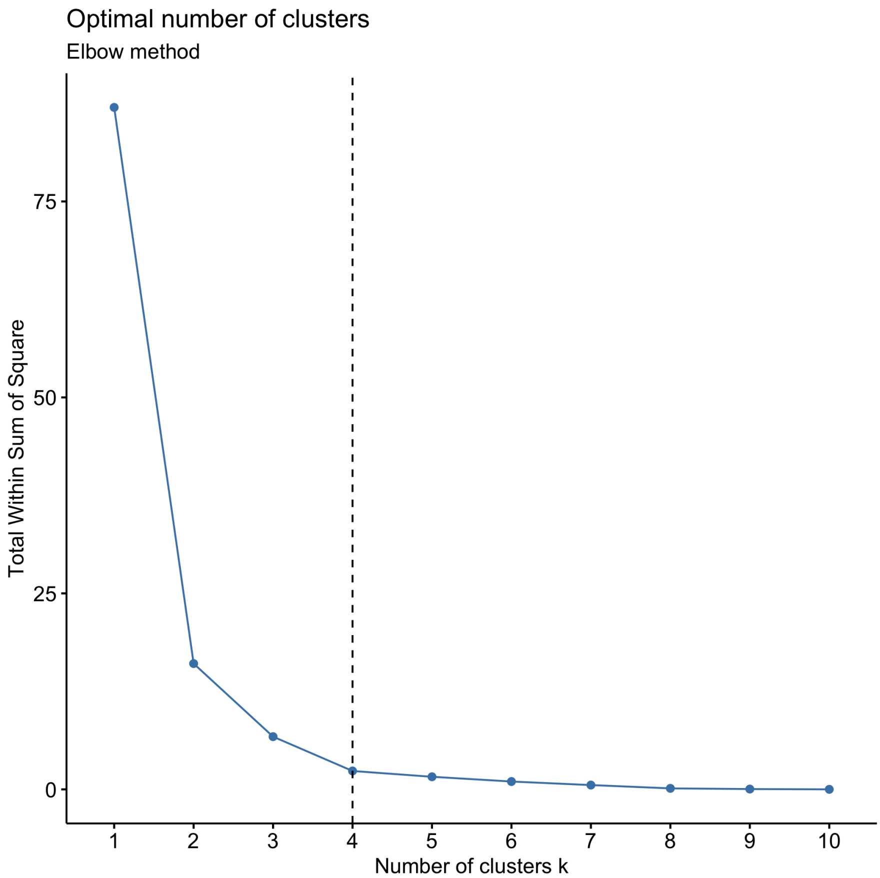

Figure A1: Elbow plot used to determine the optimal number of clusters to be taken for hierarchical clustering of questions in Study 1a. With an increase in the number of clusters (k), the average distance between each point in a cluster to its centroid decreases. To optimal number of clusters (k), corresponds to the value of k for which there is a sharp and steep fall of the distance.

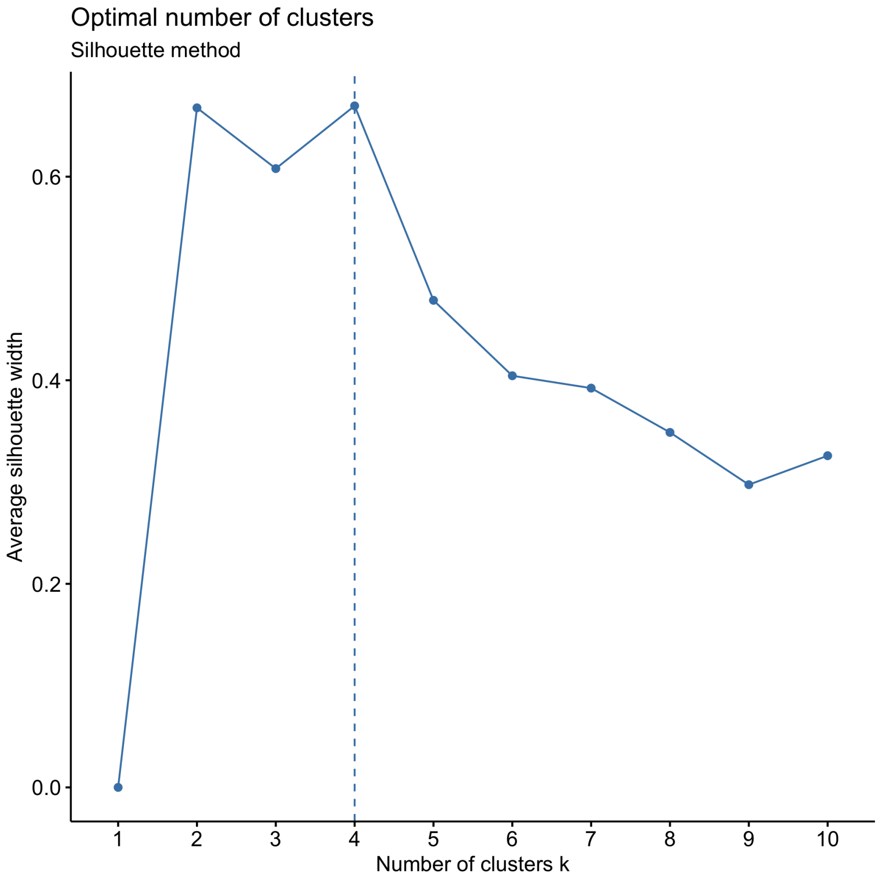

Figure A2: Silhouette plot used to determine the optimal number of clusters to be taken for hierarchical clustering of questions in Study 1a. The silhouette width indicates how similar an object is to its own cluster (cohesion) compared to other clusters (separation). The value of the silhouette ranges between [1, -1], where a high value indicates that the object is well matched to its own cluster and poorly matched to neighboring clusters.

Table A2: Study 1b: Mixed-effects logistic regression predicting children's learner choice on each question with fixed effects of age group and random intercept for subject. Adults' choices are considered as baseline.

	Being good at school				Being smarter				Being good at treasure hunting			
Predictors	OR(Beta)	SE	Z	p	OR(Beta)	SE	Z	p	OR(Beta)	SE	Z	p
(Intercept)	9.00 (2.20)	0.53	4.17	.001	2.08 (0.73)	0.34	2.16	.03	3.00 (1.10)	0.37	3.01	<.001
3- to 4-year-olds	0.17 (-1.79)	0.62	-2.9	<.001	1.00 (-0.00)	0.48	0	1	0.45 (-0.80)	0.49	-1.64	.01
5- to 6-year-olds	0.52 (-0.65)	0.67	-0.96	.34	1.93 (0.66)	0.52	1.26	.21	0.62 (-0.48)	0.49	-0.97	.33
7- to 9-year-olds	0.52 (-0.65)	0.67	-0.96	.34	1.66 (0.51)	0.51	1	.32	0.69 (-0.37)	0.5	-0.74	.46
	Being fast at jigsaw puzzles				Knowing lots of animals names				Being friendly			
(Intercept)	0.54 (-0.62)	0.33	-1.87	.06	1.67 (0.51)	0.33	1.56	.12	1.00 (-0.00)	0.32	0	1
3- to 4-year-olds	3.86 (1.35)	0.47	2.85	<.001	2.07 (0.73)	0.5	1.45	.15	2.33 (0.85)	0.47	1.81	.07
5- to 6-year-olds	8.76 (2.17)	0.53	4.07	<.001	2.07 (0.73)	0.5	1.45	.15	12.33 (2.51)	0.68	3.7	<.001
7- to 9-year-olds	2.51 (0.92)	0.46	2	.05	1.80 (0.59)	0.49	1.2	.23	2.64 (0.97)	0.48	2.04	.04
	Having more siblings				Being good at playing soccer				Seeing the furthest			
(Intercept)	4.71 (1.55)	0.42	3.73	.001	1.22 (0.20)	0.32	0.63	.53	1.11 (0.10)	0.32	0.32	.75
3- to 4-year-olds	0.56 (-0.58)	0.55	-1.06	.29	0.67 (-0.40)	0.45	-0.89	.37	2.71 (1.00)	0.48	2.07	.04
5- to 6-year-olds	0.39 (-0.93)	0.53	-1.75	.08	2.45 (0.90)	0.48	1.85	.06	1.88 (0.63)	0.46	1.36	.17
7- to 9-year-olds	0.44 (-0.82)	0.54	-1.53	.13	1.70 (0.53)	0.46	1.14	.25	1.51 (0.41)	0.45	0.9	.37
	Scoring lots of goals at soccer				Kicking a ball the furthest				Liking Ice Cream			
(Intercept)	0.43 (-0.85)	0.35	-2.46	.01	1.50 (0.41)	0.32	1.26	.21	0.67 (-0.41)	0.32	-1.26	.21
3- to 4-year-olds	1.91 (0.65)	0.47	1.38	.17	1.00 (-0.00)	0.46	0	1	1.50 (0.41)	0.45	0.9	.37
5- to 6-year-olds	2.85 (1.05)	0.47	2.23	.03	1.00 (-0.00)	0.46	0	1	4.50 (1.50)	0.49	3.09	<.001
7- to 9-year-olds	2.85 (1.05)	0.47	2.23	.03	0.81 (-0.20)	0.45	-0.45	.65	1.50 (0.41)	0.45	0.90	.37

.3 Project 2

Instructions

Instructions given to participants before the active and yoked research phase on each topic. Target keywords are written in bold.

1) Read the following text carefully:

(Nitrates). "I am Sue, and I am 22 years old. I was at the grocery store yesterday and I noticed that on some drinking water bottles it is specified in capital letters that they contain low levels of nitrates. I have asked around and apparently, many people seem to think that the **nitrates** contained in some **water** can cause **cancer**. I am really confused because I wasn't aware of this risk before, and I wonder whether there is reliable **scientific evidence** confirming this claim. Should I stop drinking mineral water containing nitrates or is this not really harmful?"

(Aluminum). "I am Bea, and I am 22 years old. I was at the drugstore yesterday and I noticed that on many deodorants it is specified in capital letters that they do not contain aluminum. I have asked around and apparently, many people seem to think that using **deodorants** containing **aluminum** can cause breast **cancer**. I am really confused because I was not aware of this risk before, and I wonder whether there is reliable **scientific evidence** confirming this claim. Should I stop using deodorants containing aluminum or is this not really harmful?"

2) Now follow the instructions below:

You have 10 minutes to search *[active condition]* — You will watch a video of the previous participant searching *[yoked condition]* — for accurate information about this topic on Google in order to give an informed suggestion to Sue/Bea. You can take notes. Your goal is to come up with a suggestion and a justification for this suggestion, and then answer some questions about this topic. Try to be as exhaustive and accurate as possible. An expert in the field will judge the accuracy and completeness of all justifications and will choose the most accurate. The best justification will be rewarded with a 25-euro Amazon voucher.

Table A3: *Source reliability.* English translation of the answers presented on the 5-item multiple-choice questionnaire used to assess participants' intuitions about the characteristics that make a website reliable or unreliable. Participants could select multiple items

Why was this source reliable?	**Why was this source unreliable?**
It was clear	It was not clear
It provided scientific evidence	It provided no scientific evidence
It was familiar	It was not familiar
It was suggested by Google	It was not suggested by Google
It was cool	It was not cool

Assessments

Table A4: *Source reliability.* Original links to web pages provided by participants for the source reliability assessment, categorized by source type.

Source type	**Link**
NGO	altroconsumo.it
IGO	salute.gov.it
Commercial	nivea.it
Blog	naturalmentemamma.it
Wikipedia	wikipedia.it
Magazine	tio.ch
Scientific journal	academic.oup.com

Note. NGO = nongovernmental organization; IGO = international governmental organization. Magazines and scientific journals were never provided as the most reliable web sources found but were visited by two participants during the active search.

Table A5: *Factual knowledge.* English translations of the forced-choice questionnaire used to assess participants' factual knowledge about each substance (nitrates and aluminum) and their relatedness to cancer. Correct answers are written in italics.

Nitrates

Do all types of water contain nitrates?

1) *Yes, both tap and bottled water contain nitrates*
2) No, only bottled still water contains nitrates
3) No, only bottled sparkling water contains nitrates

Why have some scientists hypothesized that nitrates in drinking water might cause cancer?

1) Because nitrites (NO2-) can be converted into nitrates (NO3-) within our organism and can act as precursors of N-nitroso compounds, which are considered extremely carcinogenic
2) *Because nitrates (NO3-) react within our organism to form N-nitroso compounds, which are able to modify the molecular structure of the cell and thus cause abnormal cell growth*
3) Because nitrates (NO3-) can be converted into nitrites (NO2-) within our organism and can act as precursors of N-nitroso compounds, which are considered extremely carcinogenic

According to Italian law, the amount of nitrates in drinking water must be below...

1) 40 mg/L
2) 50 mg/L
3) 40 mg/L

Aluminum

Do all deodorants contain aluminum?

1) Every commercial deodorant contains aluminum
2) Aluminum is contained only in the spray kind of deodorant and not in roll-ons
3) *Only antiperspirant deodorants contain aluminum*

Why have some scientists assumed that aluminum-containing deodorants can cause breast cancer?

1) *Because aluminum is absorbed by the skin and could have estrogen-like effects, thus promoting breast cancer*
2) Because aluminum contains estrogen, which when absorbed by the skin can promote carcinogenic cells' growth
3) Because when aluminum is absorbed by the skin it can release some toxins that can promote breast cancer

Why do some deodorants contain aluminum?

1) Because it covers the stinky chemicals excreted by sweat
2) *Because it can plug up sweat glands, thus stopping us from sweating*
3) Because it kills the bacteria producing the stinky chemicals

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