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Research Paper

# Preschoolers' inquisitiveness and science-relevant problem solving

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ABSTRACT

Preschoolers use their emerging scientific inquiry skills, including seeking information through questions, to explore, and solve problems within, the physical world around them. This study examines preschoolers' attempts to solve novel science-relevant problems and their use of science-relevant ideas within those problem solutions. Four- to five-year-olds (N = 24) were presented with seven novel problems, depicted in line drawings (e.g., determining which of two bags holds pillows, rather than rocks). Individual differences were examined in the use of foundational science-relevant concepts and skills within children's responses (California Department of Education, 2012), as well as in the child's tendency to ask questions (i.e., inquisitiveness) in a second open-ended task. MANCOVA analyses indicated that inquisitiveness was associated with the accuracy and fluency of children's problem solutions, even after accounting for differences in receptive vocabulary, gender, and age. Further research is warranted on the interplay of inquisitiveness, science knowledge, as well as other socialization and educational influences, in children's early science skills, including their ability to engineer solutions to realistic problems.

## 1. Introduction

The metaphor of the child as a "little scientist" has a long history, reflecting the widely acknowledged view that active exploration of the environment is central to children's early learning about the physical world (Gopnik, Meltzoff, & Kuhl, 1999; Karmiloff-Smith, 1994; Legare, 2012; Piaget, 1954). In the United States, Science, Technology, Engineering and Math (STEM) topics have been increasingly recognized as appropriate and relevant for children to explore in early childhood settings (California Department of Education, 2012; Greenfield et al., 2009; McClure et al., 2017; National Science Foundation, 2013). Inquiry skills are a key element of early science learning, as reflected in research-based curricula for preschool science, such as ScienceStart: (French, 2004; French, Conezio, & Boynton, 2000) and Preschool Pathways to Science (Gelman & Brenneman, 2004; Gelman, Brenneman, Macdonald, & Moisés, 2009). Drawing from developmental research, the California Department of Education (2012) describes children's experiences of scientific inquiry as ones in which "They make observations, ask questions, plan investigations, gather and interpret information, propose explanations, and communicate findings and ideas" (p. 53). These skills build from early cognitive and social abilities, and are foundational for children's formal schooling in science and for their problem solving abilities more generally. To further understand preschooler's science inquiry, the current study explores children's ability to generate solutions to science-related problems, and how this ability relates to other aspects of cognitive development, namely, the child's tendency to ask questions, and the use of science-based ideas during problem solving.

Problem solving, which is central to engineering, has several components that include having a goal, facing obstacles to achieving it, using one or more strategies to solve the problem, applying relevant knowledge and social resources as needed, and evaluating the outcome (DeLoache, Miller, & Pierroutsakos, 1998). Successful problem solving relies on executive functioning (EF) skills (e.g., working memory, inhibitory control, cognitive flexibility), which are important for regulating goal-directed behavior (Zelazo, 2015). A well-studied example of a problem-solving task linked to EF is the Tower of Hanoi (Welsh & Pennington, 1988; Welsh & Huizinga, 2005). In this task, the participant moves rings between pegs according to a set of rules to attain a defined end state, with all rings stacked in order on a predetermined peg. The clearly defined solution and the existence of optimal strategies allows researchers to manipulate task difficulty and to quantify performance. However, the task is limited in terms of allowing the participant to generate creative and diverse ways to solve a problem. The lack of ecological validity also constrains the task's relevance

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for understanding children's problem solving skills in real-world contexts. New tasks that use more meaningful objects and problem scenarios, and that allow for a variety of plausible solutions, would better capture children's ability to apply educationally relevant concepts to generate effective solutions. The current study aims to examine emerging STEM skills in this way, by focusing on problems that relate to real-world scientific phenomena (e.g., material properties, changes in state, biological concepts) and that have multiple possible solutions.

Our approach to studying early STEM skills involved developing scenarios that reflect the kinds of science content preschool-age children are likely to be introduced to in their classroom experiences. We refer, in our analysis, to physical and life science concepts (or, knowledge) from the California Department of Education's (2012) description of foundational science skills and developmentally appropriate core ideas and concepts for preschoolers at 48- and 60-months of age (p. 50–51; See Table 2). By examining the solutions children generate to hypothetical but realistic scenarios, we are able to tap into their science inquiry skills in an educationally relevant way. To illustrate, imagine a scenario in which a child is presented with a picture of two similar bags, each of which is tied shut, with one containing rocks and the other pillows. How might the child figure out which bag contains pillows, and which bag contains rocks, without opening them? To solve the problem, children might relate their knowledge about the relative weight of pillows and rocks with their understanding of various ways to determine weight (e.g., by lifting) to generate a solution that leverages this knowledge (e.g., lift each bag and deduce that the heavier bag contains rocks). Thus, children could pull from their knowledge base about natural and manmade objects, and imagine how to relate them to each other to reach the goal outlined in the problem.

Effectively solving such problems requires a representational, or symbolic, level of reasoning, that is, mental operations with symbols and language (Bruner, 1964; Karpov, 2003). In line with Bruner's (1964) description of developmental progress, Karpov (2003) describes symbolic problem solving as distinct from problems that can be solved through the manipulation of objects (visual-motor problem solving) or using pictured information (visual-imagery problem solving). The child must cognitively process ideas not present in the immediate environment, and "explore" them in a representational format. To do so, children's representational knowledge must be integrated and organized such that it can be applied productively to the problems (Fischer & Bidell, 2006). To use knowledge flexibly and creatively, the child must not only have conscious access to it (e.g., knowing that rocks are heavy), but that knowledge must also be coded linguistically and linked to related knowledge (Karmiloff-Smith, 1994). Thus, a child may have some science-relevant knowledge but may not yet be able to integrate and verbalize it in the context of problem-solving to generate a reasonable solution.

Problem solving in a decontextualized format, such as a story prompt about two bags, draws on multiple underlying cognitive processes, with a central one being language. Flexibility in the use and relation of words, such as *heavy*, *soft*, and *weight*, may facilitate the child's ability to make conceptual connections needed to solve a problem. Thus, emerging language skills in the early years are likely an important contributor, in general, to the child's ability to solve problems that extend beyond the here and now. In a recent longitudinal analysis of EF development in preschool, Nelson et al. (2016) highlighted the significance of *foundational cognitive abilities* (e.g., language, visual perception, motor skill). Such abilities are required for simply understanding and responding to any task, including those that aim to assess specific executive skills, such as using numbers in a working memory task. Earlier in the preschool period (3;0 and 3;9), variation in performance on executive tasks was primarily explained by variation in these foundational abilities; at slightly older ages (4;6 and 5;3), EF performance was explained by two related factors, reflecting foundational cognitive abilities and a specific EF component that regulates them (Nelson et al., 2016). These findings suggest that foundational cognitive skills, such as receptive language, should be accounted for in interpreting variation in problem solving performance across the preschool period, and that their role may shift around age four.[1]

Successfully solving problems related to science clearly depends on foundational cognitive skills, especially language, but these foundational skills do not explain problem-solving in science entirely. Acquiring knowledge to use for problem solving in science, and in other domains, requires both the construction and elaboration of conceptual knowledge by the child, and cultural learning processes (Karmiloff-Smith, 1994; Legare & Harris, 2016; Peterson & French, 2008). Children have access to intuitive knowledge, insights gained through active exploration, and information from social sources. In the social realm, asking questions is a strategy available to young children, perhaps universally, as a key mechanism of cultural learning and information seeking (Chouinard, 2007; Frazier, Gelman, & Wellman, 2009; Legare & Harris, 2016). Children can ask questions to resolve disequilibrium brought about by difficulties relating an experience to existing understanding (Chouinard, 2007). When children ask causal questions, parents have an opportunity to provide explanatory responses (Callanan & Oakes, 1992; Callanan & Jipson,2001).

Question-asking is an information-seeking behavior that undergoes developmental change during the preschool period (Callanan & Oakes, 1992; Chouinard, 2007; Frazier et al., 2009; Mills, Legare, Grant, & Landrum, 2011; Mills, Legare, Bills, & Mejias, 2010; Tizard, Hughes, Carmichael, & Pinkerton, 1983). During this period, children's information-seeking questions become more effective for problem solving; children increasingly identify when questioning may be useful to fill knowledge gaps, to whom a question should be directed, what to ask, and when further questioning is needed to gather sufficient explanatory information (e.g., Aguiar, Stoess, & Taylor, 2012; Mills et al., 2010; Mills & Landrum, 2014). Theory of Mind has been proposed as a source of individual differences in the effectiveness of children's questions, as it would facilitate the identification of a knowledgeable person to whom a question should be addressed (Mills & Landrum, 2014). Contextual factors also contribute to children's persistence in asking questions, such as the extent to which they receive informative responses (Chouinard, 2007; Frazier et al., 2009), and the extent to which an adult encourages and responds positively to children's questioning (Zimmerman & Pike, 1972).

In addition to normative development in the emergence and effectiveness of children's questions, individual differences in how readily children ask questions (i.e., their inquisitiveness) may be of particular significance in the context of early STEM learning. However, very little is known about individual differences in children's tendency to ask questions (i.e., their inquisitiveness) and whether any such differences are consequential for learning or problem solving. In their review of the concept of scientific curiosity, Jirout and Klahr (2012) proposed a definition of curiosity related to, but distinct from, the tendency to ask questions. Namely, curiosity is "the threshold of desired uncertainty in the environment which leads to exploratory behavior" (Jirout & Klahr, 2012, p. 150). The tendency to seek information by asking questions is one way in which exploratory behavior can manifest (Jirout & Klahr, 2012). Jirout (2011) experimentally examined curiosity and question-asking as distinct constructs, and found them to be positively associated

[1] While language may be construed as a foundational *cognitive* skill, we do not presume that language is detached from the child's motor action. Instead, in line with Glenberg and Kaschak's (2005) Indexical Hypothesis, knowledge may ultimately be action-based and embodied, such that the child's use of language reflects the mapping of words to real objects and the consideration of object affordances (i.e., how the child can interact with objects) that "mesh" with each other and with action-based goals (p. 16). Thus, a child might recognize that cutting a hole in the bag would be a feasible action, and one that meshes with the goal of observing the bag's contents. While the specific nature of the child's language processing is outside of our current focus, we argue that an assessment of the child's receptive vocabulary skill is a reasonable index of the child's command over words and concepts that could be applied to each problem-solving scenario. We thank an anonymous reviewer for bringing our attention to the Indexical Hypothesis.