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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

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[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.

Table 1
Summary of Problem Scenarios and Effective Solutions Generated by Study Subjects.

Problem Scenario	Effective solutions	% of subjects with 1+ effective solution (N = 24)
Ice: A strawberry is stuck frozen in an ice cube. What are ways to get the strawberry out?	Break or cut the ice cube Melt the ice cube (e.g., sun, microwave) Idiosyncratic fantasy: use imaginary tool (blaster)[a] Idiosyncratic fantasy: Giant puts ice on a fireplace[a]	95.8%
Bucket: A bucket filled with water is too heavy for a person to lift. What are ways to get some water to flowers that need it?	Use a smaller/different container to move some water Use an effective tool/machine/vehicle to lift the bucket (e.g., a crane) Move the bucket without lifting (push, drag) People work together to lift the bucket Fantasy: A giant lifts the bucket	75.0%
Key: A key has fallen into a lake; What are ways to get the key back up, out of the water?	A person swims or dives down Use an effective tool/machine/vehicle (e.g., net, submarine) Fantasy: Use an imaginary animal (e.g., animal is a “friend”)	75.0%
Ball: A ball is stuck in a bottle; What are ways to get the ball out?	Break or cut the bottle Take the air out of the ball[a] Idiosyncratic fantasy: A magic boy to get it out who knows a spell[a]	58.3%
Egg: Two girls found an egg. One girl thinks it is a duck egg, and the other, a goose egg. How can they find out whether it is a duck or goose egg?	Wait/watch it hatch Look at its shape[a] Wait for its mother/father to come Crack it open[b]	56.5%
Bags: Two bags are tied shut; What are ways to find out which one has pillows inside and which one has rocks inside, without opening them?	Cut a hole in the bag Lift or shake the bags Feel the bags Drop something on the bags[a]	37.5%
Seeds: A farmer has dropped broccoli and carrot seeds, which are now mixed up on the ground; What are ways to find out which ones are broccoli seeds and which are carrot seeds?	Plant them (see what grows, see how the plants look) Know which one is which, based on memory[a] Look at the seed packet[a]	20.8%

[a] Response was made by one child.
[b] Although opening the egg would jeopardize the health of the animal, for the purpose of identifying the species, such responses were considered effective.

with each other; highly curious children (i.e., those who preferred more uncertainty in an experimental task) tended to ask more questions about a short video (e.g., about bees) than low-curious children. Thus, question-asking may be construed as a verbal and social exploratory behavior, generated by curiosity, or, an underlying eagerness to resolve ambiguities in experiences. Additional research is needed to understand whether inquisitiveness is consequential for understanding individual differences in meaningful aspects of scientific inquiry, including the child's ability to problem solve, which relies on one's readiness to search for possible solutions in ambiguous contexts. Individual differences may be evident in the number of problems for which a child can generate a solution (problem solving accuracy), and in the number of effective solutions that they imagine and generate for any one problem (problem solving fluency); the current study examines problem solving using both of these conceptualizations of performance.

1.1. The current study

The current study seeks to advance our understanding of the preschool child's approach to novel, science-relevant problems, and the extent to which variation in the tendency toward inquisitiveness relates to problem solving effectiveness. In a newly designed task, a set of seven problems, depicted in drawings, were presented to four- to five-year old children. Each problem involved components that would typically be familiar to young children. For example, the *Bags* item, as in the example above, depicted two bags tied shut; children were asked to generate ways to find out which one held rocks and which one held pillows, without opening the bags. Each problem required children to think beyond the pictured items, using mental operations with symbols and language (Bruner, 1964; Karpov, 2003; Magid, Sheskin, & Schulz, 2015), and drawing on their knowledge of scientific concepts and tools. A second task prompted children to provide any “questions or ideas” in response to three photographs of unusual, but realistic, objects (e.g., a very large apple near a smaller apple). Variation in the tendency to ask questions about the pictures was expected to reflect meaningful differences in an orientation towards inquiry, or inquisitiveness.

Two main research questions were addressed in this study:

1. To what extent do preschoolers' effective problem-solving responses reflect the use of science-relevant concepts, as outlined in the California Department of Education (2012) foundations? We describe the qualities of children's responses to this task, to contextualize this analysis.
2. Are individual differences in inquisitiveness and the use of science-relevant concepts in problem solving positively related to the generation of problem solutions, even after accounting for differences in language skill and age?

2. Method

2.1. Sample

A total of 24 preschoolers (54% girls), with a mean age of 4 years 11 months (Range: 4;2–5;8) from preschools and child care centers in a large U.S. city participated in the study, with parental consent. Each of the sites served populations that were ethnically and linguistically

Table 2
Description of Science-Relevant Categories and Sample Effective and Ineffective Responses.

	Foundation, at around 48 months of age (California Department of Education, 2012)	Sample Responses
Properties and Characteristics of Nonliving Objects and Materials	Compare and contrast objects and events and begin to describe similarities and differences. Observe, investigate, and identify the characteristics and physical properties of objects and of solid and nonsolid materials (size, weight, shape, color, texture, and sound).	Effective: Bags: "Lifting them to see which one's heavy." Ineffective: Seeds: "To sort them out."
Changes in Nonliving Objects and Materials	Demonstrate awareness that objects and materials can change; explore and describe changes in objects and materials (rearrangement of parts; change in color, shape, texture, temperature).	Effective: Bucket: "Grab a small bucket, and put the water and give it to the flowers and pour it." Ball: "Cut the bottle open" Ice Cube: "Put the ice cube in the sun." Ineffective: Key: "Buy a ship that has a leak inside."
Properties and Characteristics of Living Things	Identify characteristics of a variety of animals and plants, including appearance (inside and outside) and begin to categorize them. Identify the habitats of people and familiar animals and plants in the environment and begin to realize that living things have habitats in different environments.	Effective: Eggs: "What color it is." Key: "Dive in and grab it." Ineffective: Key: "The fish have to get over there and then go up."
Changes in Living Things	Observe and explore growth and changes in humans, animals, and plants and demonstrate an understanding that living things change over time in size and in other capacities as they grow. Recognize that animals and plants require care and begin to associate feeding and watering with the growth of humans, animals, and plants.	Effective: Seeds: "We could wait until they grow." Seeds: "We could plant water on them and the sun came and we can find out all those." Egg: "They could wait until it hatches" Ineffective: Flower: "Get some rain."

diverse, including families from primarily European, East Asian, South-East Asian, and Central/South American backgrounds. While some children spoke languages other than, or in addition to, English at home, all children received preschool instruction in English. Economically, family populations typically served by the programs ranged from the lower-middle to upper-income levels.

2.2. Procedure

A researcher and the child sat next to each other at a child-sized table within the preschool facility. Once the child gave their assent, the researcher and child engaged in structured tasks, each involving discussion of pictures or photos, described below. Responses to the Picture Problem Solving and Questions and Ideas tasks were video-taped for subsequent scoring.

2.3. Measures

2.3.1. Peabody-picture vocabulary test-fourth edition (PPVT; Dunn & Dunn, 2007)

The PPVT is a widely used language assessment, which provides valid and reliable receptive vocabulary scores, normed for children aged 2.5 years through adults. Participants' English vocabulary skills were tested by prompting them to identify one of four pictures depicting a given word. Standardized scores, based on the child's age in months, were used as a measure of language development.

2.3.2. Picture problem solving task

The Picture Problem Solving Task is a new task designed to test children's ability to think through novel problem solving contexts. Children viewed black-and-white line drawings, one at a time, depicting real-world objects in problematic scenarios (e.g., two similar bags, tied shut). A practice item and six test items were developed for this assessment, and a seventh was adapted from an open-ended item from the Science Learning Assessment for kindergarteners (Samarapungavan, Mantzicopoulos, Patrick, & French, 2009). The first column of Table 1 summarizes each problem scenario. The practice item, which was presented first, depicted a cat stranded on a tree branch. The experimenter provided three scripted ways to solve the problem ("One idea is to climb up a ladder to get it and bring it down. Or, maybe we can pretend that a big giant can come and get it down. Another idea is to pretend we can fly in a helicopter and reach it to get it down"). Children were randomly presented with items in one of three counterbalanced orders.[2] For each test picture, children were presented with a brief verbal description of the depicted problem, and were then asked for ways to solve the problem. When children provided very brief responses (e.g., a tool) they were asked to tell more about the response. After each of the child's responses, the experimenter asked whether the child had additional ways to solve the problem, until the child no longer gave responses (e.g., said, "I don't know," "That's all the ways"), gave repetitive or off-task answers, shrugged and/or remained silent.

Responses were transcribed from video for scoring. Upon review of children's responses, we found an unexpected pattern of responses for three items that each involved identifying objects, namely, the Bags, Seeds, and Egg items. In each case, rather than providing a strategy for solving the problem of how to distinguish the objects, children sometimes responded with a hypothesis, or guess, about the identity of the depicted objects (e.g., guessing that one bag held rocks and the other, pillows). Such responses are described later in the results section. Problem solving strategies were coded in four ways, described next. A second coder scored 25% of cases to assess reliability. Kappa values for each of the four coded aspects, reported below, fell in the range of .61 to .80, which is considered *substantial* agreement (Landis & Koch, 1977).

2.3.2.1. Problem solving agents and means. Responses were categorized based on the type of agent that would solve the problem ("who" kappa = .77), and the general means by which the problem would be solved ("how" kappa = .80). Types of agents included an explicit or implicit "you," another realistic person, a realistic animal, or an imaginary creature. Responses that relied on a "giant" to solve the problem were coded as such, to tease apart answers that spontaneously involved fantasy, from this one that had been cued in the practice item. The "how" code captured the general means by which the agent solved the problem. Categories included the use of realistic physical means (actions, tools, and/or vehicles) to solve the problem, a force of nature (e.g., wind, fire), a mental state (e.g., remembering), and asking for help without elaborating on how the agent would solve the problem. Imaginary means included the use of a pretend tool or action (e.g., a magic spell). An additional code was used when the child's response

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[2] The Egg item, adapted from (2009) Science Learning Assessment for kindergarteners, required color to be added to its line drawing. This item was administered as part of (2009) subscale measuring Understanding of Scientific Inquiry Processes, which is not included in this report.

identified an agent, but did not indicate "how" the agent would solve the problem (e.g., "a fish" offered as a way to retrieve the key in the lake).

2.3.2.2. Problem solving effectiveness. A coding scheme was developed to identify whether or not each of the child's responses was an effective problem solution (kappa = .80). For each item, effective solutions offered by the children were identified and categorized (Table 1). Children's responses were coded according to whether they reflected (fully or partially) one of the effective solutions (e.g., Ice: "Break it with a hammer" and "hammering"). A child could have multiple responses from the same category when they included distinct solutions, such as the use of different tools or actions to move, break, or melt an object. An additional code captured idiosyncratic responses that would be effective in a make-believe context (e.g., Ball: A magic boy to get it out that knows a spell). Another code captured disallowed strategies, based on the problem specification (e.g., Bags: opening the bags, Bucket: someone strong lifts the bucket). A final code captured ineffective strategies, which would most likely not work to solve the problem. These included the use of ineffective tools or actions (e.g., Ball: put air in it; Key: A rope). Two scores were calculated to reflect problem-solving performance. An *item score* reflected the percent of items for which the child generated at least one effective solution, either realistic or imaginary. A *fluency* score captured the average number of effective strategies that the child generated across items. While both scores reflect problem-solving performance, *fluency* captured a broader range of possible scores, by going beyond dichotomous scoring of items as correct or incorrect. Responding *fluently*, that is, with multiple solutions, may tap into additional STEM-relevant cognitive skills and traits, such as divergent thinking, imaginativeness in devising solutions, and openness to approaching problems (Wallace & Russ, 2015).

2.3.2.3. Use of science-relevant concepts. A final aspect of the scoring process was informed by the California Department of Education's (2012) Preschool Learning Foundations in Science. Responses could reflect an understanding of 1) properties of non-living things, 2) properties of living things, 3) changes in non-living things or 4) changes in living things. See Table 2 for examples. Additional codes, based on patterns that emerged in children's responses, were developed to categorize children's responses when they did not contain sufficient information related to science. These identified responses that included 1) only a tool or vehicle (e.g., "a hammer"), 2) only a simple hand action ("pour it") without further explanation, 3) social or mental state processes, such as "asking" and "remembering," and 4) a control category for responses that did not include either science-relevant concepts, tools, actions, or social/mental state terms. Each response was coded into one mutually exclusive category (kappa = .68).

2.3.3. Questions and ideas task

The *Questions and Ideas Task* was newly designed to assess individual differences in children's questions and comments about physical objects and phenomena. Children were shown three photographs, one at a time, each depicting physical objects with unusual characteristics. The first photo depicted two apples that varied noticeably in size. The second photo presented a puddle with leaves in it, and with a reflection of clouds and trees. The third presented a white faux fur material with a purple light shining through from underneath it. Upon introducing the task, children were asked "what questions or ideas" they had about each image. To best elicit children's inquisitiveness and spontaneous responses, no sample answers were modeled for the children. When children paused, the experimenter asked whether the child had additional questions or ideas about the picture until the child no longer offered responses (e.g., said, "no" "I don't know," shrugged and/or remained silent).

Children's responses were transcribed from video. Examples included, "Why are they [the apples] different sizes?" "Is there a tree in the water" and "Is it fur?" Given that only five children generated any questions, the presence of any questions in children's responses was used as a measure of *inquisitiveness*. The limitations of this measure are addressed in the discussion section.

3. Results

3.1. Describing children's problem solving responses

This section describes children's responses to the problem-solving task, according to the scoring procedures detailed above. First, patterns in the overall set of strategies children generated are described. Then, the subset of responses in which children hypothesized, or guessed, about object identity are discussed.

3.1.1. Problem solving agents and means

The majority of children's strategies relied upon an explicit or implicit "you" (85.2%) referring to a person in general (e.g., "You could…"). Smaller percentages referred explicitly to another realistic person (6.7%), such as a parent, or someone strong. An additional 2.8% involved real-world animals (e.g., dog, seal, fish) as the actor to retrieve the Key in the lake. In total, 3.9% of responses referred to a "giant," and 1.4% involved any other kind of imaginary agent (e.g., seahorse friend).

Similarly, a large majority of responses (81.3%) reflected the use of realistic actions, tools, and/or vehicles to solve the problem. Some responses referred to mental actions (7.4%, e.g., remember). In other cases, children's responses referred to a force of nature (6.3%, e.g., the sun). A small percentage referred to a pretend tool or action (1.8%, e.g., magic spell). Additionally, 1.8% of responses referred to asking for help without elaborating on how the agent would solve the problem (e.g., ask an adult), and 1.4% of strategies did not indicate "how" the problem would be solved, because only an agent was mentioned (e.g., a giant); these two response types were scored as ineffective, below.

Collapsing across agents and means, a total of 5.6% of responses included a fantasy element. Despite its infrequency, fantasy was used at least once by half of the children (50%); item analysis revealed that an imaginative response was most frequently used in the Bucket item, in which children identified having a giant lift the heavy bucket of water. While the use of this agent had been primed by the practice item, having a Giant lift the bucket nevertheless reflected an appropriate response, which would be effective in an imaginative context.

3.1.2. Problemsolving effectiveness

Children's problem solving scores are described next, using two calculations for performance.

Item scores on the Problem Solving tasks were calculated based on the percent of items for which the child provided at least one effective solution. With one exception, all of the children were presented each item (one child was not presented with the Egg item due to refusal to complete testing). On average, children generated at least one effective solution to 59.7% of the items (SD = 23.1%, Range = 14–100%, 1–7 items). Regarding *fluency*, overall, children generated an average of 1.12 effective solutions for each item (*SD* = .64; Range: .29–2.57). No significant order effects were detected for either measure of problem solving effectiveness.

Given that each participant generated at least one effective solution to at least one item, floor effects were not indicated. At the same time, only four children generated an effective solution to all seven of the items, suggesting no ceiling effects. The most difficult item was the Seeds item, as only 20.8% of children provided at least one effective strategy. In contrast, 95.8% (23 of 24 children) provided at least one effective strategy for the Ice item. Across all strategies generated, 65.8% were effective; of these 92.0% were realistic, while 8.0% involved an imaginary agent or means for solving the problem.

3.1.3. Use of science-relevant concepts

Next, we describe the general type of science-relevant knowledge evident within children's responses. Note that the child's problem solving strategy could either be effective or ineffective, even if it contained science-relevant information. See Table 2 for examples. Across the sample, a total of 6% of responses referred to observing or comparing properties of non-living things, and 32% reflected changes in non-living things. In total, 16% of responses referred to observing or comparing properties of living thing, and 4% reflected changes in living things. In total, 58% of the overall set of responses reflected science-relevant content. On average, at the individual level, 56.6% of children's total strategies included some *science-relevance* (Range: 0–100%; SD = 24.8).

3.1.4. Children's use of identity-responses

For three items that involved identifying objects, children often made a guess as to the object's identity, rather than providing a problem solving strategy. Such responses were not included as either effective or ineffective strategies for problem solving. These items included Bags, Seeds, and Egg. For the Seeds item, the drawing presented long oval-shaped seeds and round seeds; some children pointed to one type of seed and indicated that it was either a carrot seed or broccoli seed. In the Bags item, children sometimes indicated that one bag held rocks and the other pillows. For the Egg item, children either guessed that it was a duck or goose egg, or, in three cases, another type of animal egg.

These types of responses were frequent, overall, with the majority of children (79%) providing an identity-response to at least one of these three problem scenarios. Just under half of this subset of children (46%) included a description with their choice (e.g., the "big" bag has rocks; the "long" seeds are carrot seeds). However, any such explanation was problematic, as there was not sufficient information in the stimuli to support a given conclusion. For example, given the variable size of "rocks," from pebbles to boulders, any perceived difference in the relative bag size was inconsequential as a basis for reasoning. The potential significance of these guessing responses is discussed in the conclusion section.

3.2. Individual differences in problem solving

To address our second research question, we examined variability in children's scores on the problem-solving task, controlling for age and vocabulary (PPVT). For the sample, PPVT standard scores averaged 112.2 (n = 23, SD = 12.5), with one score missing due to a child's refusal to complete the task. Bivariate Pearson correlations (two-tailed) were used to examine the linear relationships between child age, gender, language development (PPVT), *inquisitiveness* (asked any questions = 1), *science-relevance* (percent of child's responses that were relevant to science), *item score*, and *fluency* (Table 3). Age was positively and significantly associated with *item score* and with *fluency* of effective strategies, but was unrelated to the percent of *science-relevant* responses. Vocabulary was unrelated to *item score* and *fluency*. However, *inquisitiveness* and *science-relevance* were each positively associated with *item score* and *fluency*. A negative correlation was found between *inquisitiveness* and receptive vocabulary, reflecting the distinction between these aspects of language use and vocabulary comprehension. Child gender was associated with *fluency* at trend levels, and was thus included in subsequent analyses.

Next, we examined the effects of the key predictors on both measures of problem solving performance simultaneously. For this analysis, *science-relevance* was converted into a dummy variable (high, low) using a median split at 56.6%. We conducted a 2-way MANCOVA analysis, with problem solving (*item score, fluency*) as the dependent variable, *inquisitiveness* (any questions, no questions) and *science-relevance* (high, low) as independent factors, and receptive vocabulary, age, and gender as covariates. The analysis revealed a significant main effect of *inquisitiveness*, based on Pillai's trace (V = 0.58, $F(2, 15) = 10.23$, $p = .002$, partial $\eta^2 = .58$). Follow-up ANCOVA analyses revealed that the positive effect of *inquisitiveness* was significant for both *item score*, $F(1, 16) = 10.04$, $p = .006$ partial $\eta^2 = .39$, and *fluency* $F(1, 16) = 20.41$, $p < .001$, partial $\eta^2 = .56$. However, neither the main effect of *science-relevance*, nor its interaction with *inquisitiveness*, were significant predictors (*ps* > .10) in the multivariate (MANCOVA) or univariate (ANCOVA) analyses. Thus, above and beyond the effects of age, vocabulary, and gender, the child's tendency to ask questions was associated with stronger performance on the problem solving task. While the effect of science-relevance was in the hypothesized direction, it was non-significant once vocabulary, age, and gender were controlled.

4. Discussion

Although this study is exploratory and the sample size is small, our data suggest that when preschoolers are asked to consider imagined problem scenarios, they can apply what they know about the physical and biological world to generate plausible solutions. Moreover, the majority of children's responses included realistic components. However, children occasionally used imaginative elements in their problem solutions, consistent with, and occasionally extending beyond, the sample item used to introduce the task. We also found considerable variability in four- and five-year-olds' generation of effective problem solutions; some children gave an effective solution to each of the seven items, while others did so for only one or two items. Some of this variability may be explained by age: On average, older preschoolers generated solutions to more of the items, in comparison to the younger children. These patterns suggest that this novel task, which was designed to include components familiar to young children, can be useful for detecting developmental change and individual differences in emerging STEM skills even before school entry.

The descriptive analysis of children's problem solutions indicated that over half of the children's responses demonstrated some scientific concepts and knowledge considered foundational for preschoolers (California Department of Education, 2012). Although science-relevance, measured in this way, was positively associated with problem solving scores, it was not predictive once the effects of age, receptive vocabulary, and gender were controlled. In contrast, children's inquisitiveness, as measured by their tendency to ask questions about photos in an open-ended task, was a significant predictor of their problem solving score as well as the fluency with which they generated

Table 3
Bivariate Correlations.

	Age	Gender	PPVT	Inquisitiveness	Science Relevance	Item Score
Gender	.325					
PPVT	−.144	−.199				
Inquisitiveness	.073	.060	$-.485^{*}$			
Science Relevance	.142	−.085	.192	.231		
Item score	$.547^{**}$	.246	−.043	$.525^{**}$	$.414^{*}$	
Fluency	$.414^{*}$	$.353^{\sim}$	−.057	$.657^{***}$	$.372^{\sim}$	$.793^{***}$

$^{\sim}p < .10$; $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

multiple solutions to the problems, beyond the effects of covariates. Together, these findings suggest that individual differences in science problem solving are evident prior to school entry, and are not reducible to differences in general language development. Thus, in line with Nelson et al.' (2016) findings, foundational cognitive abilities provide support, but do not fully account, for four- to five- year old's STEM-related problem solving performance.

Children's success on the problem-solving task likely depended, in part, on their understanding of the causal relations underlying each problem. In a recent series of experiments, Magid et al. (2015) found that preschoolers could effectively evaluate competing problem solutions based on an inferred "fit between the form of a problem and a solution" (p. 109). Children were more likely to infer that a remote controller with a discrete on/off functionality was more likely to control the discrete movements of an icon on a video screen, whereas a controller with a continuous movement would more likely control an icon that moved across the screen in a continuous path. The problem solver might thus constrain their "hypothesis space" to include only those solutions that match the form of the problem. In the current study, this type of mechanism may be in play, that is, children may have detected abstract relations in these problems and used them to guide strategy selection. For example, in the Key problem, children generated animals that might retrieve the key, but only those that could conceivably swim down into the water and back up. These problem solutions, though not effective, do match the underlying goal of moving down and then up through the water.

Children who raised questions in response to novel photos generated more problem solutions, overall, compared to children who did not raise questions. Why might these aspects of science-inquiry be associated with each other? Although the two tasks are quite distinct on the surface, they each require an underlying ability to generate ideas. In the current study, the relationship we detected between inquisitiveness and problem solving may be explained, in part, by their shared requirement of generating new ideas relevant to the tasks. Imagination may play a critical role in the child's ability to process means-end relations embedded in a problem solving task, but also in generating new, divergent ideas about possible and plausible problem solutions (Magid et al., 2015; Mullineaux & Dilalla, 2009). Links between fantasy play and executive functions (i.e., working memory, attention shifting: Pierucci, O'Brien, McInnis, Gilpin, & Barber, 2014; Thibodeau, Gilpin, Brown, & Meyer, 2016) suggest that future research on the interplay of these factors may prove productive for understanding the development of inquiry skills in the early years. Practitioners would also benefit from additional research on the extent to which early inquiry is shaped through socialization and experiences in and out of the classroom, such as the practice of encouraging children to ask questions in response to observations of the physical environment and to information pictured in books.

Children's performance on this task may be reduced due to the reliance of strategic and scientific thinking on higher order cognitive skills, such as in coordinating theory and evidence under conscious control (Kuhn & Pearsall, 2000; Kuhn, 2011). Research by Nayfeld, Fuccillo, and Greenfield (2013) found that, among preschoolers in Head Start, executive functioning skills predicted gains, from fall to spring, in school readiness levels in science. These findings are consistent with the model that children must not only acquire relevant science knowledge, but also be able to regulate their thinking, to engage effectively in science-related reasoning. These issues are relevant to early Engineering, which, by definition, involves application of ideas to solve problems in both convergent and divergent ways. A child may have an understanding of the key concepts involved in a problem, but require support in accessing or coordinating that knowledge in the service of problem solving. In early education settings, a teacher may probe children's understanding of foundational science-relevant concepts in the context of problems that arise in the classroom (e.g., different ways to move liquid from a large container). Encouraging discussion and activity around real or imagined problems may make children's understanding of underlying concepts accessible to the teacher and to peers, and provide teachers with opportunities to help children strengthen connections between concepts.

Although each item prompted the child for problem solving strategies, some responses reflected a conclusion the child drew (or a guess) based on the limited information provided in the picture and prompt. This reasoning appeared to be based on perceptual similarity and rules such as similarities between carrots and the "long" seeds depicted in the picture, or the rule that rocks are "big." It is likely that, in the absence of conceptual knowledge relating seed shape to identity, children used analogical reasoning about surface features to reach a conclusion (Gelman & Coley, 1990; Goswami, 2011). In this case, children may conclude that the long seeds are associated with carrots because the perceptual similarity is too compelling to ignore, and/or because they do not yet know that the shape of a seed is inconsequential to the shape of the vegetable that grows from it. Again, variability in executive function, such as in the ability to inhibit responses based only on perceptual similarity (Goswami, 2011), may partially explain constraints in children's effective reasoning within the task.

Finally, we found that children's solutions were sometimes social in nature; children sometimes referred to other people, such as a parent or one's friends, for help with tasks. Such responses were qualitatively distinct from the more common approach of using tools and actions, independently, to solve the problem. In reality, collaboration is often useful for problem solving, and learning through cooperation and collaboration is a highly valued element of the school science curriculum (National Research Council, 2007). In this study, social responses that involved other agents varied in their level of elaboration and effectiveness (e.g., "ask an adult" versus having more than one person move the heavy bucket). Future studies might explore developmental change in the specificity and appropriateness of children's support-seeking in problem solving contexts. Existing developmental work has elucidated aspects of children's help-seeking tendencies. For example, in an experimental task, Cluver, Heyman, and Carver (2013) found that 2-year-olds selectively seek help with object retrieval problems from an adult who had been identified as a "good helper" by previously retrieving objects from novel props, compared to an adult who had demonstrated being a "bad helper" by failing to retrieve objects. Further, studies on question development suggest developmental change in the preschool period, in seeking information from relevant experts to fill knowledge gaps (e.g., Aguiar et al., 2012). Such developments in children's social approaches to problem solving hold both theoretical and practical significance for understanding young children's full repertoire of problem solving skills even before formal school entry. Additional developmental research with a STEM focus would yield new insight into children's independent and social approaches to engineering problem solutions, and how best to support children's efforts.

4.1. Limitations and areas for future research

While the descriptive and exploratory nature of this study generated new insights into preschoolers' real-world problem-solving skills, methodological limitations restrict the scope and interpretation of our findings. First, the sample size is small, which limits our statistical power and our ability to generalize our findings to a broad population. Important individual differences in problem solving may stem from differences in science content knowledge. The science-relevance of children's responses, in general, was positively but not significantly associated with generating effective solutions. However, it is possible that an effect could be detected with a larger sample and more statistical power. Further, variation in knowledge about concepts and tools more specific to each problem-solving context might be meaningfully associated with performance (e.g., about hatching eggs; about using a small container to move some liquid). Based on this study, we are not able to determine whether knowledge gaps, or a failure to integrate related pieces of knowledge, accounts for some of the difficulty children encountered (Fischer & Bidell, 2006; Karmiloff-Smith, 1994).

The current findings linking inquisitiveness to problem solving should be replicated using a task that elicits questions from children more readily. The small number of children who asked any questions precluded a more fine-grained analysis of variation in the number or types of questions posed by the child. Using a more robust measure of inquisitiveness that captures a broader range of variability in children's readiness to ask questions, and testing a larger sample of children, would help to confirm the link between preschoolers' inquisitiveness and science problem solving. As interest in preschool STEM expands, individual differences in inquisitiveness and problem solving, as well as sources of those differences (e.g., curiosity and imaginativeness; child temperament; parent science-related practices and beliefs), should be examined to elucidate developmental and socialization patterns in emerging science inquiry skills. Aspects of adult-child interaction may support the child's development of skills needed for science activities. Research on children's exploratory behavior suggests that variation among mothers' interactions with their child may partially account for differences in curiosity and object exploration (Endsley, Hutcherson, Garner, & Martin, 1979; Jirout & Klahr, 2012; Saxe & Stollak, 1971). Continued research on features of early learning environments is critical for illuminating early STEM learning and problem solving processes, and how to support them.

5. Conclusion

In early education settings, the significance of active exploration of physical objects in the environment is undeniable. Nonetheless, the intentional exploration of ideas, such as in the generation of hypothetical problem solutions, should also be considered as part of active exploration in preschool. The findings of this study suggest that preschoolers, as "little engineers," can use their emerging science content and reasoning skills to solve simple, hypothetical problems involving the physical and biological world. To apply this idea, early childhood educators should first recognize the science-relevance of many real-world experiences. The problem of how to move an object (e.g., a fallen spoon, a bug) from one part of the room to another could foster discussion of the use of real and imagined tools to pick up, push, roll, or fly the object to its new location (e.g., to the sink, to the yard). Activities that teachers intend to use to introduce science concepts might also be enhanced by viewing them as problems to solve. For example, teachers may already ask children to observe, plant, and care for one type of seed to learn about plant growth. As an extension, the class might then try to solve the problem of matching two types of seeds to the plants they each produce (Gelman, & Brenneman, 2004). To do so, children might compare, discuss, and document the characteristics of the known seed with those of a second type of seed before re-planting, giving children more opportunities to make predictions and build knowledge about plant growth.

Our findings suggest that problem solving is positively associated with children's tendency to ask questions. Though correlational, this finding is in line with the practice of encouraging children's spontaneous questions, and eliciting questions about science-relevant phenomena that interest children, based on images in books, as well as the natural environment. An orientation of inquisitiveness among children, and the process of imagining possibilities that extend beyond the child's immediate perception, have clear implications for early science inquiry and problem solving skills, and warrant further research with young children.

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