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Exploring Preschool Children's Science Content Knowledge

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Abstract

Research Findings—The purpose of this study was to describe children's science content knowledge and examine the early predictors of science content knowledge in a sample of 194 typically developing preschool children. Children's science content knowledge was assessed in the fall (Time 1) and spring (Time 2) of the preschool year. Results showed that children exhibited significant gains in science content knowledge over the course of the preschool year. Hierarchical linear modeling results indicated that the level of maternal education (i.e., holding at least a bachelor's degree) significantly predicted children's Time 1 science content knowledge. Children's cognitive, math, and language skills at Time 1 were all significant concurrent predictors of Time 1 science content knowledge. However, only Time 1 math skills significantly predicted residualized gains in science content knowledge (i.e., Time 2 scores with Time 1 scores as covariates).

Practice or Policy—Factors related to individual differences in young children's science content knowledge may be important for early childhood educators to consider in their efforts to provide more support to children who may need help with science learning.

U.S. students' science education and achievement is a pervasive concern in current education improvement efforts, as the majority of U.S. students are not proficient in science (Grigg, Lauko, & Brockway, 2006; National Center for Education Statistics, 2005). Thus, national panels and organizations have called for greater attention to the provision of high-quality science education (National Research Council, 2007). One viable solution for improving students' science achievement is to capitalize on preschool education, given that preschool science instruction has been theoretically and empirically associated with better development of scientific concepts, improved reading comprehension and causal reasoning, and increased interest in science (Eshach & Fried, 2005; French, 2004; Ginsburg &

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Golbeck, 2004; Kallery, 2004; Neuman, 1971; Watters, Diezmann, Grieshaber, & Davis, 2001).

The attention to preschool science education is supported by developmental theory and research suggesting that preschool-age children are biologically prepared and motivated to explore and learn about the world around them (Eshach & Fried, 2005; French, 2004; Gallenstein, 2003) and demonstrate strong cognitive competencies in the area of science inquiry (e.g., Kuhn & Pearsall, 2000). One important area of preschool science competency is understanding fundamental scientific concepts, referred to as *science content knowledge*. Specifically, science content knowledge encompasses “the breadth and depth of knowledge about facts, concepts, laws, and theories that describe, explain, and predict natural phenomena” (Collins, 1997, p. 304). Young children’s science content knowledge is of particular importance for comprehending more advanced scientific concepts and facilitating scientific thinking skills (Plummer & Krajcik, 2010) and is consistently associated with continued interest in science careers (National Research Council, 2007). However, to our knowledge, there are few data-based investigations specifically focused on what science content knowledge preschool children acquire or which child-specific factors are associated with preschoolers’ science content knowledge. Therefore, in the present study, we characterized preschool children’s science content knowledge, as measured across three important science domains (the human body, senses and sensory attributes, and causal reasoning), and examined the extent to which family socioeconomic status (SES); gender; and cognitive, math, and language skills were associated with science content knowledge.

THEORETICAL FRAMEWORK

Recent developmental theories and studies have shown that young children are well prepared for science learning and are capable of learning basic science concepts. Post-Piagetian conceptions of development (e.g., Gelman, 1979, 1990) lend strong theoretical support to young children’s capabilities for science learning. Post-Piagetians argue that Piaget underestimated children’s abilities, particularly those of preschool children in the preoperational stage. According to Piaget, young children in the preoperational stage can use and form symbols (i.e., words, signs, pictures) to represent their thinking but are not capable of abstract thoughts and do not have the cognitive ability to reason, make inferences, or develop explanations. The Piagetian perspective argues that young children have limited abilities to learn science given that science involves “some combination of abstract principles and controlled experimentation with multiple variables” (French & Woodring, 2012, p. 9). However, in light of post-Piagetian conceptions of development, preschool-age children have some “domain-specific organizing structures that direct attention to the data that bear on the concepts and facts relevant to a particular cognitive domain” (Gelman, 1990, p. 5). Because of this, young children can acquire rich domain-specific knowledge through experience. When they process rich domain-specific knowledge, young children can show advanced modes of reasoning in the specific domain, such as generating predictions and explaining the results of experiments (Inagaki, 1992). Thus, some researchers suggest that science knowledge acquisition is rapid for children from the very early years (e.g., Gelman, 1990; Inagaki, 1992). In fact, some studies have supported these theoretical assumptions in suggesting that science learning begins to emerge from infancy and

continues to develop with age, with young children having ideas, beliefs, and explanations of many science concepts, such as solidity, gravity, and the human body (Havu-Nuutinen, 2005; Inagaki & Hatano, 1988; Mazens & Lautrey, 2003; Spelke, 1991).

CHILDREN'S SCIENCE CONTENT KNOWLEDGE

Given that preschool-age children are capable of learning scientific concepts, national and state learning standards highlight preschool science as a key area for learning and outline the specific science content areas that young children are expected to master. From these standards, three broad content areas emerge for preschool science: life science, physical science, and earth/space science (Trundle & Saçkes, 2012). At the national level, the Head Start Outcomes Framework (Head Start Bureau, 2004) suggests that children are required to have knowledge of their bodies (life science) and the environment (earth science) and also develop growing awareness of ideas and language related to attributes of time and temperature (physical science). At the state level, 19 states (Arkansas, Connecticut, Florida, Georgia, Illinois, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, New Jersey, New Mexico, Ohio, Oklahoma, Rhode Island, Texas, Utah, Vermont) have standards specific to preschool science learning and emphasize one, two, or all three of the broad content areas. For example, state preschool standards in Ohio indicate that preschool children should master knowledge about weight, shape, size, color (physical science); learn concepts of living and nonliving things (life science); and learn about earth and space (earth/space science).

An alternative perspective departs somewhat from a general emphasis on life, physical, and earth/space science. Many have argued that these three science content areas are too broad to guide the science content knowledge that might be appropriate for preschool children (Conezio & French, 2002; French & Woodring, 2012). Such researchers suggest that science content for young children should be based on observable phenomena that the children can experience in their daily lives (French, 2004). For example, science concepts about color and light can be experienced by young children in the immediate environment. Such experiences can support children's deeper learning about these science concepts. In line with these views, some researchers have emphasized privileged domains of science knowledge such as the human body, color, seasons, and causal reasoning (French, 2004; Gelman, 1990) rather than focusing on distinct content domains such as life, physical, and earth/space science. The current study followed this particular perspective and investigated preschool children's science content knowledge as it pertained to understanding the human body, senses and sensory attributes, and causal reasoning.

THE DEVELOPMENT OF CHILDREN'S SCIENCE CONTENT KNOWLEDGE

From a developmental perspective and as aligned with the theoretical frameworks and early learning standards presented previously, young children's science content knowledge should increase across the early childhood years (French & Woodring, 2012). Some evidence supports this notion. For example, Greenfield and colleagues (2009) analyzed a large, ethnically diverse database of Head Start children's performance on a battery of school readiness measures. They used interval-level ability scores that were equated across all

school readiness domains. All of the domain scores were centered at the same value of 500. This study found that preschool children showed a significant improvement in overall readiness over the course of the academic year, but the gains in science (83.4: fall =444.9, spring =528.3) were lower than the gains in other readiness domains, such as reading (105.4: fall = 443.8, spring =549.2), math (100.4: fall =464.8, spring =565.2), and social and emotional development (104.4: fall =440, spring =544.4). French and Woodring (2012) argued that the lower gains in science were an artifact of the specific science measure used in the Greenfield et al. study, namely, the Galileo Scales for Head Start (Bergan et al., 2003). These scales constitute an indirect measure of children's science knowledge by asking teachers to respond "learned/not learned" for each item. A "learned" response, however, is determined by whether teachers have opportunities to observe the child under the right circumstances. For example, "how can a teacher know if a child can classify on the basis of whether something is a liquid or a solid if she has never had a reason to ask him to do so?" (French & Woodring, 2012, p. 22). Given the limited evidence for children's development of science content knowledge, more research is needed. Moreover, a better understanding of children's knowledge about scientific concepts may lead to the design of more effective curricula and instructional strategies (Saçkes, Flevares, & Trundle, 2010). The present study further examined children's science content knowledge gains across a preschool year using a direct measure of science content knowledge.

PREDICTORS OF SCIENCE CONTENT KNOWLEDGE

To understand preschool children's science learning, it is also important to identify potential predictors of science competency, because the identified factors could aid in determining which preschool children may struggle with learning science content knowledge and experience downstream science learning problems as they matriculate into elementary school and beyond. The current literature suggests that science achievement is associated with family SES, gender, cognitive ability, and math and language achievement, as discussed here.

Many research studies have found evidence suggesting that family SES is a powerful predictor of academic success: Generally speaking, the higher the SES of the child's family, the higher the child's academic achievement (e.g., McCall, 1981; Sirin, 2005; Whitehurst, 1997). For example, Sirin (2005) conducted a meta-analysis on the relations between SES and academic achievement and included 101,157 students (Grades K–12), 6,871 schools, and 128 school districts. This study found a medium to strong correlation between SES and academic success, with effect sizes varying across academic measures: 0.27 for science achievement, 0.35 for math achievement, and 0.32 for verbal achievement. Although we are unaware of similar research conducted with preschool-age children specific to science, a large body of research suggests that family SES significantly predicts preschool children's language and math outcomes (e.g., Burchinal, Peisner-Feinberg, Pianta, & Howes, 2002; Mashburn, Justice, Downer, & Pianta, 2009; Payne, Whitehurst, & Angell, 1994). These findings indicate that the language and math skills of preschool children from low-SES families may lag behind those of children from middle-SES backgrounds. Based on these findings, coupled with results for school-age samples, we surmise that family SES may be associated with preschoolers' science content knowledge. In addition, previous studies have

suggested that family SES incorporates family income and parental education but that each component is unique, represents a different aspect of SES, and should be considered separately from the other (e.g., Bollen, Glanville, & Stecklov, 2001). Following these studies, we included two separate family SES predictors, namely, family annual income and maternal education, and examined their unique contributions to child science outcome.

Gender is another factor frequently studied in conjunction with science content knowledge in school-age samples. Although differences in science achievement for males versus females have been found in many studies (e.g., Andre, Whigham, Hendrickson, & Chambers, 1999; Mantzicopoulos, Patrick, & Samarapungavan, 2008; Steinkamp & Maehr, 1983), these results are not always consistent. For example, Steinkamp and Maehr (1983) conducted a comprehensive review of the literature regarding gender differences in science achievement and reported that boys achieved slightly higher in science than did girls across 66 studies involving 28,000 students in Grades 1 to 12. In contrast, one recent study reported no gender difference in science competence or beliefs among kindergarten children (Mantzicopoulos et al., 2008). Some researchers have claimed that in the United States, boys start outperforming girls on science achievement in middle school, and this difference becomes more pronounced through the teenage years (e.g., Muller, Stage, & Kinzie, 2001).

Gender has not received as much attention with respect to preschool-age children's science learning. The existing research has focused primarily on language and math skills, and findings have been mixed, with some studies suggesting that gender differences in language and math skills are minimal (e.g., Hyde & Linn, 1988; Valiente, Lemery-Chalfant, & Swanson, 2010) and other studies showing that a difference exists (e.g., favoring boys in math learning; Herbert & Stipek, 2005; Valiente, Lemery-Chalfant, & Castro, 2007; Valiente, Lemery-Chalfant, Swanson, & Reiser, 2008). In the present study, we further examined the relations between gender and science content knowledge in a preschool-age sample to help understand whether and when a divergence in boys' and girls' science competence may occur.

Cognitive ability is another factor that may predict children's science content knowledge. *Cognitive ability* refers to the "ability to learn" (Spinath, Spinath, Harlaar, & Plomin, 2006, p. 364) and may include general reasoning skills such as those captured by verbal and nonverbal cognitive ability tests (Deary, Strand, Smith, & Fernandes, 2007; Spinath et al., 2006). Given that academic achievement is built on the foundation of cognitive abilities and obtained through daily learning (Spinath et al., 2006), it is no surprise that child cognitive ability has been identified as one of the most powerful predictors of academic achievement across different domains. Empirical studies have suggested that the correlations between cognitive ability and academic achievement are generally around .5 (e.g., Gustafsson & Undheim, 1996; Kuncel, Hezlett, & Ones, 2004; Laidra, Pullmann, & Allik, 2007; Spinath et al., 2006). For instance, Laidra et al. (2007) found that cognitive ability as measured by a nonverbal cognitive ability test was the best predictor of academic achievement, including science, for children in Grades 2 to 4. Significant associations between cognitive ability and science content knowledge may exist because cognitive abilities (e.g., general reasoning skills) can provide a foundation for science learning. For example, reasoning may enable children to explain their thinking, validate their problem solutions, apply patterns and

relationships to reach solutions, and generally make sense out of science (e.g., Charlesworth, 2005; Isaacs, Wagreich, & Gartzman, 1997). Despite these assumptions suggesting the importance of cognitive ability in science learning, we are unaware of any data-based studies that have examined the associations between cognitive ability and preschoolers' science content knowledge. We addressed this in the current study, examining the relations between children's nonverbal cognitive ability and science content knowledge. We focused specifically on nonverbal cognitive ability because verbal cognitive ability tests largely overlap with language measures, and we examined language as a separate predictor.

The existing literature suggests positive relations between science achievement and math skills for kindergartners (Mantzicopoulos et al., 2008) and students in Grade 8 (Wang, 2005). The relations between science and math skills may stem from the similarities and parallels between these two learning domains. Theoretically speaking, math and science involve similar scientific processes, such as inquiry and problem solving (Bybee, Ferrini-Mundy, & Loucks-Horsley, 1997; National Research Council, 1996). Both math and science are premised on discovering patterns and relationships and fundamentally require cognitive processing skills such as reasoning (e.g., Berlin & White, 1994; Charlesworth, 2005; Ginsburg & Golbeck, 2004; Isaacs et al., 1997; Pang & Good, 2000). It thus follows that although math and science are two different learning domains, they are intertwined, and learning in each domain supports learning in the other. For example, math skills such as counting, sorting/classifying, measuring, detecting patterns, and graphing/comparing are inherent in science investigations (French & Woodring, 2012). Moreover, as stated in the *National Science Education Standards* (National Research Council, 1996), "Science requires the use of mathematics in the collection and treatment of data and in the reasoning used to develop concepts, laws, and theories" (p. 214). Empirical studies have supported these hypotheses, showing significant moderate correlations between math and science skills (e.g., Mantzicopoulos et al., 2008; Wang, 2005). For instance, Mantzicopoulos et al. (2008) found a significant correlation of .41 between kindergartners' math abilities and science achievement. In addition, integrated science and math curricula have been shown to promote children's science content knowledge (effect sizes =0.22–0.33) while simultaneously supporting their math achievement (effect sizes =0.03–0.35; Hurley, 2001). Such findings suggest a potentially causal and bidirectional relation between math and science learning.

The importance of language skills in predicting science achievement is premised on the notion that language helps to structure the way in which science concepts are constructed and communicated (Lemke, 1990). In a similar manner, Ferreiro and Teberosky (1982) suggested that children actively build knowledge about science in parallel with their construction of language skills. For example, "biology is not plants and animals. It is language about plants and animals" (Moore, Moore, Cunningham, & Cunningham, 1986, p. 3). Furthermore, some researchers have argued that the association between science and language skills is causal (Casteel & Isom, 1994; Stoddart, Pinal, Latzke, & Canaday, 2002). One intervention study supports the possibility of such causal relations. Using a quasi-experimental pretest–posttest design, French (2004) found that ScienceStart!, a science-based curriculum, significantly impacted preschool children's vocabulary skills, an important component of language ($d=0.44$).

Taken together, these previous studies highlight the importance of family SES; gender; and cognitive, math, and language skills as potential predictors of preschool-age children's science content knowledge. As best we know, however, no study has examined the relations between these variables and science content knowledge for preschool-age children. In the present study, we expand upon the available corpus of work by examining how each of these variables (family SES; gender; cognitive, math, and language skills) is concurrently associated with preschool-age children's science content knowledge as well as how these variables are associated with gains in science content knowledge over the course of a preschool year. Our study provides a basic examination that may shed light on how these factors might enhance or inhibit the development of science knowledge within a preschool population.

THE CURRENT STUDY

In response to recent educational reforms highlighting the need to develop a research base on preschool science (Greenfield et al., 2009), we examined preschool children's science content knowledge and its correlates, including family SES, gender, cognitive ability, and math and language skills. Child age was included in the analysis as a control variable, given that preschool classrooms in the United States may serve children as young as 3 years to as old as 5 or 6 years (e.g., Winsler et al., 2002). The following three specific research aims guided our investigation:

1. To characterize preschool children's science content knowledge.
2. To examine the concurrent relations of child family SES, gender, cognitive ability, and math and language skills to science content knowledge at the beginning of the preschool year.
3. To examine the relations of child family SES, gender, cognitive ability, and math and language skills to science content knowledge gains over the preschool year.

METHOD

Participants

The participants were drawn from a larger study evaluating math and science professional development for early childhood educators (Piasta, Logan, Pelatti, Capps, & Petrill, 2014). The present study included only those children who had been randomly assigned to a comparison condition; educators in these classrooms had attended professional development unrelated to math and science and provided their typical classroom instruction on these topics. In total, participants included 194 children from 31 early childhood classrooms within 24 centers. Parent consent to participate in the study was obtained for four to nine children per classroom. Classrooms were affiliated with publicly funded programs (i.e., federally funded or state-funded programs including Head Start and the public school system, $n = 25$) as well as private and parochial programs ($n = 6$). The majority (68%) of the classrooms were full-day programs ($n = 21$), whereas the remainder were either half-day ($n = 5$) or mixed half/full-day (i.e., some children enrolled for half of the day, others for the full day; $n = 5$) programs. Nineteen classrooms used Creative Curriculum, four used a state-

developed curriculum, seven used a locally developed (i.e., classroom-specific) curriculum, and one classroom did not use any curriculum. In the fall of the academic year, children's ages ranged from 37 to 66 months ($M = 52.84$, $SD = 6.34$). The majority of children were White (72%); 21% were African American/Black; 6% were Hispanic/Latino; and 1% were Native American, Asian, or of another race/ethnicity. A total of 54% were boys. In total, 1% of the children had individualized education plans, and 1% had identified developmental disabilities, including autism ($n = 1$) and speech delay ($n = 4$). English language learners constituted only a small percentage of the sample (4%). Approximately 18% of children had annual family incomes less than \$25,000, 13% were between \$25,000 and \$50,000, and 69% were more than \$50,000. The highest level of maternal education varied: 36% of children's mothers held an advanced/graduate degree, 37% held a bachelor's degree, 4% held an associate's degree, 7% held a high school diploma, and 16% had not earned a high school diploma.

Procedure and Measures

Child data were collected in the fall and spring of the academic year. In the fall of the academic year, basic demographic information on each child's family (e.g., family structure, annual family income, parent education level) was collected using a questionnaire adapted from the Early Childhood Longitudinal Study (National Center for Education Statistics, 2002). In the fall (Time 1) and spring (Time 2) of the academic year, children were individually assessed by trained research assistants on a number of measures. All research assistants had prior experience working with young children. Most had completed or were enrolled in education or speech and hearing programs. Before assessing children, research assistants were trained using study protocols. For each assessment, these included (a) a PowerPoint training module with embedded video demonstrating assessment administration, (b) a written quiz (required to score at least 90% accuracy), and (c) supervised practice administrations in the lab (required to score at least 90% accuracy on a fidelity checklist). The assessment battery included measures of science content knowledge and cognitive, math, and language skills. We discuss each of these measures in turn.

Child science content knowledge—At the time that this study was undertaken, no standardized measures of science content knowledge appropriate for preschool-age children were available (Greenfield et al., 2009). We thus created a science content knowledge measure by adapting an existing informal assessment that included science content, the Core Knowledge Preschool Assessment Tool (CK-PAT; Core Knowledge Foundation, 2004). This tool, in its original form, was designed to be used by early childhood educators in their classrooms and consists of a series of assessment activities or probes tapping knowledge across various early learning domains. For the purposes of the current study, research staff selected a subset of probes that targeted children's science content knowledge and could be adapted for administration in a standardized fashion. Five science probes from the original CK-PAT, each of which included multiple items, were adapted for inclusion. To provide greater coverage of science content, we supplemented these with additional probes designed specifically for this study. The final CK-PAT science assessment consisted of 114 items and targeted children's knowledge of the human body (e.g., examiner points to the body part and asks child to name the indicated body part, such as elbow, cheek, ankle, lips, and shoulder),

the five senses and sensory attributes (e.g., child is shown two pictures and asked to point to the one that tastes sweet), and causal reasoning (e.g., examiner shuffles three pictures depicting a plant growing and lays these in a row in front of child; child looks at the pictures and determines which picture shows what happens first when a plant grows). Most of these items reflected content included in Ohio's *Early Learning Content Standards* (Ohio Department of Education, 2007). Children's responses to each item were scored as correct (1) or incorrect (0). Although the CK-PAT science assessment included items measuring various aspects of science content knowledge, factor analysis (described in detail in a subsequent section) showed that a one-factor model provided the best fit to the data for both Time 1 and Time 2 science content knowledge scores. Thus, the sum raw scores of the 114 items were used in the analysis. The internal consistency for this assessment, as measured by coefficient alpha, was .94. In addition, one recent study found that this assessment was sensitive to children's opportunities to learn about science, with greater gains on the assessment for children who had more science learning opportunities (Piasta et al., 2014).

Child family SES and gender—Caregivers of each participating child were asked to complete a demographic questionnaire. To document family income, we asked caregivers to select the scale of their annual family income from among 18 options (\$5,000 or less, \$5,001 to \$10,000, and so forth). This variable was included as a continuous scale in analyses, although we note that others have considered income status with respect to specific cutpoints (e.g., above or below federal poverty level) or relative to the number of individuals in the household. To document level of education, mothers answered the question "What is the highest level of education you have completed?" and chose from among nine options. We recoded the reported information to form mutually exclusive categories based on whether mothers had obtained degrees at the master's level, bachelor's level, or neither. In analyses, level of education was thus represented as three dummy codes (mothers had a bachelor's degree but not a master's degree, mothers had a master's degree, and mothers did not have a bachelor's degree), with mothers did not have a bachelor's degree serving as a reference group; this recoding was completed in response to data suggesting that children of more highly educated parents (e.g., those with bachelor's or master's degrees) enter school with higher levels of academic skills and continue to perform better than other children (Lee & Burkham, 2002). Child gender was also collected from the demographic questionnaire completed by caregivers. Child gender was recoded as a dichotomous variable (boy =1, girl =0).

Child cognitive ability—The Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence–III (WPPSI-III; Wechsler, 2002) was used to measure children's nonverbal cognitive ability. Previous studies indicate the WPPSI-II as one of the most highly respected and widely used assessments for measuring cognitive abilities in young children in the United States (e.g., Watkins, Campbell, Nieberding, & Hallmark, 1995). In addition, the WPPSI-II demonstrates strong concurrent validity with other measures of cognitive functioning, such as the Kaufman Brief Intelligence Test–2 (Hays, Reas, & Shaw, 2002; Kaufman & Kaufman, 2004). The Block Design subtest consists of 20 items assessing perceptual organization and non-verbal reasoning skills. It involves red and white square blocks and a spiral booklet of cards showing different designs that can be made

with the blocks. The child is presented with a design and asked to replicate the same design, within a certain time limit, using the colored blocks. According to the manual, the reliability (coefficient alpha) of the WPPSI-III ranges from .83 to .95 across different subtests. In the present sample, the coefficient alpha for the Block Design subtest was .79. Raw scores were used in the analysis.

Child math skill—Children’s math skills were measured using the Applied Problems subtest of the Woodcock–Johnson Achievement Test–III (Mather & Woodcock, 2001). The Applied Problems subtest is a 35-item subtest assessing early math reasoning and problem-solving skills. The child is presented with the problems in math orally and must perform relatively simple counting, addition, or subtraction operations. Woodcock and Mather (2001) reported that the coefficient alpha for preschool-age children was .91. For the present sample, the coefficient alpha of the Applied Problems subtest was .86. Test–retest reliability for this subtest was .73. For the statistical analysis, we converted raw scores to “item response theory-based *W* scores” as recommended in the manual (Mather & Woodcock, 2001, p. 72).

Child language skill—The Receptive One-Word Picture Vocabulary Test–Third Edition (Brownell, 2000) was administered to assess children’s receptive single-word vocabulary skills. This assessment asks children to match a word that they hear to objects, actions, or concepts presented in full-color pictures. This assessment was normed for ages 2 to 10, and the median coefficient alpha across the age ranges was .90. The coefficient alpha of this measure was .98 for the current sample. Raw scores were used for the analysis.

Analytic Strategy

For the first research aim (i.e., characterizing the preschool children’s science content knowledge), we used item factor analysis (see Wirth & Edwards, 2007) and descriptive analyses. We first examined whether children’s science content knowledge was best represented as a single factor or multiple factors. We used eigenvalues, a scree plot, and interpretability of the pattern of factor loadings to determine the appropriate number of factors. We completed the item factor analysis separately at the two time points to provide converging evidence for our conclusions. Descriptive analyses were then used to document trends and patterns of children’s performance in science content knowledge.

For the remaining research aims investigating the relations of child age, family SES, gender, cognitive ability, and math and language skills to science content knowledge and gains, we used hierarchical linear modeling (HLM; Raudenbush & Bryk, 2002) to account for the nested nature of the data. In the current study, 194 children were nested within 31 classrooms nested within 24 centers. Given the significant variance explained by the center level (Level 3) and the fact that the results from three-level and two-level models were not significantly different, a more parsimonious two-level HLM model was used, with Level 1 as the individual level (i.e., children) and Level 2 as the center level.

Models were built systematically starting with the unconditional model without any predictors to compute the intraclass correlation coefficient (ICC). ICCs obtained from the unconditional model yielded the proportion of variance in individual child outcomes falling

between centers. To address our second aim examining the concurrent prediction of children's science content knowledge at the beginning of the preschool year, Time 1 science content knowledge served as the outcome variable and all Level 1 variables (child age, family SES, gender, Time 1 cognitive ability score, Time 1 math score, and Time 1 language score) were included as predictors. To address our third research aim examining the predictors of children's science content gains across the preschool year, Time 2 science content knowledge served as the outcome variable, with Time 1 science content knowledge and all Level 1 variables (child age, family SES, gender, Time 1 cognitive ability score, Time 1 math score, and Time 1 language score) included as predictors. This allowed us to model the residualized gain in science content knowledge from fall to spring and its associations with predictor variables. For all analyses, predictor variables were group mean centered (i.e., subtracted from individual scores to form deviation scores as Level 1 predictors), because the interest in the present study was on the effects of Level 1 variables, and this type of centering allowed us to interpret parameter estimates as child-level effects within each specific center (Enders & Tofighi, 2007; Singer & Willett, 2003).

RESULTS

The means and standard deviations for children's cognitive, math, and language measures are shown in Table 1. The zero-order correlations of all of the variables are displayed in Table 2; note that these correlations do not account for the nested nature of the data.

Research Aim 1: Characterizing Preschool Children's Science Content Knowledge

To address the first research aim, we conducted an item factor analysis with Geomin rotation, implemented in Mplus (Muthén & Muthén, 2011). At both occasions of measurement, the eigenvalues supported a single-factor solution: For Time 1, the first five eigenvalues were 32.54, 6.00, 4.56, 4.34, and 3.96; for Time 2, they were 28.86, 8.08, 5.97, 5.32, and 5.09. The scree plot indicated some possibility of a second factor, but the rotated factors for the two-factor solution had no theoretical interpretation at either occasion. Thus, we concluded that a single factor provided the best description of the CK-PAT. Factor loadings for the single-factor solution were generally high, with roughly 70% of the items having factor loadings above .40 at both occasions, a common cutoff for an informative indicator (e.g., Stevens, 1992). Approximately 40% of the items had loadings above .55, considered "very good" by criteria proposed by Comrey and Lee (1992). For simplicity, all further analyses were completed using an unweighted sum score of all CK-PAT items; the pattern of results was the same when we included only items with factor loadings above .5, included only items with factor loadings above .40, or used a factor outcome in a multilevel structural equation modeling framework.

We also examined the descriptive data from the science content knowledge measure. Large variation was observed in children's Time 1 and Time 2 science content knowledge. The mean Time 1 science content knowledge score was 80.37 ($SD = 16.19$; maximum score = 114). The mean Time 2 science content knowledge score was 88.43 ($SD = 20.23$; maximum score = 114). The difference between the mean Time 1 score and the mean Time 2 score was statistically significant ($p < .001$), suggesting that, on average, children in the current study

exhibited gains in science content knowledge across the preschool year. Calculation of Cohen's d (.55) indicated a medium effect size.

Research Aim 2: Concurrent Relations of Child Age, Family SES, Gender, Cognitive Ability, and Math and Language Skills With Science Content Knowledge

To address the second research aim, we first tested the unconditional model for Time 1 science content knowledge using HLM. The ICC obtained from the unconditional model with Time 1 science content knowledge as the outcome indicated that 28% of the variance in Time 1 science content knowledge was attributable to between-center variance. As described previously, we then regressed the Time 1 science content knowledge variable on the children's age, SES, gender, cognitive ability, and math and language skill variables to evaluate concurrent associations with each independent variable, controlling for the others. Table 3 displays the HLM results. Among the SES variables (i.e., family income, maternal education: master's degree or not, maternal education: bachelor's degree or not), only one (maternal education: bachelor's degree or not) was a significant predictor of children's science content knowledge ($\gamma=4.55, p=.050$), indicating that children whose mothers held a bachelor's degree outperformed those children whose mothers held associate's degrees or had no college degree. Children's Time 1 cognitive ($\gamma=0.46, p=.017$), math ($\gamma=0.20, p<.001$), and language ($\gamma=0.21, p<.001$) skills were all significant and positive concurrent predictors of Time 1 science content knowledge when the other predictors were controlled. In contrast, the relation between gender and Time 1 science content knowledge was not statistically significant, indicating that boys and girls performed similarly. To measure the effect size, we calculated R_1^2 , which estimates the proportional reduction in within-center variance in the more parameterized model relative to the variance in the simpler unconditional model (Snijders & Bosker, 1999). The proportional reduction of prediction error variance at Level 1 was 44% for the model with Time 1 science content knowledge as the outcome and children's age, SES, gender, cognitive ability, and math and language skills as predictors.

Research Aim 3: Relations Between Child Age, Family SES, Gender, Cognitive Ability, and Math and Language Skills and Science Content Knowledge Gains

To address the third research aim, we considered children's gains in science content knowledge. The ICC from the unconditional model predicting Time 2 science content knowledge indicated that 37% of the variance in Time 2 science content knowledge was explained by between-center variance. Table 4 presents the HLM results. Time 1 math skill was the only significant predictor of the residualized gains in children's science content knowledge ($\gamma=0.15, p<.001$) when we controlled for age, Time 1 science knowledge, and other predictors. For the effect size, the proportional reduction of prediction error variance at Level 1 was 35% for the model with Time 2 science content knowledge as the outcome and children's age, SES, gender, cognitive ability, and math and language skills as predictors with Time 1 science content knowledge controlled.

DISCUSSION

The purposes of the study were threefold: (a) to characterize the science content knowledge of preschool children; (b) to investigate the concurrent relations of child family SES, gender, cognitive abilities, and math and language skills to science content knowledge; and (c) to examine the relations of child family SES, gender, cognitive abilities, and math and language skills to gains in science content knowledge. Three major findings, which are discussed in turn, are the following: (a) a single factor best characterized preschool science content knowledge as measured by the CK-PAT, on which preschool-age children showed a considerable amount of science content knowledge and made significant gains across the preschool year; (b) there was no gender difference in children's science content knowledge; and (c) although the overall level of science content knowledge was associated with mothers' education level and children's cognitive abilities and math and language skills, only math skills significantly predicted the gains in science content knowledge across the preschool year.

Concerning the first major finding, we found that a single factor of children's science content knowledge was supported over other multifactor models. The finding that preschool science content knowledge is not differentiated into topic areas or concept areas does not support the existence of distinct dimensions of science content knowledge (e.g., understanding of the human body, senses and sensory attributes, and causal reasoning for the CK-PAT; life and physical science more broadly). However, this finding is consistent with the findings of other studies of preschool-age children's academic (Purpura, Baroody, & Lonigan, 2013) and cognitive (Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Wiebe, Espy, & Charak, 2008) abilities suggesting an overall unitary learning model. For instance, in one recent study (Purpura et al., 2013), preschool children completed a battery of six mathematics tasks (i.e., verbal counting, one-to-one counting, cardinality, subtilizing, set comparison, and story problems). Results showed that these six tasks were not differentiated into concept areas and loaded onto a single factor, namely, informal mathematical knowledge.

We also found that preschool children demonstrated substantial science content knowledge, even at the beginning of the preschool year, as well as gains in this knowledge across the year. These findings are congruent with previous research studies and recent developmental theories showing that young children can develop basic science understandings and knowledge during their earliest years and that learning experiences during early childhood can cultivate their science growth (e.g., Eshach & Fried, 2005; French, 2004; Gallenstein, 2003; Greenfield et al., 2009). Our findings further support the notion that science education can begin during the early years of preschool (e.g., Ginsburg & Golbeck, 2004; Watters et al., 2001).

Despite the gains in science content knowledge observed among preschool children, it should be noted that the effect size was quite modest and needs to be interpreted with caution. We compared children's gains obtained in this study with those from the study of Greenfield et al. (2009) using the same equation for calculating Cohen's *d*. In the study of Greenfield et al., the effect size of yearly gains with Head Start children was 1.75 for early

math, 1.70 for language and literacy, and 1.51 for early science, with our result of 0.55 much lower than these effect sizes. The combination of our study and this previous study indicates that children show an improvement during the year in science but that the effect size for yearly gains may be smaller than those for other academic domains such as early math and language and literacy skills. Research studies suggest that environmental effects are important for child development and that lack of needed stimulation may result in a child's development not reaching its full potential (Hadzigeorgiou, 2002). Thus, one explanation for lower levels of science content knowledge may be fewer science learning opportunities and/or a lower quality of science teaching in some early childhood classrooms (Early et al., 2010; Greenfield et al., 2009; Piasta et al., 2014; Piasta, Pelatti, & Miller, 2013; Tilgner, 1990; Trundle & Saçkes, 2012). For instance, one research study showed that only 3 min per day was spent on science instruction in preschool classrooms (Connor, Morrison, & Slominski, 2006). Similarly, La Paro et al. (2009) reported that, on average, preschoolers spent 7% of time in science activities, with greater amounts of time spent in other content area activities. Although a more recent study found greater amounts of science learning opportunities than earlier studies (24 min per day, 25% of instructional time; Piasta et al., 2013), the quality of such learning opportunities may be variable (Saçkes, Trundle, Bell, & O'Connell, 2011; Tu, 2006). For example, Tu (2006) found that about 87% of the activities that early childhood educators labeled as *science* were not related to science concepts.

It is worth noting that the effect size of yearly gains in science achievement in our study was smaller than those obtained by Greenfield et al. (2009). The smaller effect size might be explained by the fact that different science measures were used across the studies. As mentioned previously, an indirect measure of children's science content knowledge with children's skills rated by their teachers was used in the study of Greenfield et al., whereas our study used a direct measure. Teacher ratings of children may be influenced by the variability of the children within teachers' classrooms (French & Woodring, 2012) and teachers' characteristics and perspectives (Mashburn, Hamre, Downer, & Pianta, 2006). However, a direct measure of children's learning demonstrates construct validity and predicts academic outcomes without the potential for observer (e.g., teacher) bias (Diamond, Kirkham, & Amso, 2002; Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

Concerning the second major finding, results showed that boys and girls had similar science content knowledge in preschool. This finding differs from the gender gap found in middle school-age children (Muller et al., 2001) but aligns with previous studies showing no gender difference in science achievement in early elementary school (Mantzicopoulos et al., 2008). This finding is promising in that girls do not appear to be lagging in their abilities to learn science as found in studies with older children. Perhaps gender differences in older children may be a result of differential science experiences as children continue through school, with boys having more exposure to microscopes, fuses, batteries, and pulleys and girls having more exposure to bread making, knitting, and sewing (Jones, Howe, & Rua, 2000). Our findings indicate that capabilities to understand science concepts are the same across boys and girls in the preschool years.

The third major finding indicated that, although mothers' education level and children's cognitive abilities and math and language skills were significant and concurrent predictors

of science content knowledge, only math skills significantly predicted preschool gains in science content knowledge. As described before, two separate family SES predictors, family annual income and maternal education, were included in this study. Only maternal education was significantly related to science content knowledge. That is, children whose mothers held a bachelor's degree demonstrated better science content knowledge than those children whose mothers did not. This finding is consistent with previous studies suggesting that children of more highly educated mothers demonstrate higher levels of academic skills than other children (Lee & Burkham, 2002; Magnuson, Sexton, Davis-Kean, & Huston, 2009). Following this finding, the nonsignificant relation between children's mothers holding a master's degree (i.e., an even higher level of education) and their science content knowledge found in this study is paradoxical and surprising. One possible explanation is that more educated mothers such as those who have a master's degree may be more likely to work and work for more hours (Carneiro, Meghir, & Parey, 2013). They may not provide more learning opportunities than those mothers who hold only a bachelor's degree. However, this assumption remains an empirical question and other possible explanations exist, requiring further study of this phenomenon.

Children's cognitive abilities significantly predicted their concurrent science content knowledge, which is in accordance with previous findings showing that cognitive ability is a primary predictor of academic success (e.g., Spinath et al., 2006; Steinkamp & Maehr, 1983). The significant concurrent relations between children's language skills and science content knowledge extend the evidence showing that science achievement is related to language skills for elementary school-age students (e.g., Mantzicopoulos et al., 2008; Stoddart et al., 2002). Our data suggest that the same holds true for preschool-age children even after nonverbal cognitive ability is controlled. That is, preschool children who had higher language skills evidenced higher scores in science content knowledge than children who had lower skills in this function at the beginning of preschool years. This finding supports the assumption that language process is the basic system for learning science content knowledge, which is composed of "facts, concepts, laws, and theories" (Casteel & Isom, 1994, p. 540). Thus, we recommend that early childhood educators capitalize on these parallels by planning instructional activities that capitalize on the links between language and science.

Finally, children's math skills significantly predicted not only their concurrent science content knowledge but also gains in science content knowledge even after their cognitive abilities were controlled. These findings extend research studies showing a strong association between math and science learning (e.g., Berlin & White, 1994; Mantzicopoulos et al., 2008; Pang & Good, 2000). Furthermore, these findings lend empirical support to the reform documents in math and science that identify a correlation between math and science (e.g., American Association for the Advancement of Science, 1998). One explanation for the strong relations between math and science is that both content areas involve similar skills, such as inquiry and problem solving, and both use similar reasoning skills, as previously described (e.g., Bybee et al., 1997; Charlesworth, 2005; Ginsburg & Golbeck, 2004). Likewise, there is overlap of math and science learning standards for preschool children. According to the Head Start Outcomes Framework (Head Start Bureau, 2004), science learning objectives include developing the ability to observe and discuss common properties

and differences and comparisons among objects and materials, which is similar to a math learning objective: recognizing, describing, comparing, and naming common shapes, their parts, and attributes. As our data are correlational, we cannot conclude a causal connection such that math skills promote science content knowledge. However, pending further research, we tentatively suggest that classroom instruction at the preschool level emphasize math–science connections.

Implications

Taken together, our results concerning child-specific factors associated with science content knowledge have two notable implications. First, they prove helpful in understanding why some children might not do well in acquiring science content knowledge. Our results indicate that children whose mothers do not have bachelor's degrees and who have lower cognitive, math, and language skills demonstrate lower science content knowledge. These findings lead to a critical message: These factors may place young children at risk for struggling in the area of science learning at the beginning of the preschool years. Early childhood educators need to be aware of such risk indicators in order to provide more support to children who may need help with science learning. However, it is promising that neither maternal education nor cognitive or language abilities predicted gains in science content knowledge. Thus, we argue that all children, regardless of such factors, are fully capable of learning science content knowledge in preschool, and our findings, coupled with the findings of others (e.g., Greenfield et al., 2009), point to the need to ensure that preschool children are afforded science learning opportunities. Although these child factors explained the amount of variance in science content knowledge, it should be noted that a significant amount of variance was also due to between-center differences. Specifically, 28% of the variance in Time 1 science content knowledge and 37% in Time 2 science content knowledge could be accounted for by center-level variables. Such results indicate that school learning experiences, such as actual classroom practices and curricular approaches, may also be important factors in the development of science content knowledge. Future research should examine the unique contribution of school learning experiences to early science learning when taking child factors into account.

Second, these findings provide a research-based rationale for the recent educational reform that suggests using a comprehensive and integrated content curriculum in early childhood settings. Integration in content areas facilitates knowledge transformation in the study of different topics and improves the acquisition of content knowledge (Lipson, Valencia, Wixson, & Peters, 1993). Thus, a science-based curriculum may offer great potential as a classroom-based tool to improve children's academic achievement through integrating science, cognitive, math, and language learning objectives. It may be particularly important to integrate math and science curricula for preschool children, given the stronger relations between math and science found in the current study. However, at present, few science-based integrated curricula are well researched and empirically supported for at-scale use by early childhood educators, and few efforts have been made to prepare teachers in the practice of curriculum integration (Pang & Good, 2000). Thus, developing a science-based integrated curriculum and supporting early childhood teachers as to how they can integrate science into other content areas seems to be timely and warranted.

Limitations, Future Directions, and Conclusion

In light of these three findings, several limitations must be acknowledged. First, the unique relations identified in this study provide important foundational information for understanding the interactional development of science content knowledge. However, these relations are correlational in nature. Although our correlational findings may have potentially important implications for preschool science instruction, we cannot draw strong claims or conclusions concerning causal relations. Future experimental and longitudinal research is needed to identify and evaluate the causal relations among these skills and domains. Second, our science content knowledge measure was very specific in terms of its content, in that we only assessed science content knowledge in three specific areas (i.e., the human body, senses and sensory attributes, and causal reasoning). However, preschool children have knowledge and preconceptions about many science concepts across many other areas, such as weight and shape, sound, light, weather, seasons, life cycles, and so forth (Trundle & Saçkes, 2012). Future research should broaden to include additional measures of science content knowledge. In addition, only the factor structure and reliability (i.e., internal consistency) for our measure of science content knowledge were examined; the current study did not provide a full psychometric evaluation of the tool. Although such analysis was sufficient for our current purposes, future research is needed to provide a more comprehensive psychometric analysis and improve the utility of science content knowledge measures for researchers and educators. Third, our measure of language assessed the construct of vocabulary, only one component of young children's language skills. Thus, it is possible that if additional measures of various aspects of language (e.g., grammar, academic language) had been incorporated into the present study, the results may have been different. It would thus be important to replicate and extend these findings in future works using multiple language measures. Finally, although the Applied Problems subtest of the Woodcock–Johnson Achievement Test–III (Mather & Woodcock, 2001) used in this study is a commonly used mathematics assessment and demonstrates strong reliability, this tool is limited in its content (i.e., it includes only a narrow range of early mathematic skills) and its sensitivity for identifying children with weak mathematics skills (Clements, Sarama, & Liu, 2008; Weiland et al., 2012). Future studies should replicate these findings using an early mathematics measure that addresses these limitations.

In conclusion, our research represents a first step in examining preschool children's science content knowledge and makes an important contribution to the literature. The results of our study indicate that young children develop a fundamental understanding of science concepts during their earliest school years. The results also underscore the importance of maternal education and children's cognitive abilities and math and language skills in determining the extent of science content knowledge exhibited upon preschool entry and specify the distinct role math skills play in science content knowledge gains over the preschool year. Such findings are informative to efforts aimed at developing effective classroom curricula and interventions that may aid in reducing, or even eliminating, later science difficulties.

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TABLE 1

Descriptive Statistics for Children's Cognitive, Math, and Language Measures

Measure	M	SD	Range
Raw score: cognitive skills	19.42	4.46	6–32
Standard score: cognitive skills	8.88	3.41	1–18
Raw score: math skills	12.34	5.05	0–25
Standard score: math skills	107.91	13.50	72–147
W score: math skills	406.69	24.53	318–462
Raw score: language skills	52.85	17.08	0–102
Standard score: language skills	102.63	17.75	55–145

Note. Cognitive skill scores are from the Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence–III (Wechsler, 2002); math skill scores are from the Applied Problems subtest of the Woodcock–Johnson Achievement Test–III (Mather & Woodcock, 2001); language skill scores are from the Receptive One-Word Picture Vocabulary Test–Third Edition (Brownell, 2000).

TABLE 2

Bivariate Correlation Matrix for the Variables

Variable	1	2	3	4	5	6	7	8	9	10
1. Child age	—	-.01	.07	-.09	.01	.43**	.34**	.32**	.46**	.31**
2. Family income		—	.44**	.70**	.05	.23**	.51**	.39**	.52**	.49**
3. Mother: master's or not			—	.46**	.02	.24**	.34**	.27**	.28**	.33**
4. Mother: bachelor's or not				—	-.01	.21**	.43**	.37**	.44**	.39**
5. Gender (1 =boy, 0 =girl)					—	.06	.06	.12	.14	.06
6. Time 1 cognitive skills						—	.48**	.46**	.56**	.49**
7. Time 1 math skills							—	.64**	.75**	.79**
8. Time 1 language skills								—	.70**	.64**
9. Time 1 science									—	.84**
10. Time 2 science										—

 $p < .001$.

TABLE 3

Hierarchical Linear Modeling Results for Time 1 Science Content Knowledge

Variable	Coefficient (SE)	p
Fixed effects		
Intercept	75.70** (2.82)	<.001
Age	8.43** (1.62)	<.001
SES (family income)	0.16 (0.23)	.484
SES (mother: master's or not)	-1.71 (1.93)	.377
SES (mother: bachelor's or not)	4.55* (2.30)	.050
Gender (1 =boy, 0 =girl)	1.35 (1.49)	.367
Time 1 cognitive skills	0.46* (0.19)	.017
Time 1 math skills	0.20** (0.05)	<.001
Time 1 language skills	0.21** (0.06)	<.001

Variable	Variance	p
Random effects		
Center level	89.96	<.001
Child level	70.51	

Note. SES =socioeconomic status.

*
p <.05.

**
p <.001.

TABLE 4

Hierarchical Linear Modeling Results for Science Content Knowledge Gains

Variable	Coefficient (SE)	p
Fixed effects		
Intercept	85.65 (2.46)	<.001
Time 1 science content knowledge	0.47** (0.07)	<.001
Age	-3.00* (1.33)	.026
SES (family income)	0.19 (0.17)	.276
SES (mother: master's or not)	1.24 (1.45)	.396
SES (mother: bachelor's or not)	0.70 (1.73)	.686
Gender (1 =boy, 0 =girl)	-0.23 (1.11)	.838
Time 1 cognitive skills	-0.13 (0.16)	.447
Time 1 math skills	0.15** (0.04)	<.001
Time 1 language skills	0.07 (0.05)	.163
Random effects		
Center level	79.48	<.001
Child level	36.68	

Note. SES =socioeconomic status.

*
p <.05.

**
p <.001.