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Children's science vocabulary uniquely predicts individual differences in science knowledge

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ABSTRACT

Science achievement gaps are a persistent social issue and are largely explained by individual differences in science knowledge before formal schooling. We were interested in whether children's science vocabulary relates to these differences in science knowledge. This experiment examined whether children's science vocabulary predicted their science knowledge above and beyond general vocabulary size and demographic variables. Children aged 3 to 11 years (N = 91; 59 boys) participated in-person at a laboratory within a large university in a mid-size city in the midwestern United States. The tasks that the children completed assessed general receptive vocabulary, science productive vocabulary, general science knowledge, and conceptions of science as a practice. We found that science vocabulary was the strongest predictor of science knowledge above and beyond other factors, indicating that science vocabulary production may predict individual differences in science knowledge specifically when achievement gaps emerge (β = .28). In addition, children who produced more of certain types of science words, such as size and physical property words, depicted more science equipment and language elements in their drawings of scientists. These findings suggest that learning new words may be related to conceptual development in science and that examining early science vocabulary is a key step toward fully understanding science knowledge gaps.

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Introduction

Science achievement gaps, or disparities in science performance across children, are a pressing societal issue. Research on science performance in the United States indicates that such gaps are present as early as elementary school (U.S. Department of Education, 2000, 2015) and exist within and across groups of children. Moreover, they have major implications for children's academic and life success. Indeed, children who achieve less in science often have lower levels of interest and motivation in science, which may lead them to fall behind academically in both the short term and long term (Leibham, Alexander, & Johnson, 2013; Singh, Granville, & Dika, 2002; Wang, 2013). When children fall behind, it can have wide-reaching implications for their overall life success. For instance, lower-achieving children can have a poorer understanding of public policy issues that require a level of scientific understanding, such as climate change, and therefore may have insufficient knowledge for making important life decisions. Furthermore, lower-achieving children are more likely to later experience lower levels of employment and overall well-being (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2010, 2011). In sum, this low scientific literacy often negatively affects individual children and the United States' place in today's highly competitive, technology-focused global economy (Drew, 2011).

What causes persistent science achievement gaps? To answer this question, Morgan, Farkas, Hillemeier, and Maczuga (2016) conducted analyses of a longitudinal sample of more than 7,000 children in the United States, following them from kindergarten through eighth grade. They found that general science knowledge in kindergarten, as measured by science questions within a general knowledge test, was the strongest predictor of early science achievement and the strongest contributor to science achievement gaps. Critically, this early general science knowledge was the strongest predictor above and beyond many other factors measured in the study, including gender, race and ethnicity, socioeconomic status (SES), family marital status, parenting quality and sensitivity, English as a first or second language, teacher approaches to learning, math ability, and reading ability. In brief, science achievement gaps are present as early as kindergarten, persist into high school, and are largely explained by the science knowledge that children already have prior to starting formal schooling (Morgan et al., 2016; Sackes, Trundle, & Bell, 2013; Sackes, Trundle, Bell, & O'Connell, 2011). Although research has suggested that children's early science knowledge is important for explaining science achievement gaps, there remains an open question: What leads to individual differences in science knowledge before schooling?

Several disciplines are actively working on answering this question, for example, by examining issues of diversity and equity in science learning and documenting the informal science learning experiences of children. However, the fields of cognitive science and developmental psychology have had a relatively minor role in answering this research question and addressing science knowledge gaps. This is a missed opportunity; these fields have a long history of elucidating the environmental factors that contribute to individual and developmental differences in knowledge.

One replicable finding in cognitive science and developmental psychology is that the language we acquire shapes the way in which we think and learn new information. Developmental psychologists have found that early vocabulary size predicts children's cognitive and educational outcomes in other domains such as general processing speed and problem solving (Marchman & Fernald, 2008; Neuman, Newman, & Dwyer, 2011; Waxman & Leddon, 2011) and academic performance (Bleses, Makransky, Dale, Højen, & Ari, 2016; Milton & Treffers-Daller, 2013; Nagy & Townsend, 2012). Moreover, domain-specific vocabulary is particularly predictive of cognitive and educational outcomes. For instance, children who produce more spatial language, and who use this language adaptively, display stronger spatial skills (Miller, Vlach, & Simmering, 2017; Pruden, Levine, & Huttenlocher, 2011). Given that general and domain-specific vocabulary size predict various outcomes, it may be that the size of children's vocabulary, and in particular their science vocabulary, explains variance in their science knowledge. Thus, our central hypothesis is that children's early science vocabulary contributes to science knowledge differences.

Additional support for our hypothesis comes from beyond psychological science. The experiences of teachers and educators have led them to hypothesize that a lack of important vocabulary might be holding children back from gaining science knowledge. Interventions have been targeted toward building children's science vocabulary (e.g., interactive book reading) so that they do not stay behind in preschool and kindergarten when knowledge gaps emerge (Gonzalez et al., 2011; Leung, 2008; Parsons & Bryant, 2016) and can catch up to their peers through middle school and beyond (Brown & Concannon, 2016; Helman, Calhoon, & Kern, 2014). Indeed, having a larger science vocabulary and practice in producing these science words supports receptive and expressive knowledge of these words (Best, Dockrell, & Braisby, 2006; Spycher, 2009; Wright & Gotwals, 2017). In brief, educational intervention research has argued that science vocabulary is important before and throughout the school years.

Although these lines of work indirectly support our hypothesis, there are limitations of this research that leave open the question of whether children's science vocabulary can explain differences in their science knowledge. For instance, previous research on science vocabulary and science knowledge has focused only on how science vocabulary interventions further improve knowledge of science vocabulary itself (e.g., Gonzalez et al., 2011; Leung, 2008; Spycher, 2009). Furthermore, this research has not yet examined other factors that purportedly relate to science knowledge gaps such as age, gender, and SES (Morgan et al., 2016; National Science Board, 2018; Reardon, 2011; Sackes et al., 2011; U. S. Department of Education, 2015). Critically, studies do not control for children's general vocabulary size, which is likely highly correlated with their science vocabulary size. Finally, it is necessary to establish that a potential correlational link exists between science vocabulary and science knowledge before future research can later determine whether these variables are causally linked. In sum, the current research addressed these limitations by examining how these factors relate to children's science knowledge and thus is a first step in determining the mechanism(s) by which children's early science knowledge relates to science performance gaps.

Current Study

To determine whether children's science vocabulary predicts individual differences in their science knowledge, we examined children's science vocabulary, general vocabulary, science knowledge, and demographic variables simultaneously. We looked at individual differences in science knowledge broadly instead of between specific demographic groups (as previous research has done) because science knowledge gaps also exist across all children regardless of demographic background. Moreover, it is important to examine how children's science vocabulary relates to their science knowledge generally before determining differences between specific demographic groups.

We predicted that children's science vocabulary would predict their science knowledge above and beyond the other factors. If we did not find these results, it would provide support for the alternative hypothesis: children's science vocabulary could be unrelated to what they know and understand about science, suggesting that other mechanisms explain science knowledge gaps. Such potential mechanisms are described in the Discussion.

We used a series of four tasks to determine whether the amount and type of science words children produce relates to their science knowledge. The two science knowledge tasks were the Woodcock–Johnson, Test 18 (Science)–Fourth Edition (Woodcock–Johnson Science Assessment; Schrank, McGrew, & Mather, 2014), a standardized test of children's science knowledge (e.g., facts about science), and the Draw-A-Scientist task (Chambers, 1983), a task that measures children's beliefs about science (e.g., what scientists do). We used these two measures of science knowledge because it comes in two forms: science knowledge consists of both understanding key facts and concepts (e.g., understanding that density is the relation between an object's mass and volume) and epistemic beliefs surrounding the practice of science that lead to the discovery and acquisition of these concepts (e.g., understanding that scientists measure density in a lab using rulers and scales). Indeed, the Next Generation Science Standards suggest that aside from traditional fact-based explanations, science should also be taught as a human endeavor (National Research Council, 2013). The general language measure was the Peabody Picture Vocabulary Test–Fourth Edition (PPVT; Dunn & Dunn, 2007), a measure of children's receptive vocabulary. Finally, parents completed a Science Vocabulary Checklist (developed by our research team) that measures children's science-based productive vocabulary. We defined *science vocabulary* as words used when learning or discussing key science facts and concepts and when engaging in or witnessing the practice of science. These four tasks afforded the opportunity to explore whether there were relations between children's vocabulary and science knowledge.

Method

Participants

The participants were 91 children (59 boys; M_{age} = 7 years 2 months, range = 3 years 6 months–11 years 6 months) who were recruited from local schools in a mid-size city in the midwestern United States. Children were recruited using phone calls and flyers sent to local schools. Morgan and colleagues (2016) found a science knowledge gap beginning at kindergarten and persisting into elementary school. Thus, we chose to examine children's learning before and after kindergarten to determine whether children's science vocabulary would predict the science knowledge gap in early and later development.

All parents provided demographic data about their children and families. Children came from predominantly White middle- to upper-SES families (75.8% of families were White, 68.1% of families had a parent with a graduate degree, and 41.8% of families earned more than $100,000 per year). SES was calculated on a point-based scale combining information on household income and parental education. Children received a storybook and $10 as a "thank you" for their participation in the study. An additional 4 participants were excluded due to one or more tasks being incomplete.

Power Analysis

Given that an effect size could not be derived from previous research, we conducted a power analysis for a regression analysis with five predictor variables and an estimated medium effect size (Cohen's f^2 = .15). The results of the power analysis revealed that a sample size of 90 children would yield at least 80% power. Thus, the data collection plan used a cutoff of 90 participants successfully completing the study, with data collection ending in the month that this number of participants was reached.

Materials and Procedure

All experiments were first approved by the University of Wisconsin-Madison Education and Social/Behavioral Sciences Institutional Review Board. All children participated in-person at a laboratory within a large university. Children participated in three tasks: the PPVT (Dunn & Dunn, 2007), the Woodcock–Johnson Science Assessment (Schrank et al., 2014), and the Draw-A-Scientist task (Chambers, 1983). Children were randomly assigned to one of six orders of task presentation. Parents completed the Science Vocabulary Checklist and family demographics survey prior to the start of the experiment.

Peabody Picture Vocabulary Test

We used the PPVT (Dunn & Dunn, 2007) to assess children's general receptive vocabulary. We wanted to determine the unique contribution of science vocabulary to children's science knowledge, and thus this measure was used to control for general vocabulary size. In this standardized test, the experimenter said a word to children, and children were instructed to point to the picture (out of four possible pictures) that best represented the given word. Children's raw score on the PPVT was used as a measure of their general receptive vocabulary.

Science Vocabulary Checklist

We used a parent-report Science Vocabulary Checklist to assess children's science vocabulary. This checklist afforded a relative estimate of how many science words children produce and, more specifically, what types of words they produce. In this task, we asked parents to report the science words they had heard their children say out loud. The words were organized into six categories (Weather and Space, Experimental, Physics, Animal and Life Science, Environmental Science, Size and Physical Properties) and consisted of words typically acquired both during and beyond the age range in this study, as measured by adult estimates of acquisition age (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012). To date, a standardized measure of science vocabulary does not exist. Thus, the next best approach was for us to create a measure of science vocabulary based on measurements that have had success in being standardized or been shown to be reliable ways of measuring children's productive vocabulary, such as parent-report vocabulary checklists (e.g., MacArthur–Bates Communicative Development Inventory; Fenson et al., 2007). Indeed, this method has been shown to be effective for a wide age range of children from infancy to childhood, and in specific domains, such as spatial words (e.g., Miller et al., 2017) and emotion words (Baron-Cohen, Golan, Wheelwright, Granader, & Hill, 2010). Furthermore, adults reflecting on their own word knowledge accurately estimate the ages at which they acquired words from a checklist (e.g., age of acquisition norms; Kuperman et al., 2012). The full checklist is provided in the Appendix.

Woodcock–Johnson Science Assessment

We used the Woodcock–Johnson Science Assessment (Schrank et al., 2014) to assess children's science knowledge. We chose this standardized test because it covered the broadest range of science topics, was adapted for the broadest age range, and was standardized for a national sample. In this standardized test, the experimenter asked children science questions that require a verbal response (i.e., "How do we take in the air we breathe?") or asked children to identify a picture of a science-related item. The science concepts covered in this test range from concepts typically understood by children under 2 years of age through adulthood. The number of correct items was used as the measure of children's science knowledge.

Draw-A-Scientist Task

We used the Draw-A-Scientist task (Chambers, 1983) as a measure of children's general perceptions of science and scientists because it has been frequently used to measure beliefs about the practice of science among children in the age range of this study (Finson, 2002; Losh, Wilke, & Pop, 2008; Miller, Nolla, Eagly, & Uttal, 2018), including children under 6 years (Barman, 1997; Lee, 2010). Moreover, drawings have often been successfully used with preschool- and kindergarten-age children to assess their knowledge across multiple domains (e.g., Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Barlow, Jolley, White, & Galbraith, 2003; Bruck, Melnyk, & Ceci, 2000; Butler, Gross, & Hayne, 1995; Chang, 2012; Hala, Hug, & Henderson, 2003). Researchers have used the Draw-A-Scientist task because it provides a concrete representation of children's ideas about what science is and what scientists do, including their first stereotypical idea (the first drawing) and a secondary idea (the second drawing). Therefore, this task can be used to connect the components of children's drawings with the components of their productive vocabulary.

In this task, children were given two blank sheets of white paper, one at a time, and a set of 10 Crayola markers in "Classic colors" plus two additional flesh-tone markers from the "Multicultural colors" set. The experimenter handed children the first sheet of paper and gave them the following verbal instructions: "Imagine that tomorrow you are going on a trip [anywhere] to visit a scientist in a place where the scientist is working right now. Draw the scientist busy with the work this scientist does." Children were given an unlimited amount of time to complete the first drawing. In line with previous studies' administration of this task, after children indicated that they were finished with the first drawing, the experimenter prompted children to tell them about their drawing and wrote down what the children said. The experimenter then collected the first drawing, gave children the second sheet of paper, and repeated the same verbal instructions. After children completed the second drawing, the experimenter prompted children to explain their drawing. All children, including preschool-age children, were able to provide rich explanations of what was included in their drawings regardless of their level of artistic ability.

Coding Protocol for Draw-A-Scientist Task. We developed a coding protocol to identify the information depicted in each drawing and modeled it after the original coding scheme in Chambers' (1983) study to include information about both the scientist's appearance and symbols of scientific research and knowledge. The items coded for included the race, gender, and clothing of the scientist in the drawing, the location depicted, the language included in the drawing, and the type of science-related activities and science equipment included in the drawing. The components coded for are listed in Table 2 (see Results). It was often difficult to fully decipher all components of children's drawings. Therefore, the experimenter obtained more information about children's drawings by saying, "Tell me about your drawing." Information from these verbal descriptions and information from the drawings alone were used together in the coding protocol. All children's descriptions were used in the coding protocol regardless of the clarity of their drawings. Children's descriptions were highly detailed on average, including nearly all components coded for in the experiment. All drawings were coded by two coders to establish inter-rater reliability. Reliability was calculated using Cohen's kappa (κ = .84 across all categories and drawings) and was high in each individual category (race = .82, gender = .78, clothing = .87, location = .75, language = .88, science activities = .87, science equipment = .82). Because inter-rater reliability was high across all items, the data used for analysis were taken from the first coder's records.

Results

Descriptive Statistics

We began our analysis by calculating the descriptive statistics for children's performance on the PPVT and the Woodcock–Johnson Science Assessment, as well as parental report on the Science Vocabulary Checklist. Children's performance on the PPVT was measured using the raw score. Children's performance on the Woodcock–Johnson Science Assessment was measured using the total number of correct items. Children's science vocabulary was calculated by summing the number of words children produced according to the Science Vocabulary Checklist. Results of these analyses are described in Table 1.

We also calculated the frequency of elements included in children's drawings from the Draw-A-Scientist task. Children's drawings depicted a diversity of individuals, activities, and equipment (Fig. 1 and Table 2). Fig. 1 shows examples of children's drawings and the activities depicted in them. Overall, children's beliefs about science in this experiment closely reflected those of previous research (e.g., Chambers, 1983; Miller et al., 2018).

Table 1
Descriptive Statistics for the Peabody Picture Vocabulary Test, Woodcock–Johnson Science Assessment, and Science Vocabulary Checklist

Task type	*Max score*	*M*	*SD*	*Range*
Peabody Picture Vocabulary Test	228	138.10	33.20	36–204
Woodcock–Johnson Science Assessment	40	16.15	4.49	3–26
Science Vocabulary Checklist	94	74.59	14.12	23–93
Weather and Space words	17	15.20	1.75	6–17
Experimental words	19	13.92	3.90	4–19
Physics words	11	9.21	1.37	3–11
Animal and Life Science words	15	10.98	3.10	2–15
Environmental Science words	12	9.53	1.62	4–12
Size and Physical Property words	20	15.76	4.05	1–20

Table 2
Elements of Children's Drawings in the Draw-A-Scientist Task

Drawing element	*n*	%
Race		
No scientist/human present	23	12.5
Ambiguous	94	58.4
Light skin color	55	34.2
Dark skin color	12	7.5
Gender		
No scientist/human present	22	12
Ambiguous	52	32.1
Female	19	11.7
Male	91	56.2
Location		
Not recognizable/no scientist present	88	47.8
Indoor traditional lab (e.g., at a table with beakers)	47	49
Indoor office (e.g., sitting at a desk)	20	20.8
Indoor non-lab (e.g., in a classroom)	15	15.6
Outdoor lab (e.g., archaeological site)	6	6.3
Outdoor non-lab (e.g., outdoors but with no science-related activity)	8	8.3
Clothing		
None present	103	56
Lab coat	27	28.7
Goggles	16	17
Gloves	4	4.3
Street/casual clothing	47	50
Language elements		
None present	155	84.2
Non-science language	20	66.7
Science-related language (e.g., "My experiment worked!") or equations (e.g., $E = MC^2$)	6	20
Numbers/mathematical equations (e.g., 1 + 1 = 2)	2	6.7
Letters (but no words)	2	6.7
Activity type		
None present	52	28.3
Using chemicals/potions	60	40.5
Examining things (e.g., using a microscope)	23	15.5
Measuring things (e.g., using a scale)	0	0
Teaching/instructing others	7	4.7
Studying the weather/space	5	3.4
Using a machine (e.g., a computer)	8	5.4
Writing/reading/working on paperwork	12	8.1
Physics-related activity (e.g., studying motion or gravity)	6	4.1
Studying animals/insects	17	11.5
Studying plants/soil (e.g., archaeology, growing plants)	10	6.8
Non-science-related activity	9	6.1
Science equipment type		
None present	34	18.5
Chemicals/potions, beakers	62	25.9
Machines (e.g., computers)	19	7.9
Measurement items (e.g., scales)	1	0.4
Items for examining (e.g., microscopes)	22	9.2
Medical equipment	2	0.8
Animals/insects	16	6.7
Fantasy animals (e.g., aliens)	1	0.4
Plants/soil and related tools (e.g., shovels)	10	4.2
Papers/books/writing tools	21	8.8
Table or desk/drawers	85	35.6
Non-science-related items	16	6.7

Note. There were 182 drawings (2 per child). The percentages for "No scientist/human present" and "None present" are calculated relative to all drawings. The percentages for each other element are calculated relative to the total number of elements depicted in the drawings.

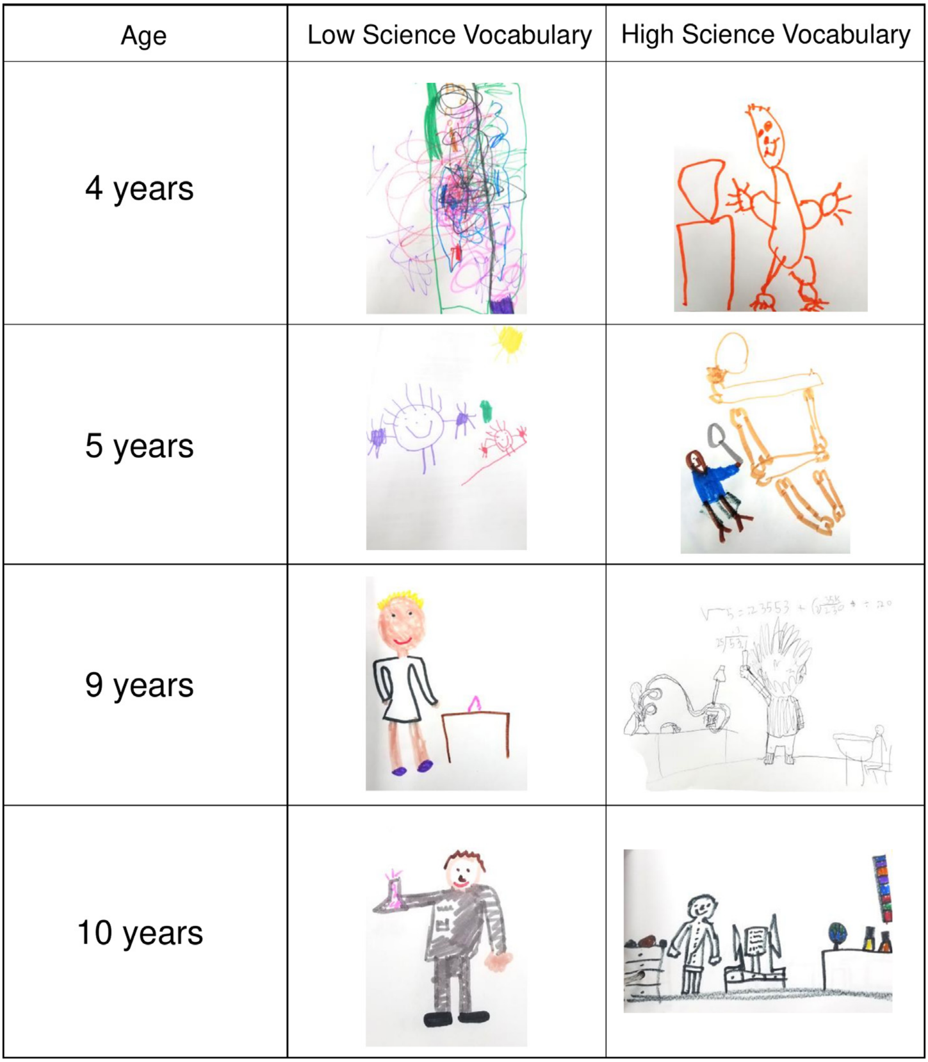

Fig. 1. Children's drawings from the Draw-A-Scientist task. Drawings by 4-, 5-, 9-, and 10-year-old children are shown. Drawings on the left had low science vocabulary, whereas drawings on the right had high science vocabulary for their age groups.

Standardized Assessment of Science Knowledge

We started our analyses by conducting bivariate and partial correlations between all variables to be included in the hierarchical regression models (Table 3). These correlations followed expected patterns (e.g., age was strongly correlated with cognitive tasks) and provide evidence that the Science Vocabulary Checklist was measuring children's science vocabulary. That is, these correlations provide evidence against alternative explanations for what the Science Vocabulary Checklist measures. For instance, there was a significant positive correlation between age and science vocabulary, $r(89) = .62$, $p < .001$. This suggests that the Science Vocabulary Checklist indeed captures variations in children's science vocabulary rather than other stable, non-time-dependent factors such as parental

Table 3
Direct and Partial Correlations for Hierarchical Regression Variables

	Age (months)	Gender	SES	PPVT (raw score)	Total science words	Woodcock–Johnson (number correct)
Age (months)	–					
Gender	.104	–				
SES	−.113	−.186	–			
PPVT (raw score)	.837***	.014	.117	–	.462***	.629***
Total science words	.616***	−.052	.010	.710***	–	.561***
Woodcock–Johnson (number correct)	.758***	.000	.093	.868***	.749***	–

Note. Correlations below the diagonal are direct correlations. Correlations above the diagonal are partial correlations controlling for age, gender, and socioeconomic status (SES). PPVT, Peabody Picture Vocabulary Test–Fourth Edition.
*** $p < .001$.

interest, involvement, and knowledge of science, which typically do not vary across broad periods of time (e.g., Impey, Formanek, Buxner, & Wenger, 2017; Low, Yoon, Roberts, & Rounds, 2005). Indeed, there is little reason to think that parents of 9-year-old children have significantly greater interest, involvement, and knowledge of science than parents of 3-year-old children.

To test our hypothesis that individual differences in children's language abilities relate to early differences in science knowledge, we conducted a series of hierarchical regression models with our first measure of science knowledge, Woodcock–Johnson Science Assessment performance, as the outcome measure. Results of the hierarchical regression models (Table 4) predicting science knowledge (Woodcock–Johnson score) revealed that both PPVT score and productive science vocabulary predicted science knowledge above and beyond demographic variables such as age, gender, and SES (Step 3; $\beta = .28$, $p < .001$).

The comprehensive age range of this study provided us with the ability and statistical power to conduct additional hierarchical regressions with three separate age groups. Thus, we conducted exploratory analyses examining whether science vocabulary predicts science knowledge specifically when these gaps emerge around kindergarten and while they continue to widen throughout elementary school (Morgan et al., 2016). Given that we used a medium effect size for the initial regression and found that science vocabulary contributed a considerable portion of the variance ($R^2 = .794$), we estimated a large effect size for the analyses with age subgroups. We also used two predictor variables due to the smaller sample size among the age subgroups. Using a large effect size (Cohen's $f^2 = .55$) for a regression analysis with two predictor variables and $\alpha = .05$, we needed 21 participants per group to have 80% power to observe an effect. Therefore, we separated participants into three groups: preschool and kindergarten age (36–71 months; $n = 27$), early elementary age (72–107 months; $n = 42$), and late elementary age ($\geq$ 108 months; $n = 22$).

When we completed these regression analyses with early elementary age children (Table 4, Model 3; $n = 42$; 72–107 months), we did not find that productive science vocabulary was a strong predictor of science knowledge ($\beta = .11$, $p = .447$). However, when we completed these regression analyses with late elementary-age children (Model 4; $n = 22$; $\geq$108 months), results revealed that productive science vocabulary remained a strong predictor of science knowledge separate from PPVT score ($\beta = .36$, $p = .033$). This was particularly true for preschool- and kindergarten-age children (Model 2; $n = 27$; 36–71 months; $\beta = .45$, $p = .004$). These findings suggest that production of science vocabulary may be particularly important even before kindergarten, when research has established that science achievement gaps are already present (Morgan et al., 2016).

Lastly, we completed these regression analyses with each separate category from the Science Vocabulary Checklist (Table 5). We found that Size and Physical Property words predicted science knowledge above and beyond PPVT score for all children (Model 11: $\beta = .30$, $p < .001$). Animal and Life Science words and Size and Physical Property words were strong predictors of science knowledge among preschool- and kindergarten-age children (Model 8: $\beta = .41$, $p = .004$; Model 12: $\beta = .44$, $p = .003$). No multicollinearity symptoms were found for any of the regression models (all variance inflation factors < 5). Taken together, these results suggest that children's vocabulary, including their

Table 4
Hierarchical Regression Analyses Between Age Groups

	R^2	ΔR^2	b	SE	β
Model 1: All age groups (N = 91)					
Step 1	0.598	.598***			
Age (months)			0.141	0.013	.775***
Gender			−.348	0.728	−.036
SES			0.633	0.27	.174*
Step 2	0.757	.159***			
Age (months)			0.017	0.021	0.095
Gender			0.067	0.573	0.007
SES			0.046	0.227	0.013
PPVT (raw score)			0.108	0.015	.788***
Step 3	0.794	.037***			
Age (months)			0.017	0.019	0.092
Gender			0.337	0.536	0.034
SES			0.137	0.212	0.038
PPVT (raw score)			0.081	0.016	.589***
Total science words			0.089	0.024	.278***
Model 2: Preschool and Kindergarten (N = 27)					
Step 1	0.619	.619***			
PPVT (raw score)			0.121	0.019	.787***
Step 2	0.735	.116**			
PPVT (raw score)			0.075	0.021	.491**
Total science words			0.116	0.036	.451**
Model 3: Early elementary (N = 42)					
Step 1	0.336	.336***			
PPVT (raw score)			0.074	0.016	.579***
Step 2	0.346	0.01			
PPVT (raw score)			0.068	0.018	.535**
Total science words			0.026	0.033	0.109
Model 4: Late elementary (N = 22)					
Step 1	0.437	.437**			
PPVT (raw score)			0.123	0.031	.661**
Step 2	0.56	.122*			
PPVT (raw score)			0.105	0.029	.567**
Total science words			0.138	0.06	.362*

Note. Outcome variable: Number correct on Woodcock–Johnson Science Assessment. Abbreviations: SES: socioeconomic status, PPVT: Peabody Picture Vocabulary Test-Fourth Edition.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

overall and category-specific science vocabulary, may indeed explain variability in their science knowledge.

In addition, we searched for overlap between words included in the Science Vocabulary Checklist and words included on questions in the Woodcock–Johnson Science Assessment. We found only a small percentage of overlap, with 11 of the 94 words (11.7%) in the Science Vocabulary Checklist being included in the Woodcock–Johnson Science Assessment (one word per question). These included four Weather and Space words (earth, moon, planet, and star), two Experimental words (cause and measure), two Physics words (energy and sound), one Animal and Life Science word (molecules), one Environmental Science word (plant), and one Size and Physical Property word (light). In addition, only 5 of these 11 items were questions that the majority of children answered. The remaining six items were questions that few to no children had the opportunity to answer (i.e., the questions were past their ceiling item). This minor overlap suggests that the relation we found between science vocabulary and science knowledge is likely not due to the measures used in this experiment.

Table 5
Hierarchical Regression Analyses Between Science Word Categories

	R^2	ΔR^2	*b*	*SE*	*β*
Model 1: Weather and Space words (all)					
Step 1	0.598	.598***			
Age (months)			0.141	0.013	.775***
Gender			−.348	0.728	−.036
SES			0.633	0.27	.174*
Step 2	0.757	.159***			
Age (months)			0.017	0.021	0.095
Gender			0.067	0.573	0.007
SES			0.046	0.227	0.013
PPVT (raw score)			0.108	0.015	.788***
Step 3	0.776	.019*			
Age (months)			0.026	0.02	0.141
Gender			−.106	0.558	−.011
SES			0.078	0.22	0.022
PPVT (raw score)			0.085	0.018	.618***
Total Weather and Space words			0.492	0.197	.192*
Model 2: Weather and Space words (Preschool and Kindergarten only)					
Step 1	0.619	.619***			
PPVT (raw score)			0.121	0.019	.787***
Step 2	0.646	0.027			
PPVT (raw score)			0.096	0.026	.623**
Total Weather and Space words			0.385	0.283	0.232
Model 3: Experimental words (all)					
Step 1	0.598	.598***			
Age (months)			0.141	0.013	.775***
Gender			−0.348	0.728	−0.036
SES			0.633	0.27	.174*
Step 2	0.757	.159***			
Age (months)			0.017	0.021	0.095
Gender			0.067	0.573	0.007
SES			0.046	0.227	0.013
PPVT (raw score)			0.108	0.015	.788***
Step 3	0.774	.017*			
Age (months)			0.016	0.02	0.09
Gender			0.159	0.558	0.016
SES			0.124	0.223	0.034
PPVT (raw score)			0.094	0.016	.687***
Total Experimental words			0.196	0.084	.167*
Model 4: Experimental words (Preschool and Kindergarten only)					
Step 1	0.619	.619***			
PPVT (raw score)			0.121	0.019	.787***
Step 2	0.707	.088*			
PPVT (raw score)			0.1	0.019	.650***
Total Experimental words			0.372	0.139	.327*
Model 5: Physics words (all)					
Step 1	0.598	.598***			
Age (months)			0.141	0.013	.775***
Gender			−.348	0.728	−.036
SES			0.633	0.27	.174*
Step 2	0.757	.159***			
Age (months)			0.017	0.021	0.095
Gender			0.067	0.573	0.007
SES			0.046	0.227	0.013
PPVT (raw score)			0.108	0.015	.788***

(*continued on next page*)

Table 5 (*continued*)

	R^2	ΔR^2	*b*	*SE*	*β*
Step 3	0.767	0.01			
Age (months)			0.017	0.02	0.093
Gender			0.207	0.57	0.021
SES			0.05	0.224	0.014
PPVT (raw score)			0.1	0.016	.726***
Total Physics words			0.401	0.227	0.118
Model 6: Physics words (Preschool and Kindergarten only)					
Step 1	0.619	.619***			
PPVT (raw score)			0.121	0.019	.787***
Step 2	0.656	0.036			
PPVT (raw score)			0.104	0.021	.678***
Total Physics words			0.502	0.316	0.22
Model 7: Animal and Life Science words (all)					
Step 1	0.598	.598***			
Age (months)			0.141	0.013	.775***
Gender			−.348	0.728	−.036
SES			0.633	0.27	.174*
Step 2	0.757	.159***			
Age (months)			0.017	0.021	0.095
Gender			0.067	0.573	0.007
SES			0.046	0.227	0.013
PPVT (raw score)			0.108	0.015	.788***
Step 3	0.793	.036**			
Age (months)			0.02	0.019	0.11
Gender			0.357	0.539	0.037
SES			0.078	0.211	0.021
PPVT (raw score)			0.085	0.016	.616***
Total Animal and Life Science words			0.358	0.101	.249**
Model 8: Animal and Life Science words (Preschool and Kindergarten only)					
Step 1	0.619	.619***			
PPVT (raw score)			0.121	0.019	.787***
Step 2	0.733	.114**			
PPVT (raw score)			0.085	0.02	.557***
Total Animal and Life Science words			0.463	0.145	.408**
Model 9: Environmental Science words (all)					
Step 1	0.598	.598***			
Age (months)			0.141	0.013	.775***
Gender			−.348	0.728	−.036
SES			0.633	0.27	.174*
Step 2	0.757	.159***			
Age (months)			0.017	0.021	0.095
Gender			0.067	0.573	0.007
SES			0.046	0.227	0.013
PPVT (raw score)			0.108	0.015	.788***
Step 3	0.774	.017*			
Age (months)			0.015	0.02	0.084
Gender			0.328	0.567	0.034
SES			0.132	0.224	0.036
PPVT (raw score)			0.092	0.016	.673***
Total Environmental Science words			0.504	0.215	.181*
Model 10: Environmental Science. words (Preschool and Kindergarten only)					
Step 1	0.619	.619***			
PPVT (raw score)			0.121	0.019	.787***
Step 2	0.644	0.025			
PPVT (raw score)			0.096	0.027	.625**
Total Environmental Science words			0.53	0.407	0.227

Table 5 (*continued*)

	R^2	ΔR^2	*b*	*SE*	*β*
Model 11: Size and Physical Property words (all)					
Step 1	0.598	.598***			
Age (months)			0.141	0.013	.775***
Gender			−.348	0.728	−.036
SES			0.633	0.27	.174*
Step 2	0.757	.159***			
Age (months)			0.017	0.021	0.095
Gender			0.067	0.573	0.007
SES			0.046	0.227	0.013
PPVT (raw score)			0.108	0.015	.788***
Step 3	0.803	.046***			
Age (months)			0.011	0.019	0.058
Gender			0.482	0.529	0.049
SES			0.145	0.207	0.04
PPVT (raw score)			0.085	0.015	.618***
Total Size and Physical Property words			0.335	0.081	.295***
Model 12: Size and Physical Property words (Preschool and Kindergarten only)					
Step 1	0.619	.619***			
PPVT (raw score)			0.121	0.019	.787***
Step 2	0.738	.119**			
PPVT (raw score)			0.079	0.02	.518**
Total Size and Physical Property words			0.366	0.111	.438**

Note. Outcome variable: Number correct on Woodcock–Johnson Science Assessment. Abbreviations: SES: socioeconomic status, PPVT: Peabody Picture Vocabulary Test-Fourth Edition.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Beliefs About Scientists and the Practice of Science

We also tested whether children's science vocabulary is reflected in tests of the second component of science knowledge: children's epistemic beliefs about the practice of science. To do this, we conducted bivariate and partial correlations between elements of children's drawings from the Draw-A-Scientist task and performance on the PPVT, Woodcock–Johnson Science Assessment, and Science Vocabulary Checklist (Table 6). The partial correlations controlled for age, gender, and SES because these variables have previously been related to science knowledge outcomes (Morgan et al., 2016; National Science Board, 2018; Reardon, 2011; Sackes et al., 2011; U.S. Department of Education, 2015). Thus, we also examined whether the relation between science vocabulary and beliefs about science and scientists held even when considering demographic variables that have previously been used to explain gaps in this knowledge. For the elements of children's drawings specifically, we chose to look at correlations in the following categories: science equipment, science activities, language elements, location, and clothing elements. These elements were chosen because each reflects how children conceptualize scientists or the practice of science and because the variability in each subcategory was high (at least 25% of the sample included these elements). We used the number of different elements within a category for these correlations (i.e., the number of different types of science equipment components).

Results of partial correlations controlling for age, gender, and SES revealed that children who had higher science knowledge depicted more science equipment elements in their drawings, $r(75) = .24$, $p = .036$. This was also true for children's science vocabulary; children who produced more science words overall also drew more types of science equipment, $r(75) = .23$, $p = .047$. Therefore, even when controlling for demographic variables purported to underlie science knowledge gaps, children who know more science facts and produce more science vocabulary have a broader idea of the materials involved in the practice of science.

Table 6
Direct and Partial Correlations for Demographic Variables, Task Performance, and Elements of Children's Drawings

	Age	Gender	SES	PPVT	All sci words	WJ	Sci equip: Total	Equip: Chemicals	Equip: Desk	Sci act: Total	Act: None	Act: Chemicals	Lang elem: Total	Lang: None	Loc: None	Loc: Trad lab	Clothes: Total	Clothes: None	Clothes: Casual
Age	–																		
Gender	0.104	–																	
SES	–.113	–.186	–																
PPVT	.837***	0.014	0.117	–	.462***	.629***	.344**	0.062	0.18	.312**	–.096	0.043	0.099	–.062	–.045	0.063	0.141	–.218	.241*
All sci words.	.616***	–.052	0.01	.710***	–	.561***	.228*	0.095	0.067	0.148	0.019	0.083	0.2	–.217	0.081	0.061	–.018	–.054	0.172
WJ	.758***	0	0.093	.868***	.749***	–	.240*	0.092	0.194	0.212	–.038	0.087	0.192	–.262*	–.045	0.02	0.097	–.157	.258*
Sci equip: Total	.529***	–.007	0.113	.600***	.482***	.550***	–	.352**	.566***	.544***	–.264*	.243*	0.138	–.093	–.275*	.432***	0.135	–.135	0.158
Equip: Chemicals	.444***	–.006	0.043	.402***	.372***	.410***	.509***	–	.244*	.356**	–.371**	.971***	0.07	0.017	–.223	.651***	0.047	–.154	–.032
Equip: Desk	.353**	0.031	0.125	.386***	.273**	.394***	.630***	.361***	–	0.175	–.252*	.234*	–.002	–.044	–.515***	.566***	0.169	–.172	0.189
Sci act: Total	.409***	0.103	0.079	.489***	.361***	.449***	.648***	.482***	.323**	–	–.624***	.380**	.291**	–.155	–.094	0.215	0.116	–.240*	0.221
Act: None	–.524***	–.077	–.033	–.490***	–.338**	–.435***	–.468***	–.531***	–.325**	–.677***	–	–.431***	–.028	–.020	.312**	–.175	0.02	0.166	–.079
Act: Chemicals	.416***	0.011	0.021	.364***	.344**	.382***	.417***	.978***	.343**	.491***	–.561***	–	0.091	0	–.200	.613***	0.051	–.190	–.002
Lang Elem: Total	.215*	0.029	–.050	.221*	.266*	.273**	.220*	0.137	0.06	.328**	–.121	0.148	–	–.770***	0.01	0.074	–.217	0.146	0.013
Lang: None	–.176	–.080	0.022	–.173	–.251*	–.289**	–.166	–.054	–.093	–.207*	0.069	–.062	–.783***	–	0.051	–.111	0.218	–.140	0.008
Loc: None	–.293**	0.001	–.076	–.294**	–.127	–.252*	–.368***	–.292**	–.487***	–.196	.392***	–.266**	–.066	0.105	–	–.379***	–.094	–.120	–.018
Loc: Trad lab	.331**	0.067	0.065	.304**	.271**	.275**	.531***	.705***	.610***	.351**	–.331**	.677***	0.11	–.141	–.399***	–	0.157	–.199	0.006
Clothes: Total	.437***	0.177	–.036	.432***	.254*	.359***	.296**	0.185	.267*	.236*	–.218*	0.177	–.080	0.094	–.189	.238*	–	–.743***	.528***
Clothes: None	–.405***	–.170	0.065	–.435***	–.283**	–.364***	–.273**	–.270**	–.275**	–.324**	.314**	–.289**	0.035	–.041	0.07	–.288**	–.772***	–	–.563***
Clothes: Casual	.297**	0.107	–.092	.348**	.319**	.334**	.234*	0.084	.247*	.264*	–.206	0.099	0.074	–.045	–.127	0.091	.593***	–.642***	–

Note. Correlations below the diagonal are bivariate correlations. Correlations above the diagonal are partial correlations while controlling for age, gender, and socioeconomic status (SES). Abbreviations: PPVT: Peabody Picture Vocabulary Test–Fourth Edition, WJ: Woodcock–Johnson, Test 18 (Science)–Fourth Edition, sci: science, equip: equipment, act: activities, lang: language, elem: elements, loc: location, trad: traditional.

* $p < .05$.
** $p < .01$.
*** $p < .001$.

Further partial correlations also found relations within the science elements children depicted in their drawings. When controlling for demographic variables, children who drew more science equipment also depicted a more diverse range of science activities, $r(75) = .54$, $p < .001$, and were more likely to view science as occurring in a traditional indoor lab setting with chemicals and beakers, $r(75) = .43$, $p < .001$. Children who depicted more science activities also included more language elements in their drawings, $r(75) = .29$, $p = .01$. These results indicate that the elements children choose to draw when prompted about science are highly interconnected, suggesting that all of them relate to children's broader idea of the practice of science.

To further test our hypothesis that there is a relation between children's science vocabulary and their beliefs about science, we conducted exploratory bivariate and partial correlations between elements of children's drawings from the Draw-A-Scientist task and performance on each individual word category in the Science Vocabulary Checklist (Table 7). The drawing elements included were identical to those in Table 6. The science vocabulary words were organized into six categories: Weather and Space, Experimental, Physics, Animal and Life Science, Environmental Science, and Size and Physical Properties.

Results of these additional partial correlations when controlling for age, gender, and SES revealed that children who produced more Environmental Science words, $r(75) = .23$, $p = .043$, and Size and Physical Property words, $r(75) = .25$, $p = .029$, drew more science equipment elements. In addition, children who produced more Size and Physical Property words, $r(75) = .24$, $p = .032$, depicted more language elements in their drawings. Thus, the specific types of science words children produce may also be important in forming their beliefs about science. We discuss this possibility in the Discussion.

Discussion

The central goal of this study was to determine whether there was a relation between children's science vocabulary and their science knowledge. We found that productive science vocabulary predicted science knowledge above and beyond general receptive vocabulary size and demographic variables previously purported to explain the science knowledge gap, including age, gender, and SES. This relation appears to be particularly important among children of preschool and kindergarten age, the age when science knowledge gaps emerge. We also found that children with larger science vocabularies depicted more extensive and diverse science activities, equipment, and language in their drawings. This suggests that these children have a broader idea of the activities, materials, and language involved in the practice of science.

Why do we observe a relation between children's science vocabulary and their science knowledge? One possibility is that there is a causal relation between words and knowledge. That is, acquiring science words may drive science learning. Previous research suggests that word knowledge facilitates basic cognitive processes such as inference and reasoning, allowing words to function as priors for learning new information (e.g., Casasola, 2005; Miller et al., 2017; Waxman & Leddon, 2011). That is, learning words can help children to acquire and build a network of new categories and concepts, which in turn helps them to learn more words. Therefore, science words might be important for science knowledge because words shape children's conceptual development in science.

A second reason why science vocabulary may be important for science knowledge is for communicating with others about science. When speaking about a science concept, using the proper language associated with that concept is essential to getting one's intended point across (Halliday & Martin, 1993). Indeed, researchers propose that teachers should use appropriate disciplinary science language when speaking with students to promote scientific literacy (Lemke, 1990; Moje, 2007). That is, educators should use words that are developmentally appropriate for children to understand instead of jargon that is primarily used by experts (Avraamidou & Osborne, 2009). For example, children will be more likely to understand the word and concept of "freezing" over the word "nucleation" when being told about the process of liquid becoming ice. In addition, children themselves benefit from being trained to use science vocabulary in classroom conversation to clearly communicate their

Table 7
Direct and Partial Correlations for Science Vocabulary Checklist Categories and Elements of Children's Drawings

	Sci equip: Total	Equip: Chemicals	Equip: Desk	Sci act: Total	Act: None	Act: Chemicals	Lang elem: Total	Lang: None	Loc: None	Loc: Trad lab	Clothes: Total	Clothes: None	Clothes: Casual	Wx/Space words	Exp words	Physics words	Anim/Life words	Environ words	Size/Phys words
Sci equip: Total	–	.352**	.566***	.544***	−.264*	.243*	.138	−.093	−.275*	.432***	.135	−.135	.158	.087	.217	.169	.159	.231*	.248*
Equip: Chemicals	.509***	–	.244*	.356**	−.371**	.971***	.070	.017	−.223	.651***	.047	−.154	−.032	.045	.151	.008	.060	−.023	.116
Equip: Desk	.630***	.361***	–	.175	−.252*	.234*	−.002	−.044	−.515***	.566***	.169	−.172	.189	−.065	.028	.017	.046	.136	.140
Sci act: Total	.648***	.482***	.323**	–	−.624***	.380**	.291**	−.155	−.094	.215	.116	−.240*	.221	.093	.128	.056	.116	.114	.181
Act: None	−.468***	−.531***	−.325**	−.677***	–	−.431***	−.028	−.020	.312**	−.175	.020	.166	−.079	−.008	.034	.027	.030	.000	−.001
Act: Chemicals	.417***	.978***	.343**	.491***	−.561***	–	.091	.000	−.200	.613***	.051	−.190	−.002	.037	.132	−.007	.057	−.041	.111
Lang elem: Total	.220*	.137	.060	.328**	−.121	.148	–	−.770***	.010	.074	−.217	.146	.013	.107	.213	.102	.140	.097	.244*
Lang: None	−.166	−.054	−.093	−.207*	.069	−.062	−.783***	–	.051	−.111	.218	−.140	.008	−.124	−.213	−.120	−.223	−.153	−.192
Loc: None	−.368***	−.292**	−.487***	−.196	.392***	−.266**	−.066	.105	–	−.379***	−.094	−.120	−.018	.113	.099	.039	.117	.021	.010
Loc: Trad lab	.531***	.705***	.610***	.351**	−.331**	.677***	.110	−.141	−.399***	–	.157	−.199	.006	−.011	.073	.012	.028	.057	.095
Clothes: Total	.296**	.185	.267**	.236*	−.218*	.177	−.080	.094	−.189	.238*	–	−.743***	.528***	−.039	−.001	−.027	.003	−.098	.004
Clothes: None	−.273**	−.270**	−.275**	−.324**	.314**	−.289**	.035	−.041	.070	−.288**	−.772***	–	−.563***	−.053	−.072	.011	−.085	.004	−.024
Clothes: Casual	.234*	.084	.247*	.264*	−.206	.099	.074	−.045	−.127	.091	.593***	−.642***	–	.123	.160	.197	.146	.141	.131
Wx/Space words	.338**	.284**	.169	.300**	−.295**	.262*	.190	−.190	−.060	.190	.214*	−.262*	.280**	–	.608***	.612***	.618***	.683***	.690***
Exp words	.440***	.399***	.239*	.329**	−.280**	.371***	.273**	−.251*	−.086	.274**	.218*	−.281**	.308**	.712***	–	.628***	.661***	.549***	.684***
Physics words	.364***	.243*	.140	.232*	−.266*	.214*	.173	−.166	−.119	.170	.192	−.181	.300**	.677***	.705***	–	.644***	.650***	.691***
Anim/Life words	.400***	.299**	.234*	.301**	−.276**	.277**	.198	−.242*	−.071	.205	.227*	−.251*	.251*	.702***	.733***	.700***	–	.758***	.735***
Environ words	.474***	.278**	.308**	.312**	−.319**	.245*	.207*	−.214*	−.160	.250*	.175	−.221*	.285**	.740***	.696***	.708***	.797***	–	.750***
Size/Phys words	.491***	.368***	.297**	.379***	−.352**	.345**	.288**	−.223*	−.177	.283**	.274**	−.261*	.288**	.750***	.779***	.779***	.792***	.812***	–

Note. Correlations below the diagonal are bivariate correlations. Correlations above the diagonal are partial correlations controlling for age, gender, and socioeconomic status. Abbreviations: sci: science, equip: equipment, act: activities, lang: language, elem: elements, loc: location, trad: traditional, Wx/Space: Weather and Space, Exp: Experimental, Anim/Life: Animal and Life Science, Environ: Environmental, Size/Phys: Size and Physical Properties.

* $p < .05$.
** $p < .01$.
*** $p < .001$.

own thoughts and explanations of a science topic (Wright & Gotwals, 2017). Finally, science vocabulary can improve science communication in practical ways: it saves time and improves clarity to use a concise keyword such as "experiment" during communication rather than an indirect explanation such as "an activity you do to test whether a prediction might be true." In sum, individuals need words to properly communicate science concepts in a social setting, and producing more relevant science words may allow individuals to articulate their existing science knowledge more efficiently.

However, an alternative explanation is that this potential causal pathway operates in the opposite direction. That is, science knowledge may drive changes in children's science vocabulary. Children who understand a given science concept may be inclined to later learn the associated vocabulary, especially because vocabulary is more easily learned with more connections to prior knowledge (Gonzalez et al., 2011). For instance, in the case of the word "freezing," a child who lives in a cold climate has likely experienced playing with icicles or seeing frozen lakes in winter before the first time they hear the word "freezing." Because of those prior experiences, this child may be more adept at learning the word "freezing" than a child who lives in a hot climate and does not have experience with icicles or frozen lakes. Indeed, prior knowledge and contextual experience lead to more rapid word learning both generally and in science (Best et al., 2006; Carlisle, Fleming, & Gudbrandsen, 2000; Kaefer, Neuman, & Pinkham, 2015).

One could also argue that science vocabulary and science knowledge are the same construct. Indeed, standardized assessments consist of many vocabulary-based questions that require individuals to produce an answer involving science words. The current study provides some evidence against this possibility. Specifically, the Draw-A-Scientist task measured children's drawing-based beliefs about science as a practice without prompts to access or report science vocabulary words. Results revealed significant correlations between children's science vocabulary production and the science elements included in children's drawings. Thus, we observed the relation between science words and science knowledge in a task that did not ask children to explicitly use science words, suggesting that science vocabulary and science knowledge may be distinct constructs.

When looking at the hierarchical regression analyses, one may also notice that besides children's science vocabulary, children's general receptive vocabulary (PPVT) scores are highly predictive of their science knowledge (Woodcock–Johnson scores) as well. This result is not surprising; children who perform higher on one standardized test are likely to perform higher on subsequent standardized tests. In this case, children who have more knowledge of general vocabulary words are likely to also have more general science knowledge. Therefore, the predictive power of general receptive vocabulary does not negate the significant relation we observed between children's science vocabulary and their science knowledge.

Finally, one could argue that the predominantly White, middle- to upper-SES background of the parents in this study is a confounding factor in determining a relation between science vocabulary and science knowledge. Specifically, one may perceive the Science Vocabulary Checklist as being a measure of parental attention to children's science learning. Indeed, highly educated and wealthier parents tend to be more involved in their children's education (Berthelsen & Walker, 2008; McQuiggan, Megra, & Grady, 2017). Parents who attend to their children's science learning may look at the science notes and materials children bring home from school and may assume that their children have said the words from these materials out loud. However, we controlled for family SES (i.e., household income and education level) throughout our analyses. Furthermore, despite our convenience sample, we still found a large variation in the number of words parents checked off on the Science Vocabulary Checklist. Thus, it is unlikely that parents' engagement with their children's science learning explains our pattern of results.

Indeed, all the above possibilities for why we observed a relation between science vocabulary and science knowledge are equally likely until further research further informs the nature of this relation. Therefore, future research should expand the scope of this work to more fully elucidate the nature of this relation. For instance, our sample was a convenience sample and thus was fairly homogeneous regarding demographic factors such as race, ethnicity, and SES. Moreover, this study did not track children's science vocabulary and science knowledge over time. If we collected data from a larger group of children with broader demographic representation and followed them longitudinally, we would gain a comprehensive view of individual differences in children's science vocabulary in relation to their changes in science knowledge over time. Thus, an important next step in this line of work is to conduct longitudinal analyses of science vocabulary and knowledge and see whether these gaps correspond to science performance gaps.

Another exciting avenue for research involves looking further into the nature of children's science vocabulary knowledge. Results of this study examined children's science vocabulary knowledge only in terms of the words they produce. There are many possible types of knowledge behind the science words children say. For example, children may produce a word without knowing its meaning, they may know a word pertains to science in general but nothing beyond that, they may know only whether the connotation is positive or negative, or they may know the word and understand how to apply it to different sentences. Moreover, future research should also examine children's receptive science vocabulary, which may differ from their productive science vocabulary. For instance, children may be able to produce a science word but may lack experience with visual representations of that word such as through performing experiments. Such work will further illuminate the relation between children's science vocabulary and their science knowledge.

In sum, this work demonstrates that differences in children's science vocabulary can explain differences in science knowledge. The unique contribution of this work is that it identifies a malleable factor, science vocabulary, that could potentially be an important component of future efforts to minimize science knowledge gaps inside and outside the classroom. Indeed, most research on science achievement gaps compares science knowledge differences across sociodemographic groups (e.g., country of residence, SES, gender, race) and thus examines factors that cannot be readily changed (e.g., Beese & Liang, 2010; Broer, Bai, & Fonseca, 2019; Guglielmi & Brekke, 2017; U.S. Department of Education, 2009). Furthermore, this work serves as a model for how to begin building bridges between psychological science and educational practice. Psychological science has historically contributed little to understanding science achievement gaps. This work shows that psychological science can aid in elucidating the mechanisms underlying these gaps and thus is a first step toward providing ideas for malleable factors for future educational interventions.

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Appendix

Child's name:____________________________ Birthdate:________________ Gender:_____

Person completing form (relationship to child):_________________________

Today's date:___________________

Science Vocabulary Checklist

Children understand many more words than they can say. We are particularly interested in the SCIENCE WORDS that your child SAYS (e.g., words related to different science topics such as physics or the weather). Please go through this list and check the words that you have heard your child use. If your child uses a different pronunciation of a word, mark it anyway.

This is a "catalogue" of all words that are used by children of a variety of ages. Do not worry if your child says only a few of these words right now.

WEATHER AND SPACE					
Cloud	○	Weather	○	Moon	○
Precipitation	○	Autumn	○	Star	○
Rain	○	Spring	○	Earth	○
Snow	○	Summer	○	Planet	○
Storm	○	Winter	○	Space	○
Wind	○	Seasons	○		

EXPERIMENTAL					
Change	○	Ruler	○	Theory	○
Cause	○	Observe	○	Pattern	○
Effect	○	Record	○	Experiment	○
Create	○	Discover	○	Explore	○
Design	○	Learn	○	Test	○
Mix	○	Guess	○		
Measure	○	Question	○		

PHYSICS					
Buoyancy	○	Balance	○	Speed	○
Float	○	Pull	○	Energy	○
Sink	○	Push	○	Sound	○
Weight	○	Move	○		

ANIMAL AND LIFE SCIENCE					
Camouflage	○	Germs	○	Carnivore	○
Hibernation	○	Molecules	○	Herbivore	○
Habitat	○	Grow	○	Predator	○
Nest	○	Molting	○	Insect	○
Cocoon	○	Living	○	Reptile	○

ENVIRONMENTAL SCIENCE					
Erosion	○	Fossil	○	Ocean	○
Sand	○	Plant	○	Mountain	○
Soil	○	Nature	○	Forest	○
Seed	○	Pollution	○	Tundra	○

SIZE AND PHYSICAL PROPERTIES					
Temperature	○	Gas	○	Thick	○
Boiling	○	Metal	○	Thin	○
Heat	○	Material	○	Symmetry	○
Melt	○	Texture	○	Magnification	○
Freeze	○	Bumpy	○	Light	○
Solid	○	Smooth	○	Reflection	○
Liquid	○	Flat	○		

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