ESTIMATING THE RELATIONSHIP BETWEEN PRESCHOOL ATTENDANCE AND KINDERGARTEN SCIENCE ACHIEVEMENT: IMPLICATIONS FOR EARLY SCIENCE ACHIEVEMENT GAPS

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Abstract
Recent evidence demonstrates that disparities by race/ethnicity and socioeconomic status in science achievement are present in the earliest grades of school. Preschool represents one potential policy solution; however, little research has explored the relationship between preschool attendance and science outcomes. This study examines whether preschool participation may improve science outcomes overall and reduce science achievement gaps by race/ethnicity, gender, and socioeconomic status. Using data from the Early Childhood Longitudinal Study of 2011, this study uses school and classroom fixed effects models with a robust set of controls to estimate the relationship between preschool attendance and early science outcomes. Results suggest that attending preschool is predictive of higher teacher-rated science ability in the fall of kindergarten but that preschool is not predictive of higher science achievement in the spring of kindergarten. The relationship is not found to consistently differ by student race, socioeconomic status, or gender, though descriptive results demonstrate that subgroups have different patterns of preschool attendance. Implications for policy and practice are discussed.

https://doi.org/10.1162/edfp_a_00247

1. INTRODUCTION

Advancing science achievement among American youth is a pressing policy goal for educational stakeholders. Unfortunately, results from international assessments show the United States lags other countries in a number of indicators of science achievement (Lee and Buxton 2010; OECD 2018). Furthermore, within the United States, disparities exist across groups in science performance. It is well documented that women and racial minorities are underrepresented in the science workforce, a gap that is linkable to disparities in science participation in higher education and K–12 schooling (Chen and Weko 2009; Riegle-Crumb and King 2010; Beede et al. 2011; Neuhauser 2015).

Although science achievement in the postsecondary and secondary sectors has been well studied (e.g., Maltese and Tai 2011; Wang 2015; Gottfried and Bozick 2016), less attention has been given to science in the earliest grades of school. Emerging evidence, however, suggests that trajectories of science achievement and disparities between groups are present in the early years of school (Kohlhaas, Lin, and Chu 2010; Maerten-Rivera et al. 2010; Quinn and Cooc 2015; Curran and Kellogg 2016; Morgan et al. 2016; Curran 2017). For instance, Curran and Kellogg (2016) document substantial race/ethnicity gaps in science achievement as early as kindergarten, and other work demonstrates that general knowledge achievement, including science, is one of the strongest predictors of science achievement through the end of eighth grade (Morgan et al. 2016). Such work suggests the need for an increased focus on early intervention as a mechanism for improving overall levels of science achievement while also improving equity in science achievement between subgroups.

Preschool is one of the most promising interventions for improving early academic performance. Although a large body of literature has demonstrated the positive effects of high-quality preschool on early elementary achievement (e.g., Magnuson, Ruhm, and Waldfogel 2007a; Gormley, Phillips, and Gayer 2008), most of this work has focused on the impacts of preschool on reading and mathematics outcomes. Comparatively, few studies have explored the relationship between participation in preschool and early elementary science outcomes, and those that do tend to focus on limited geographic regions or specific preschool programs (Henry, Gordon, and Rickman 2006; Greenfield et al. 2009). As a result, we have little evidence on the average relationship between preschool participation and science outcomes and the degree to which preschool participation might serve to mitigate early science achievement gaps.

The purpose of this paper is to provide evidence on the relationship between preschool participation and science outcomes in the kindergarten year. Furthermore, the study seeks to assess the degree to which preschool participation may mitigate early science achievement gaps as well as the ways in which structural, policy-amenable characteristics of preschools may contribute to differential science outcomes. To this end, this study uses the newly released Early Childhood Longitudinal Study of 2011 (ECLS-K:2011) to address the following research questions:

(1) What is the relationship between participation in preschool and science achievement during the spring of kindergarten?
(2) What is the relationship between participation in preschool and teacher-rated science ability during the fall of kindergarten?

(3) Do these relationships vary by student characteristics such as race/ethnicity, gender, or socioeconomic status?
(4) Does the relationship between participation in preschool and teacher-rated science ability or science achievement vary by the location of the preschool (in a K–12 school or not) or by full-time or part-time attendance?

This study has the potential to provide important information to policy makers and educational practitioners seeking to improve overall levels of and equity in science achievement. In the following sections, I provide an overview of the extant research on preschool and science achievement. I then present the data and methodology, and conclude with the findings and implications for policy and practice.

2. PRIOR LITERATURE

Early Science Achievement

Student achievement in science has been an active area of research for quite some time, reflecting policy priorities around developing a workforce capable of engaging in scientific fields (National Science Technology Council 2013). This research, however, has tended to focus on science achievement in the collegiate, secondary, or upper elementary levels of schooling, with far less work examining science achievement during the first years of formal schooling (e.g., Maltese and Tai 2011; Wang 2015; Gottfried and Bozick 2016).

Emerging evidence, however, suggests that early elementary science achievement is important for future science achievement, and that such achievement is not equal across subgroups of students (Quinn and Cooc 2015; Curran and Kellogg 2016; Morgan et al. 2016; Curran 2017). Morgan and colleagues used data from the Early Childhood Longitudinal Study (ECLS-K) to predict science achievement through eighth grade. They found that a first grade general knowledge assessment, which tested science (among other components), was a stronger predictor of science achievement from third to eighth grade than measures of mathematics achievement, reading achievement, or observable student characteristics. Furthermore, among similar covariates, kindergarten general knowledge was the strongest predictor of first grade general knowledge (Morgan et al. 2016). These findings suggest that early science performance predicts future academic trajectories, serving as a foundation for future science achievement.

Unfortunately, evidence suggests that these early science trajectories vary significantly across racial/ethnic, gender, and socioeconomic subgroups. Curran and Kellogg (2016) found that racial/ethnic gaps in science achievement exist in kindergarten, with white students outperforming black and Hispanic students by over three quarters of a standard deviation. Work by others confirms that these racial/ethnic science gaps are present through the upper elementary and middle school years (Kohlhaas, Lin, and Chu 2010; Quinn and Cooc 2015; Morgan et al. 2016). In a similar fashion, large socioeconomic gaps in science achievement are documented as early as kindergarten (Morgan et al. 2016; Curran 2017). For instance, Curran (2017) finds the gap in science achievement at kindergarten between families near the 90th percentile of income compared with those near the 10th percentile is approximately one standard deviation. Though gender gaps are less pronounced in the kindergarten year, they begin appearing by first grade and are reported at nearly a quarter of a standard deviation by third grade, with boys outperforming girls (Quinn and Cooc 2015; Curran and Kellogg 2016). In short, the early presence of science achievement gaps and the importance of early science achievement as a predictor of later science achievement suggests the potential for early intervention to improve science achievement overall and equity in science achievement between subgroups.

Science in Early Childhood Education

Preschool education represents one possible mechanism to influence early science achievement. Over the last several decades, early childhood education has expanded dramatically, with a number of states pushing for universal preschool programs (Fitzpatrick 2008; Curran 2015). Coupled with enrollment in private preschool and the federally funded Head Start program, more than 65 percent of four-year-olds now attend some form of preschool care, with nearly 40 percent in a state pre-K or Head Start program (Barnett et al. 2016; NCES 2016).

Despite the increasing prevalence of preschool education, little research has examined the relationship between preschool participation and science achievement. Nevertheless, a large body of research has demonstrated connections between high-quality preschool and early academic achievement in other subjects, such as mathematics and reading. For instance, targeted programs such as the High/Scope Perry Preschool Project and the Abecedarian Project have been shown to produce academic gains in the early years of kindergarten, as well as reduced incarceration and higher levels of educational attainment later in life (Campbell et al. 2002; Belfield et al. 2006; Temple and Reynolds 2007). Similarly, studies have found positive impacts of state-sponsored preschool programs and the federally funded Head Start program on academic outcomes (Henry, Gordon, and Rickman 2006; Fitzpatrick 2008; Gormley, Phillips, and Gayer 2008; Wong et al. 2008; Camilli et al. 2010; Puma et al. 2010). At a national level, prior work using the original Early Childhood Longitudinal Study has documented a positive relationship between center-based preschool participation and early academic achievement (Magnuson, Ruhm, and Waldfogel 2007a; Claessens, Engel, and Curran 2014). In addition to overall positive effects, prior work also suggests that preschool may particularly benefit racial minorities and, in some cases, students from lower-income households (Magnuson et al. 2004; Magnuson, Ruhm, and Waldfogel 2007a; Fitzpatrick 2008; Bassok 2010; Weiland and Yoshikawa 2013). Furthermore, though prior work is mixed, some research demonstrates that the size of the relationship can vary based on structural components of the preschool environment, such as whether the preschool is co-located with a K–12 school or whether students attend on a part-time or full-time basis (Robin, Frede, and Barnett 2006; Magnuson, Ruhm, and Waldfogel 2007a, 2007b; Reynolds et al. 2014; Leow and Wen 2016).

Very few of these studies, however, have examined the impact of preschool participation on early science outcomes. In one of the few studies that does examine science outcomes, Henry, Gordon, and Rickman (2006) estimate that participation in the Georgia state preschool program predicted higher teacher-rated science ability in the fall of kindergarten than students who attended Head Start. Their study, however, is limited to evidence from a single state's preschool program and did not include a standardized science achievement test.

Although there is little evidence on the relationship between preschool attendance and science outcomes, studies of the prevalence of science instruction in preschool settings, as well as the emphasis on science in preschool state standards, suggest that the emphasis on science in preschool can vary significantly across settings. A recent survey of state early-learning standards found approximately 94 percent of states had science early-learning standards (DeBruin-Parecki and Slutzky 2016). Approximately two thirds included science as a specifically named section in the standards, and the other third included science learning standards under another content domain (DeBruin-Parecki and Slutzky 2016). Though science content is almost universal in state early-learning standards, not all preschool providers are required to adhere to state standards. The extent to which such standards are required varies significantly across preschool settings. For instance, 66 percent of states require that state-funded preschools in public school buildings use the standards, compared with 30 percent for other center-based preschools, and only 8 percent for parochial preschools (DeBruin-Parecki and Slutzky 2016). That the requirement to adhere to state science standards varies based on whether the preschool is a state-funded program in a public school building suggests the possibility of variation in relationships between preschool attendance and science outcomes across preschool type and preschool location.

At the same time, evidence suggests that, in addition to varying across settings, science instruction is often limited in preschool. In a study of twenty preschool classrooms across thirteen Midwestern child care centers, Tu (2006) found that about half of classrooms had a formal science area but less than 5 percent of time was spent on formal science instruction and less than 10 percent of time was spent on informal science learning. Relatedly, a study of preschools in Oklahoma, a state with a universal preschool program, found that students in state-funded preschool as well as in Head Start received approximately the same amount of science instruction (about 17 percent of time), though the frequency of both was about half that of English language arts (24–30 percent of time; Phillips, Gormley, and Lowenstein 2009). Compared with a broader sample of state-run and Head Start preschool programs, however, preschools in Oklahoma provided students with 30–50 percent more science instruction, suggesting that national averages are lower (Phillips, Gormley, and Lowenstein 2009). Similarly, Cabell et al. (2013) found science instructional time to be much lower than that of social studies, literacy, or reading in a sample of both Head Start, school-based, and other preschools.

Science instruction in preschool may vary across settings depending, in part, on a number of characteristics of preschool settings. Qualitative work suggests that some preschool teachers are hesitant to teach science because of a perceived lack of science content knowledge and science pedagogical knowledge (Timur 2012). Other work, however, suggests that some groups of teachers may not see these as the most salient limitations. In a sample of Head Start teachers, most had positive views toward comfort of teaching science but cited a lack of preparation time, lack of materials, and a lack of available instructional time as the largest obstacles to science instruction (Maier, Greenfield, and Bulotsky-Shearer 2013). That teachers cite a lack of preparation and instructional time as an obstacle to science instruction suggests the possibility that relationships between preschool attendance and science outcomes could vary based on whether students attend preschool part-time or full-time.

Although science instruction time is limited in many preschool settings, the research nevertheless supports the potential for such instruction to improve school readiness indicators such as early achievement. In a study of Head Start classrooms, Fuccillo (2011) found that, compared with mathematics instruction or to circle time, science instruction prompted more higher-level instructional interactions. The study demonstrated that the use of higher-level questioning in these contexts was related to gains in both cognitive flexibility and science outcomes (Fuccillo 2011). In another study, Cabell et al. (2013) utilized data from over three hundred teachers across both Head Start, public school preschool programs, and other preschool programs to similarly examine the relationship between preschool activities and instructional quality. The results of this study confirmed those of Fuccillo (2011), finding that the most effective instructional interactions took place during science instruction. These findings are consistent with other work that shows higher-order dialogue when reading informational science books in preschool (Price, Bradley, and Smith 2012). Although research on the effectiveness of preschool science instruction is often limited because of a lack of early science assessments (Greenfield 2015), these findings suggest the possibility that attending preschool could improve early science outcomes.

In short, then, the evidence is unclear as to whether one should expect positive relationships between preschool attendance and science outcomes. On the one hand, the literature points to the potential benefits of science instruction in preschool, yet, on the other hand, the evidence suggests that little time is devoted to science instruction in preschool. Coupled with the variation in science instructional time across preschools, this body of evidence suggests the importance of exploring the relationship between preschool attendance and early science outcomes at scale. This study seeks to address this issue by using nationally representative data to estimate the relationship between preschool participation and science outcomes in kindergarten, while also exploring differential relationships for subgroups of students. Furthermore, given that science instruction may vary based on structural components of preschools, this study examines two such aspects of preschools—their location and part-time/full-time enrollment. In the next section, I describe the unique data source that allows for exploration of these questions.

3. DATA

I draw on data from the newly released Early Childhood Longitudinal Study of 2010–11 (ECLS-K:2011). The ECLS-K:2011 consists of a representative set of kindergartners from the 2010–11 school year who will be followed through fifth grade. The survey used a complex multistage sampling strategy to produce nationally representative estimates of public and private school students (Tourangeau et al. 2015a, b). The ECLS-K:2011 provides the most current evidence on the experiences of elementary school students.

The ECLS-K:2011 is unique in its inclusion of science achievement scores in the kindergarten year. Unlike the original ECLS-K, which collected data on kindergartners in the 1998–99 school year and lacked such early science assessments, the new study allows for the exploration of the relationship between early childhood education experiences and subsequent science achievement during the first year of formal schooling.

The ECLS-K:2011 science assessment included questions pertaining to the physical sciences, life sciences, environmental sciences, and scientific inquiry (Tourangeau et al. 2015a, b). The science assessment was developed from commonalities in the 2009 science standards from six states (Arizona, California, Florida, New Mexico, Texas, and Virginia) as well as from input from a panel of educators and subject area curriculum specialists (Tourangeau et al. 2015a, b). Consequently, the science assessment has a high level of validity, reflecting both state science standards and expert input. With regard to reliability, the test items were subjected to pilot field tests prior to selection of the final assessment items and had a reliability of 0.75, a lower reliability than for mathematics and reading as a result of the wider range of content assessed on the science achievement test (Tourangeau et al., 2015a, b). The science assessment, given in the spring of the kindergarten year, included a consistent set of items for all students and was administered verbally so as not to depend on written responses (Tourangeau et al. 2015a, b). For this study, I used standardized versions of the science theta score, which were derived from item response theory measures. In particular, I standardized the measures within the kindergarten year using sampling weights and survey settings to account for the complex sampling design of the ECLS-K:2011. This standardized science achievement score served as the primary dependent variable for this study.

In addition to exploring standardized science achievement, I also used a series of teacher-rated science ability measures gathered during the fall semester of kindergarten. Teacher-rated science ability measures have been used in prior studies of preschool (Henry, Gordon, and Rickman 2006). As a part of the survey, teachers rated each student on their proficiency on eight different science competencies. The competencies included "uses his/her sense to explore and observe," "forms explanations based on observations and explorations," "classifies and compares living and nonliving things in different ways," "makes logical predictions when pursuing scientific investigations," "communicates scientific information," "demonstrates understanding of physical science concepts," "demonstrates understanding of life science concepts," and "demonstrates understanding of earth and space science concepts" (Tourangeau et al. 2015a, b). Teachers could rate students' ability in each of these competencies as "not yet," "beginning," "in progress," "intermediate," or "proficient." They also had the option of specifying that the skill was not applicable or had not yet been taught. After recoding "not applicable or skill not yet taught" to missing, I created a composite version of these eight measures (Cronbach's alpha of 0.979 for the combined scale) and used the composite as well as each of the eight original measures as additional dependent variables of interest.

Because it is true that many kindergarten teachers had not had an opportunity to evaluate students' science abilities in the fall semester of kindergarten, the teacher-rated ability measure is limited to data from teachers who did indicate they had an opportunity to teach or observe the skill. As a means of assessing the validity of the fall teacher-rated ability measures in science, I compared their correlations with the spring achievement test to that of mathematics, which also had a fall achievement test. The correlation between the fall teacher-rated science ability composite measure and the spring science achievement score was similar to that for fall teacher-rated mathematics ability and spring mathematics standardized achievement scores (0.35 and 0.40, respectively). The fall teacher-rated mathematics ability composite, in turn, was moderately correlated (0.50) with the fall mathematics achievement test, suggesting that teachers' fall ratings of student ability are reasonable measures of student ability.

The primary independent variable of interest was an indicator of whether a student attended any formal preschool setting with the exclusion of Head Start. The ECLS-K asked the parents a series of questions regarding the children's early educational experiences in the year prior to kindergarten. In particular, parents could specify whether a child was in center-based care, a state-sponsored preschool program, Head Start, or whether a child was cared for by relatives or nonrelatives. I followed precedent from the literature in creating mutually exclusive indicators of early care (Magnuson et al. 2007a). In particular, I coded students as having attended Head Start if the parent indicated that any of the forms of early care were a Head Start program. I coded the student as having attended state-sponsored child care if the parent indicated that the program was state-sponsored and that it was not Head Start. Center-based care represented any formal preschool experience that was not Head Start or a state-sponsored program. The primary independent variable of interest, preschool, included those students in center-based care or state-sponsored care. Although I used this measure as the primary independent variable of interest, I also made use of the disaggregated center-based, state-sponsored, and Head Start preschool variables in alternative specifications.

In addition to the primary dependent and independent variables of interest, I used a number of covariates to mitigate selection bias. My list of control variables included a robust set of child, family, and neighborhood covariates from the original ECLS-K that aligns closely with those used by Magnuson and colleagues in a prior study of preschool (2007a). In particular, I controlled for measures such as child race, child gender, family structure, family income, parental education, parental workforce participation, educational expectations, access to books and other resources, participation in extracurricular and enrichment activities, and neighborhood safety, among others. The full list of control variables along with descriptive statistics on the control variables is provided in Appendix table A.1.

The primary analytic sample for this study consisted of students with available information on their preschool participation, as well as an available standardized science achievement score from the spring of kindergarten. Although observations were dropped due to missing data on these variables, in order to maintain representativeness, the use of weights to adjust for nonresponse and missing data attempted to adjust for these lost observations. Observations missing data on non-key variables, such as the control variables, were dealt with through the use of multiple imputation. Multiple imputation has been shown to have strong properties for handling missing data (Allison 2009) and allows for the retention of observations with missing data on control variables. I used thirty-five imputed datasets and implemented multiple imputation through the multivariate normal approach in Stata 14 (Schafer 1997; Graham, Olchowski, and Gilreath 2007). After imputation and the application of survey weights, the final analytic sample for this study consisted of 10,500 students (rounded to comply with Institute of Education Sciences restricted data standards).

4. METHODS

The primary analytic approach involved ordinary least squares regression with a robust set of student, parent, and neighborhood control variables. In addition, I included school fixed effects as well as, in some specifications, classroom fixed effects, implicitly controlling for both observed and unobserved characteristics that are fixed within schools or classrooms, respectively. The primary analytic model is shown in equation 1:

$$ScienceOutcome_{iy} = \beta_0 + \beta_1 Preschool_{iy} + \beta_2 X_{iy} + \gamma_y + e_{iy}, \tag{1}$$

where *ScienceOutcome* is the standardized science test score in the spring of kindergarten or the teacher-rated science ability measure in the fall of kindergarten for student i in school or classroom y. *Preschool* is a binary indicator of whether the student attended preschool (center-based or state-sponsored) or, in some models, disaggregated binary indicators of participation in center-based preschool, state-sponsored preschool, or Head Start. X is a vector of child, family, and contextual control variables, and γ represents the inclusion of either school or classroom fixed effects depending on the model. In this model, β_1 represents the covariate of interest and can be interpreted as the difference in standardized science achievement or teacher-rated ability for students who attended preschool compared with those who did not after controlling for the covariates and school or classroom fixed effects. Across models, the comparison group is students who were not in a formal early child care setting (center-based, state-sponsored, or Head Start). The estimates were weighted to account for the complex sampling design of the ECLS-K, and standard errors were estimated using Taylor series linearization.

One limitation of the science achievement tests is that they were administered in the spring semester of the kindergarten year. Consequently, by the time of the test, students had varying opportunities throughout the year to augment their science comprehension. Given a large body of literature around the "fade out" of preschool effects, one would expect the relationship between preschool attendance and science achievement to be smaller in the spring semester than it would have been at the start of kindergarten (Gibbs, Ludwig, and Miller 2011; Claessens, Engel, and Curran 2014; Lipsey, Farran, and Hofer 2015). The models predicting teacher-rated science ability during the fall of kindergarten partially address this issue by picking up science ability earlier in the academic year.

In addition to the primary models, I also fit models exploring differential relationships for subgroups of students defined by race/ethnicity, gender, and socioeconomic status. In particular, I fit versions of the model shown in equation 1 that included interactions between the preschool variable and dummy variables indicating student race, student gender, or family income quartile. These models take the form shown in equation 2:

$$\begin{aligned} ScienceOutcome_{iy} = {} & \beta_0 + \beta_1 Preschool_{iy} + \beta_2 Preschool_{iy} * Subgroup\_Indicator_{iy} \\ & + \beta_3 X_{iy} + \gamma_y + e_{iy}, \end{aligned} \tag{2}$$

where the variables and covariates are the same as equation 1 except for the interaction term between preschool and the subgroup indicators (race/ethnicity, gender, or income bracket depending on the model). The key coefficient of interest in these models is β_2, which can be interpreted as the differential relationship between preschool attendance and science outcomes for each subgroup.

Finally, I fit models that examined the relationship between structural characteristics of the preschool environment and early science outcomes. These models inform policy-amenable characteristics of preschools that prior literature suggests may be related to preschool effects (Robin, Frede, and Barnett 2006; Magnuson, Ruhm, and Waldfogel 2007a, b; Maier, Greenfield, and Bulotsky-Shearer 2013; Reynolds et al. 2014; DeBruin-Parecki and Slutzky 2016; Leow and Wen 2016). In particular, I fit variants of the primary model (equation 1) in which the preschool indicator was replaced with measures of whether the preschool attended was located in a K–12 school building or not, or with measures of whether the student attended the preschool full or part-time. In the first of these models, two binary indicators, one representing preschool attendance in a K-12 building and another representing preschool attendance in a non-K-12 building, were included in the model. In the second of these models, an indicator for full-time enrollment (>20 hours per week) was included along with an indicator for part-time enrollment (20 or fewer hours per week), a part/full-time distinction used in prior literature (Magnuson, Ruhm, and Waldfogel 2007a). As with the primary models, these models included an indicator for Head Start participation, making the comparison group those students who did not attend any formal preschool.

Assessing the effects of preschool on early elementary achievement is complicated by issues of selection. In particular, the students who participated in preschool may differ systematically from those who did not in ways that would independently influence their academic outcomes. As a result, any attempt to isolate the effects of preschool on science outcomes must attempt to account for such selection bias. My analytic strategy addresses a number of potential sources of bias, although it does not entirely eliminate the possibility of confounding variables. Consequently, the results should be interpreted as covariate-adjusted relationships rather than causal estimates.

5. RESULTS

I find that participation in preschool is generally predictive of increased teacher-rated science ability during the fall of kindergarten but is not significantly related to standardized science achievement during the spring of kindergarten. I find, however, that the relationship varies by type of preschool with the positive relationship between preschool participation and teacher-rated science ability being driven primarily by participation in center-based preschool as opposed to state-sponsored preschool or Head Start. The relationship between preschool participation and science ability/achievement is generally consistent across student race, gender, and family income, although there is suggestive evidence of larger impacts for black and male students. Nevertheless, descriptive statistics suggest that white students and more affluent students have different patterns of preschool attendance than their nonwhite or less-affluent peers. Finally, the relationship between preschool participation and teacher-rated science ability appears largest

Table 1. Means and Standard Errors of Preschool Participation, Science Achievement, and Teacher-Rated Science Ability for Full Sample by Preschool Status

	Full Sample	Preschool (Center-Based or State-Sponsored)	Center-Based Preschool	State-Sponsored Preschool	Head Start	No Formal Preschool
Spring science achievement (standardized)	0.0690 (0.032)	0.292 (0.026)	0.385 (0.027)	0.0445 (0.040)	−0.366 (0.044)	−0.128 (0.047)
Teacher-rated science ability at fall of K						
Sense	2.843 (0.029)	2.988 (0.036)	3.036 (0.044)	2.857 (0.046)	2.649 (0.052)	2.656 (0.032)
Explain	2.621 (0.027)	2.788 (0.034)	2.865 (0.041)	2.581 (0.042)	2.355 (0.047)	2.419 (0.037)
Classify	2.845 (0.030)	3.016 (0.035)	3.088 (0.040)	2.822 (0.058)	2.588 (0.046)	2.642 (0.043)
Predict	2.653 (0.031)	2.818 (0.036)	2.869 (0.040)	2.681 (0.055)	2.411 (0.051)	2.449 (0.040)
Communicate	2.437 (0.032)	2.583 (0.039)	2.633 (0.046)	2.453 (0.049)	2.226 (0.044)	2.264 (0.039)
Physical science	2.575 (0.027)	2.709 (0.035)	2.761 (0.042)	2.577 (0.048)	2.359 (0.040)	2.426 (0.035)
Life science	2.814 (0.027)	2.955 (0.034)	3.003 (0.038)	2.825 (0.054)	2.646 (0.043)	2.621 (0.032)
Earth/space science	2.372 (0.035)	2.542 (0.044)	2.577 (0.051)	2.450 (0.063)	2.161 (0.049)	2.157 (0.046)
Composite	2.582 (0.037)	2.764 (0.047)	2.831 (0.054)	2.590 (0.071)	2.404 (0.055)	2.328 (0.042)
Preschool (center-based or state-sponsored)	0.556	1.000	1.000	1.000	0.000	0.000
Center-based preschool	0.404	0.727	1.000	0.000	0.000	0.000
State-sponsored preschool	0.152	0.273	0.000	1.000	0.000	0.000
Head Start	0.153	0.000	0.000	0.000	1.000	0.000
Relative care	0.067	0.000	0.000	0.000	0.000	0.231
Nonrelative care	0.024	0.000	0.000	0.000	0.000	0.083
Parental care	0.200	0.000	0.000	0.000	0.000	0.687
Structural components						
Not located in K–12 school	0.377	0.678	0.779	0.411	0.000	0.000
Located in K–12 school	0.179	0.322	0.221	0.589	0.000	0.000
Full time (>20 hrs/week)	0.246	0.443	0.433	0.469	0.000	0.000
Part time (≤20 hrs/week)	0.310	0.557	0.567	0.531	0.000	0.000
N	10,500	5,950	4,430	1,520	1,560	2,990

Notes: Standard errors of nonbinary variables shown in parentheses. Sample sizes for teacher-rated ability vary due to missing data.

for preschools not located in K–12 buildings. In this section, I present the results that support these findings.

Descriptive Statistics

Participation in some form of preschool child care is common. As shown in table 1, over 70 percent of kindergarten students had taken part in either center-based preschool, Head Start, or a state-sponsored preschool program. Of these formal child care settings, center-based preschool was the most common, with over 40 percent of the sample having taken part in a center-based setting that is not Head Start or a state-sponsored preschool program.

Table 2. Means and Standard Errors of Preschool Participation, Science Achievement, and Teacher-Rated Science Ability for Full Sample and by Student Characteristics

	Full Sample	White	Black	Hispanic	Asian	Boys	Girls	Higher Income	Lower Income
Spring science achievement (standardized)	0.0690 (0.032)	0.408 (0.023)	−0.424 (0.065)	−0.568 (0.046)	−0.0965 (0.055)	0.0834 (0.031)	0.0536 (0.035)	0.360 (0.021)	−0.358 (0.041)
Teacher-rated science ability at fall of K									
Sense	2.843 (0.029)	2.987 (0.036)	2.664 (0.059)	2.527 (0.039)	2.871 (0.106)	2.812 (0.031)	2.877 (0.034)	3.007 (0.037)	2.602 (0.032)
Explain	2.621 (0.027)	2.783 (0.035)	2.360 (0.069)	2.289 (0.035)	2.749 (0.088)	2.592 (0.033)	2.651 (0.033)	2.819 (0.035)	2.323 (0.028)
Classify	2.845 (0.030)	3.009 (0.035)	2.633 (0.071)	2.507 (0.042)	2.869 (0.100)	2.817 (0.036)	2.875 (0.032)	3.052 (0.036)	2.538 (0.037)
Predict	2.653 (0.031)	2.810 (0.039)	2.429 (0.064)	2.318 (0.041)	2.721 (0.077)	2.649 (0.035)	2.656 (0.035)	2.856 (0.037)	2.348 (0.033)
Communicate	2.437 (0.032)	2.591 (0.039)	2.251 (0.053)	2.125 (0.041)	2.582 (0.126)	2.409 (0.036)	2.466 (0.035)	2.618 (0.040)	2.185 (0.032)
Physical science	2.575 (0.027)	2.723 (0.036)	2.399 (0.050)	2.281 (0.036)	2.629 (0.107)	2.559 (0.029)	2.593 (0.032)	2.755 (0.036)	2.321 (0.028)
Life science	2.814 (0.027)	2.936 (0.035)	2.718 (0.072)	2.548 (0.037)	2.829 (0.091)	2.789 (0.028)	2.841 (0.032)	2.977 (0.032)	2.577 (0.036)
Earth/space science	2.372 (0.035)	2.522 (0.046)	2.178 (0.066)	2.100 (0.041)	2.549 (0.139)	2.378 (0.039)	2.365 (0.040)	2.569 (0.049)	2.104 (0.033)
Composite	2.582 (0.037)	2.755 (0.044)	2.395 (0.077)	2.254 (0.045)	2.720 (0.181)	2.557 (0.045)	2.607 (0.039)	2.788 (0.050)	2.297 (0.033)
Preschool (center-based or state-sponsored)	0.556	0.654	0.376	0.377	0.652	0.560	0.553	0.692	0.357
Center-based preschool	0.404	0.509	0.225	0.207	0.538	0.402	0.407	0.545	0.199
State-sponsored preschool	0.152	0.145	0.152	0.170	0.113	0.158	0.145	0.147	0.158
Head Start	0.153	0.093	0.332	0.220	0.096	0.156	0.150	0.078	0.264
Relative care	0.067	0.055	0.079	0.094	0.053	0.063	0.072	0.050	0.092
Nonrelative care	0.024	0.029	0.016	0.020	0.006	0.022	0.026	0.030	0.015
Parental care	0.200	0.168	0.198	0.289	0.194	0.199	0.200	0.150	0.272
Structural components									
Not located in K–12 school	0.377	0.470	0.242	0.188	0.490	0.377	0.378	0.500	0.197
Located in K–12 school	0.179	0.184	0.134	0.188	0.160	0.183	0.175	0.192	0.159
Full time (> 20 hrs/week)	0.246	0.256	0.283	0.169	0.341	0.254	0.238	0.293	0.178
Part time (≤ 20 hrs/week)	0.310	0.398	0.093	0.207	0.310	0.306	0.314	0.399	0.178
N	10,500	5,780	1,200	2,180	700	5,370	5,130	6,410	4,090

Notes: Standard errors of nonbinary variables shown in parentheses. Sample sizes for teacher-rated ability vary due to missing data.

Despite the high proportion of students taking part in preschool, not all groups of students took part at the same rate. In particular, there were significant differences across student race/ethnicity and family income in the rate of participation in preschool, particularly center-based preschool. As shown in table 2, more than half of white and Asian students took part in a center-based preschool program, whereas less than one quarter of black and Hispanic students were in such a setting. Black and Hispanic students were, however, more likely to take part in the federally funded Head Start program than white students. Similarly, students from higher-income households ($40,000 or more) were approximately two and half times more likely to take part in center-based preschool than their peers from lower-income households, and only about a quarter as likely to take part in Head Start. There were no meaningful differences in preschool participation across gender.

The results shown in tables 1 and 2 also point to differences in spring of kindergarten science achievement across preschool care, across race/ethnicity, and across family income. Students who participated in preschool (other than Head Start) performed almost half a standard deviation higher than those not in preschool. Across student race/ethnicity, in the spring of kindergarten, white students scored over 0.8 of a standard deviation higher than black and Hispanic students in science achievement. Students from higher-income families scored approximately 0.7 standard deviations higher than their peers from lower-income families.

Similar trends were observed on the teacher ratings of science ability at the fall of kindergarten. In particular, students having attended preschool were rated approximately 0.4 units higher on the composite scale (0 to 4 representing not yet to proficient) of teacher-rated science ability than those who had not attended any formal preschool. A similar difference was observed when comparing white students with black or Hispanic students and when comparing students from higher-income backgrounds with students from lower-income backgrounds.

The descriptive results suggest then that there are large differences in science ability/achievement between students who attended preschool and those who did not. Furthermore, gaps were present across student race/ethnicity and family income in science achievement levels, teacher-rated science ability, and participation in preschool. These results suggest the possibility that preschool may contribute to early science outcomes and that differences in participation across race and family income may explain some of the early science achievement gaps. To further explore this relationship, I turn next to results of regressions that include a robust set of individual and family controls, as well as school and classroom fixed effects. As the standardized achievement test is both likely more reliable and is available for a larger sample of students, I begin with a presentation of results for spring standardized science achievement and then discuss fall of kindergarten teacher-rated science ability.

Standardized Science Achievement During Spring of Kindergarten

Table 3 shows results of regression models predicting standardized science achievement during the spring of kindergarten from participation in preschool. The upper panel of the table includes regression results from models including a single binary indicator of participation in preschool (center-based or state-sponsored) and the lower panel includes disaggregated measures of center-based preschool, state-sponsored preschool, and Head Start. The omitted group in all of the regression models in both panels include students not in formal early childhood care (not in center-based, state-sponsored, or Head Start).

Table 3 shows results of models that progressively add controls for family income, contextual factors, school fixed effects, and classroom fixed effects. As shown in the upper panel of column 1, the bivariate regression captures the same relationship shown in the conditional means of table 1—namely, that students who participated in preschool scored almost half a standard deviation higher on the science assessment. When adding

Table 3. Coefficients and Standard Errors from Regressions Predicting Spring of Kindergarten Standardized Science Achievement from Preschool Participation

	Spring of Kindergarten Science Achievement (Standardized)				
	(1)	(2)	(3)	(4)	(5)
Preschool (center-based or state-sponsored)	0.420** (0.0396)	0.206** (0.0341)	0.0001 (0.0254)	0.0106 (0.0238)	0.00275 (0.0293)
Center-based preschool	0.513** (0.0407)	0.263** (0.0348)	0.0147 (0.0284)	0.0239 (0.0251)	0.0141 (0.0314)
State-sponsored preschool	0.173** (0.0560)	0.0839+ (0.0469)	−0.0275 (0.0302)	−0.0169 (0.0336)	−0.0236 (0.0410)
Head Start	−0.238** (0.0408)	−0.117** (0.0389)	−0.106** (0.0288)	−0.0968** (0.0333)	−0.102* (0.0405)
Income controls		X	X	X	X
Child, family, and contextual controls			X	X	X
School fixed effects				X	
Classroom fixed effects					X
Observations	10,500	10,500	10,500	10,500	10,500

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. The omitted category in all models is students who were not in a formal preschool setting—namely, those who were cared for by relatives, nonrelatives, or parents, and were not in a center-based, state-sponsored, or Head Start program.

$^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.

controls for family income (column 2), however, this relationship was reduced by approximately half. Column 3 accounted for differences in child, family, and contextual factors. As shown, accounting for these factors reduced the relationship between preschool participation and science achievement to near zero.

The fixed effects models (columns 4 and 5) implicitly control for all fixed aspects of students in either the school or classroom. The advantage of these models is that they control for both observable and unobservable characteristics common among students attending the same school or classroom. As shown, the relationship between preschool and spring of kindergarten science achievement remains nonsignificant with the addition of school or classroom fixed effects, suggesting that the robust set of family income and child, family, and contextual controls were already accounting for much of the differences in students across these settings.

Examining results of the models with disaggregated indicators of preschool demonstrates a similar trend (bottom panel of table 3). In particular, the relationship between center-based preschool as well as state-sponsored preschool and science achievement is positive and significant in the unadjusted model (column 1). However, this relationship becomes statistically nonsignificant when controlling for the full range of family income and child, family, and contextual controls (column 3). Likewise, models with school and classroom fixed effects (columns 4 and 5) also show no significant relationship. The relationship between Head Start and standardized science achievement is consistently negative, although given the targeted nature of Head Start, this relationship may be driven by unobserved characteristics of the students participating in Head Start.

The statistical nonsignificance observed for standardized science achievement was also observed for mathematics and reading outcomes during the spring of

Table 4. Coefficients and Standard Errors from Regressions Predicting Spring and Fall of Kindergarten Standardized Math and Reading Achievement from Preschool Participation

Panel A: Spring of Kindergarten Mathematics and Reading Achievement										
	Spring of Kindergarten Math Achievement (std.)					Spring of Kindergarten Reading Achievement (std.)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Preschool (center-based or state-sponsored)	0.376** (0.0315)	0.178** (0.0263)	0.00624 (0.0213)	0.0274 (0.0260)	0.0379 (0.0330)	0.342** (0.0295)	0.180** (0.0265)	0.0162 (0.0208)	0.0327 (0.0245)	0.0279 (0.0299)
Income controls		X	X	X	X		X	X	X	X
Child, family, and contextual controls			X	X	X			X	X	X
School fixed effects				X					X	
Classroom fixed effects					X					X
Observations	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
Panel B: Fall of Kindergarten Mathematics and Reading Achievement										
	Fall of Kindergarten Math Achievement (std.)					Fall of Kindergarten Reading Achievement (std.)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Preschool (center-based or state-sponsored)	0.514** (0.0417)	0.309** (0.0347)	0.123** (0.0253)	0.0981** (0.0245)	0.0814* (0.0317)	0.483** (0.0356)	0.305** (0.0314)	0.129** (0.0237)	0.122** (0.0246)	0.117** (0.0319)
Income controls		X	X	X	X		X	X	X	X
Child, family, and contextual controls			X	X	X			X	X	X
School fixed effects				X					X	
Classroom fixed effects					X					X
Observations	10,320	10,320	10,320	10,320	10,320	10,340	10,340	10,340	10,340	10,340

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. The omitted category in all models is students who were not in a formal preschool setting—namely, those who were cared for by relatives, nonrelatives, or parents, and were not in a center-based, state-sponsored, or Head Start program. std = standardized.

$^{**}p < 0.01$; $^{*}p < 0.05$.

kindergarten. Panel A of table 4 shows results of similar regression models predicting standardized mathematics and reading achievement (basic reading and early literacy skills) in the spring of kindergarten. As shown, estimates with the full set of controls and the fixed effects models were also statistically nonsignificant for mathematics and reading, although the magnitude of such estimates was larger than that for science. Unlike science, the ECLS-K did include standardized achievement tests for mathematics and reading in the fall of kindergarten. Panel B of table 4 shows results from models predicting standardized mathematics and reading achievement in the fall of kindergarten. As shown, preschool participation predicts statistically significant higher scores (approximately 0.10 standard deviations or SD) in mathematics and reading achievement during the fall of kindergarten even in the fully controlled models. The presence of a significant relationship in the fall of kindergarten but not in the spring of kindergarten is consistent with a "fade out" of preschool effects, as documented in the literature (Gibbs, Ludwig, and Miller 2011; Claessens, Engel, and Curran 2014; Lipsey, Farran, and Hofer 2015). To assess whether preschool participation's relationship with science outcomes might also be stronger in the fall of kindergarten, I turn next to results of models predicting fall of kindergarten teacher-rated science ability.

Table 5. Coefficients and Standard Errors from Regressions Predicting Fall of Kindergarten Teacher-Rated Science Ability from Preschool Participation

	Sense	Explain	Classify	Predict	Communicate	Physical Science	Life Science	Earth/ Space Science	Composite
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Preschool (center-based or state-sponsored)	0.0820* (0.0354)	0.0783+ (0.0445)	0.0921* (0.0406)	0.0644 (0.0412)	0.0894+ (0.0457)	0.0643 (0.0408)	0.0867* (0.0370)	0.0869+ (0.0508)	0.133** (0.0510)
Center-based preschool	0.111** (0.0383)	0.118* (0.0458)	0.130** (0.0434)	0.0887* (0.0447)	0.108* (0.0500)	0.0963* (0.0440)	0.112** (0.0402)	0.0975+ (0.0557)	0.180** (0.0563)
State-sponsored preschool	0.0168 (0.0467)	−0.0127 (0.0607)	0.000221 (0.0553)	0.00790 (0.0552)	0.0486 (0.0562)	−0.00522 (0.0536)	0.0297 (0.0491)	0.0644 (0.0670)	0.0372 (0.0647)
Head Start	0.0546 (0.0446)	0.0140 (0.0532)	0.0465 (0.0513)	0.0348 (0.0517)	0.0488 (0.0549)	0.00799 (0.0486)	0.0444 (0.0448)	0.0419 (0.0596)	0.0694 (0.0616)
Income controls	X	X	X	X	X	X	X	X	X
Child, family, and contextual controls	X	X	X	X	X	X	X	X	X
Classroom fixed effects	X	X	X	X	X	X	X	X	X
Observations	7,500	6,490	6,050	6,320	5,960	6,510	6,770	4,270	3,390

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. Sample sizes vary across this table as teachers had the option of not answering the question and instead noting they had not had the opportunity to observe the skill. The omitted category in all models is students who were not in a formal preschool setting—namely, those who were cared for by relatives, nonrelatives, or parents, and were not in a center-based, state-sponsored, or Head Start program.

$^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.

Teacher Perceptions of Science Ability

A limitation of the science achievement test in the ECLS is that it was administered during the latter half of the kindergarten year. Given evidence on the fade out of preschool effects (Gibbs, Ludwig, and Miller 2011; Claessens, Engel, and Curran 2014; Lipsey, Farran, and Hofer 2015), one would expect smaller relationships at the end of kindergarten than at the beginning. Although a standardized test of science achievement was not available during the fall of kindergarten, teachers did provide their reports of students' ability within eight different science competencies. Results from regressions predicting these ratings show a consistent positive relationship between preschool attendance and teacher-rated science ability during the fall of kindergarten. In particular, as shown in the top panel of table 5, participation in preschool had at least a marginally significant ($p < 0.10$) and positive relationship with all except two of the teacher ratings—namely, predicting and physical science. The relationship between preschool participation and the composite measure (column 9) of teacher-rated science ability was also positive and statistically significant. The magnitude, 0.133 units on a 0 to 4 scale ranging from not yet having the skill to proficient at the skill, equates to an approximately 0.06 standard deviation larger composite teacher rating of science ability on the composite scale.

When disaggregating the preschool measure into types of preschool attended (bottom portion of table 5), the results suggest that the positive relationship observed is driven primarily by participation in center-based preschool as opposed to participation in state-sponsored preschool. In particular, participation in center-based preschool is predictive of higher teacher-rated science ability in each of the eight science competency areas. Likewise, the composite score (column 9) is approximately 0.18 units higher for students who attended center-based preschool than for students who were in no formal preschool care. The relationship for state-sponsored and Head Start participation lean in the positive direction but are considerably smaller in magnitude and are not statistically distinguishable from zero.

Although teacher ratings may be more subject to personal bias or perception, the models shown in table 5 used classroom fixed effects, meaning that the comparisons were restricted to those ratings conducted by the same teacher. In short, any systematic differences in teacher ratings, such as a teacher who consistently rates students lower or higher, was accounted for by the classroom fixed effect.

Student Subgroup Interactions

Next, models were estimated in which the binary indicator for preschool was interacted with binary indicators for student race, student gender, and family income. Appendix tables A.2 through A.4 show results of these models for both spring of kindergarten standardized science achievement, as well as fall of kindergarten teacher-rated science ability. In general, the interaction terms are statistically nonsignificant. Exceptions include a marginally significant ($p < 0.10$) and positive interaction on the standardized science achievement score between preschool attendance and being black, as well as a marginally significant negative relationship between the teacher-rated composite and the interaction term between preschool and the indicator for a female student. With the exception of these suggestive results for black and female students, the interaction models results suggest that, after controlling for the wide range of covariates, the positive relationship between preschool attendance and elementary science achievement does not vary systematically for students of different race, gender, or family income.

Location and Full-Time/Part-Time Attendance

Finally, results suggest that the relationship between preschool attendance and early science outcomes may be sensitive to whether the preschool setting is located in a K–12 school as well as to whether students attend full-time or part-time. As shown in Appendix table A.5, I find that attendance in a preschool setting not located in a K–12 school predicts significantly higher teacher-rated science ability in the fall of kindergarten, whereas attendance at a preschool setting in a K–12 school does not. As with the primary models, neither attendance at a preschool in or out of a K–12 school is significantly related to standardized science achievement in the spring of kindergarten. Results of models predicting science outcomes from indicators of full- or part-time attendance in preschool are shown in table A.6. As shown, both full- and part-time attendance are predictive of higher teacher-rated science ability in the fall of kindergarten, although neither is predictive of significantly higher science achievement in the spring of kindergarten.

6. DISCUSSION

This study suggests that attending preschool may result in higher science ability at the fall of kindergarten but that such higher science ability does not persist to measurable differences in science achievement in the spring of kindergarten. Furthermore, the results suggest that the relationship between preschool attendance and early science outcomes tend to be consistent across subgroups of students. Nevertheless, the results point to potential differences by type of preschool (center-based, state-sponsored, or Head Start) as well as differences by preschool characteristics such as whether the preschool is located in a K–12 school. The results have important implications for the study of equity in early science achievement. In this section, I put the findings in context of prior literature while discussing the implications of the findings.

First, the finding that preschool participation tends to be related to teacher-rated science ability in the fall of kindergarten is consistent with prior work on the positive academic impacts of early childhood education. In particular, prior studies have demonstrated a positive relationship between preschool participation and mathematics and reading achievement in the fall of kindergarten (e.g., Magnuson, Ruhm, and Waldfogel 2007a; Gormley, Phillips, and Gayer 2008), and, though limited to teacher-rated ability rather than standardized achievement, this study demonstrates that these generally positive relationships may extend to the subject of science. In doing so, this study builds on prior work that found a positive relationship between preschool attendance and teacher-rated science ability by validating the findings with a nationally representative dataset (Henry, Gordon, and Rickman 2006).

There are several possible mechanisms by which this positive relationship may be working. First, it is possible that participation in preschool offers students more exposure to scientific concepts and processes. A robust body of literature demonstrates the importance of “opportunity to learn,” or the concept that exposure to material is a necessary prerequisite for learning that material (Carroll 1963, 1989; Sørensen and Hallinan 1977; Wang 1998; Aguirre-Muñoz and Boscardin 2008; Hong 2012; Claessens, Engel, and Curran 2014; Jez and Wassmer 2015). Preschool participation, therefore, may improve early science outcomes by providing an increased opportunity to learn science. Such a mechanism would be consistent with literature that shows science instruction in preschool facilitates higher-order instruction (Fuccillo 2011; Cabell et al. 2013). A second mechanism, however, is that preschool participation may affect students’ science ability through increased mathematics and reading ability (see, e.g., O’Reilly and McNamara 2007). Increased language skills may offer students the opportunity to interact with materials that, in turn, expand scientific knowledge, and increased mathematics ability may foster reasoning skills that translate to scientific domains. The data available in the current study lack details to explore the mechanisms behind the observed relationship, but future research might further explore the relationship between particular components of the preschool experience and science outcomes to further understand the mechanisms at work.

Despite the positive relationship with teacher-rated science ability, the results did not indicate a significant relationship between preschool attendance and science achievement on a standardized test in the spring of kindergarten. While this lack of relationship could indicate the teacher-rated ability outcomes were not picking up true science knowledge, it is also plausible that any science learning gains attributable to preschool attendance have faded out by the end of kindergarten. Indeed, results for mathematics and reading show nonsignificant relationships between preschool attendance and spring achievement despite positive relationships in the fall of kindergarten. This finding would be consistent with the broad literature on the fade out of preschool effects (Gibbs, Ludwig, and Miller 2011; Claessens, Engel, and Curran 2014; Lipsey, Farran, and Hofer 2015).

In addition to these general findings, there was also evidence of heterogeneity across types of preschool attended. In particular, the positive relationship between preschool attendance and teacher-rated science ability appears to be driven predominantly by attendance in center-based preschool as opposed to state-sponsored preschool or Head Start. Although these differential relationships suggest the possibility of differential effects on science outcomes, these relationships must be interpreted cautiously. Head Start and many state-sponsored preschool programs are targeted toward disadvantaged student groups. Prior literature has noted the complexities of fully accounting for omitted variable bias in correlational studies of these targeted programs (Magnuson, Ruhm, and Waldfogel 2007a). Given the evidence of plausible positive causal effects of Head Start and state-sponsored programs on other subjects (Gormley, Phillips, and Gayer 2008; Puma et al. 2010) and some evidence of their positive effects on early science ability (Henry, Gordon, and Rickman 2006), these coefficients should not be taken as evidence of negative or null effects of Head Start and state-sponsored programs on science achievement. Instead, the differences between the estimates for center-based preschool and other preschools suggest the need for future research exploring possible heterogeneity in the impact of each of these settings on early science achievement.

In addition to heterogeneity by sector of preschool, the results also point to the importance of considering the structural characteristics of preschool programs. The point estimate on full-time preschool was larger than that for part-time attendance (though not statistically so), which suggests that more time-intensive preschool experiences may yield larger benefits. The research has documented that some preschool teachers feel a lack of instructional time hinders their ability to teach science in preschool, so a full-time program may alleviate this issue and result in more science instruction (Maier, Greenfield, and Bulotsky-Shearer 2013). Furthermore, the finding that the positive relationship between preschool attendance and teacher-rated ability appears to be driven more by attendance in preschool settings not located in K–12 school settings suggests that preschools in non-K–12 environments may be approaching science instruction differently than those embedded in K–12 schools. This finding contrasts with earlier work that found positive relationships between preschools colocating with K–12 environments and academic achievement in other subjects (Magnuson, Ruhm, and Waldfogel 2007a). It is possible that preschools in K–12 settings feel more pressure than those not in such settings to emphasize mathematics and reading at the expense of science instruction through the increased accountability context of K–12 schools (Marx and Harris 2006). Future research could further explore the factors that explain this differential relationship.

Finally, recent literature has drawn attention to disparities in early science achievement, particularly along lines of race/ethnicity and family income (Curran and Kellogg 2016; Curran 2017). The results of this study inform ways in which policy makers may begin to address and mitigate these disparities. First, though there were some marginally significant relationships, the models with race/ethnicity interactions did not show any consistent differences across race/ethnicity in the relationship between preschool attendance and early science achievement. This suggests, on average, that any gains in early science outcomes produced by participation in preschool do not vary significantly by race/ethnicity. Similar null findings on interactions with student gender and family income suggest no significant differential effects of preschool on science outcomes for these subgroups either.

That said, the descriptive statistics point to significant differences across race–ethnicity and family income in aspects of preschool attendance. In particular, white students are over twice as likely to have participated in center-based preschool than their black or Hispanic counterparts. Likewise, students from higher-income families are over two and half times more likely to have participated in center-based preschool than their peers from lower-income families. Although overall rates of participation in some form of preschool (either Head Start, center-based, or state-based preschool) are fairly similar between students of different race/ethnicity, the differences in types of preschool settings attended by students of different race/ethnicity suggest the possibility that students of different race/ethnicity are systematically exposed to differential preschool experiences with regard to science. Though the data used in the study did not allow for an exploration of the amount or type of science instruction across preschool settings, future studies could explore whether the science instructional components of different preschool types account for differences in science outcomes by race/ethnicity.

While students in different race/ethnic groups differed largely on the type of formal preschool care attended as opposed to the probability of being in any formal preschool care, students of different family income levels experienced not only differential likelihood in attending different types of care but also differential likelihood of being in any formal preschool care. In particular, students from lower-income households were almost 25 percent less likely to have participated in center-based preschool, Head Start, or state-sponsored preschool. This difference suggests a need for increased access to quality care for students from lower-income households.

7. CONCLUSIONS

Science and the related STEM fields (science, technology, engineering, and mathematics) continue to be priority areas for improving student achievement. International evidence suggests that our students lag behind many other developed nations in science achievement (Martin et al. 2012; OECD 2013) and evidence from within the United States points to significant disparities across racial/ethnic groups in science achievement (Chen and Weko 2009; Kohlhaas, Lin, and Chu 2010; Quinn and Cooc 2015). Given recent evidence that these disparities are present as early as kindergarten (Curran and Kellogg 2016; Morgan et al. 2016), identifying interventions that may improve early science achievement overall and mitigate achievement gaps is of particular importance.

This study has addressed one such intervention, namely, preschool, and its relationship with early science outcomes and achievement gaps. The findings suggest that preschool attendance, particularly center-based preschool, may increase academic performance in science but that any such gains are not sustained to the end of kindergarten. The results also highlight systematic differences in the types of preschool environments experienced by students of different racial/ethnic background and family income. In doing so, this study builds on a very limited set of prior studies that have explored the relationship between preschool and science achievement or science ability by providing evidence from a nationally representative dataset (Henry et al. 2006). The results of this study point to the need for increased attention to early science achievement and preschool by both policy makers and researchers. Such attention holds the potential to improve early science outcomes for all students, particularly those most in need.

ACKNOWLEDGMENTS

The author would like to thank participants in the UNC Education Policy Colloquium Series, as well as the editors and anonymous reviewers, for valuable feedback on earlier versions of this paper.

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APPENDIX A: ADDITIONAL DATA

Table A.1. Control Variables for Full Sample and by Preschool Subgroup

	Full Sample	Any Preschool	Center-Based Preschool	State-Funded Preschool	Head Start	No Formal Preschool
Family income						
$5,001 to $10,000	0.036	0.017	0.014	0.026	0.080	0.048
$10,001 to $15,000	0.058	0.029	0.020	0.052	0.112	0.085
$15,001 to $20,000	0.058	0.031	0.023	0.054	0.116	0.079
$20,001 to $25,000	0.078	0.044	0.033	0.075	0.146	0.106
$25,001 to $30,000	0.049	0.039	0.030	0.062	0.074	0.056
$30,001 to $35,000	0.049	0.041	0.034	0.059	0.062	0.057
$35,001 to $40,000	0.047	0.043	0.035	0.065	0.047	0.055
$40,001 to $45,000	0.034	0.028	0.023	0.043	0.036	0.042
$45,001 to $50,000	0.037	0.036	0.032	0.045	0.035	0.041
$50,001 to $55,000	0.034	0.035	0.033	0.038	0.029	0.035
$55,001 to $60,000	0.032	0.034	0.032	0.040	0.015	0.037
$60,001 to $65,000	0.034	0.036	0.036	0.036	0.024	0.036
$65,001 to $70,000	0.033	0.039	0.040	0.034	0.019	0.031
$70,001 to $75,000	0.041	0.048	0.051	0.042	0.028	0.032
$75,001 to $100,000	0.138	0.179	0.192	0.143	0.056	0.101
$100,001 to $200,000	0.168	0.242	0.283	0.131	0.048	0.090
$200,001 or more	0.044	0.063	0.077	0.025	0.013	0.025

Table A.1. Continued.

	Full Sample	Any Preschool	Center-Based Preschool	State-Funded Preschool	Head Start	No Formal Preschool
Primary parent employed full-time	0.418	0.469	0.473	0.457	0.410	0.325
Primary parent employed part-time	0.210	0.226	0.236	0.202	0.194	0.186
Secondary parent employed full-time	0.757	0.825	0.848	0.763	0.609	0.705
Secondary parent employed part-time	0.075	0.061	0.057	0.072	0.101	0.087
Child is female	0.485	0.482	0.489	0.465	0.474	0.497
Primary parent education level						
9th–12th grade	0.072	0.037	0.021	0.078	0.100	0.124
High school diploma or equivalent	0.200	0.133	0.105	0.205	0.327	0.261
Vocational technical program	0.057	0.048	0.042	0.065	0.063	0.070
Some college	0.272	0.271	0.258	0.305	0.314	0.253
Bachelor's degree	0.219	0.296	0.332	0.200	0.073	0.147
Some graduate/professional school	0.020	0.026	0.027	0.021	0.007	0.016
Master's degree or higher	0.121	0.177	0.207	0.097	0.041	0.055
Second parent education level						
9th–12th grade	0.085	0.043	0.028	0.084	0.166	0.122
High school diploma or equivalent	0.289	0.228	0.188	0.333	0.411	0.342
Vocational technical program	0.051	0.053	0.049	0.063	0.050	0.048
Some college	0.213	0.223	0.223	0.222	0.182	0.211
Bachelor's degree	0.174	0.236	0.276	0.130	0.074	0.108
Some graduate/professional school	0.013	0.018	0.019	0.015	0.000	0.009
Master's degree or higher	0.126	0.177	0.206	0.100	0.040	0.075
Child weight (pounds)	47.040	46.860	46.430	48.000	47.900	46.930
	(0.150)	(0.180)	(0.183)	(0.289)	(0.343)	(0.244)
Child height (inches)	44.780	44.830	44.830	44.810	44.750	44.690
	(0.040)	(0.042)	(0.051)	(0.066)	(0.088)	(0.067)
Black	0.122	0.083	0.068	0.122	0.264	0.122
Hispanic	0.215	0.146	0.110	0.242	0.310	0.298
Asian	0.036	0.042	0.048	0.027	0.023	0.031
Hawaiian	0.003	0.001	0.002	0.000	0.003	0.005
Native American	0.008	0.007	0.003	0.018	0.014	0.007
Two or more races	0.042	0.045	0.046	0.043	0.036	0.038
Non-English language used at home	0.225	0.159	0.131	0.235	0.300	0.310
Mother or child participated in WIC	0.483	0.327	0.246	0.541	0.821	0.602
Number of siblings	1.479	1.376	1.366	1.403	1.514	1.657
	(0.024)	(0.024)	(0.028)	(0.037)	(0.037)	(0.037)
Two-parent household	0.716	0.787	0.819	0.702	0.491	0.698
One parent and one other adult	0.065	0.053	0.044	0.077	0.101	0.070
Other guardians	0.021	0.015	0.011	0.026	0.040	0.023
Parental expectations for child						
Graduate from high school	0.043	0.028	0.021	0.048	0.072	0.057
Attend vocational or technical school	0.023	0.019	0.017	0.027	0.031	0.024
Attend two or more years of college	0.117	0.097	0.083	0.134	0.164	0.130
Finish four-year college	0.480	0.528	0.552	0.462	0.366	0.450
Earn a master's degree	0.166	0.182	0.193	0.154	0.148	0.143
Earn a doctorate	0.170	0.144	0.133	0.175	0.217	0.193
Important child counts (1–5, essential to not important)	2.031	2.045	2.057	2.014	1.967	2.036
	(0.015)	(0.015)	(0.017)	(0.026)	(0.023)	(0.024)
Important child shares (1–5, essential to not important)	1.632	1.590	1.580	1.616	1.693	1.680
	(0.010)	(0.012)	(0.012)	(0.021)	(0.016)	(0.015)
Important child uses pencil (1–5, essential to not important)	1.868	1.837	1.838	1.835	1.899	1.911
	(0.012)	(0.015)	(0.016)	(0.029)	(0.019)	(0.016)
Important child pays attention (1–5, essential to not important)	1.859	1.869	1.891	1.810	1.837	1.849
	(0.012)	(0.016)	(0.016)	(0.023)	(0.020)	(0.014)
Important child knows letters (1–5, essential to not important)	1.902	1.889	1.897	1.868	1.887	1.935
	(0.016)	(0.019)	(0.020)	(0.029)	(0.022)	(0.018)

Table A.1. Continued.

	Full Sample	Any Preschool	Center-Based Preschool	State-Funded Preschool	Head Start	No Formal Preschool
Frequency of activities (1–4, not at all to every day)						
Sing	3.142 (0.013)	3.140 (0.015)	3.137 (0.018)	3.148 (0.023)	3.212 (0.027)	3.109 (0.018)
Art	2.779 (0.012)	2.772 (0.015)	2.775 (0.016)	2.763 (0.026)	2.780 (0.024)	2.792 (0.017)
Chores	3.275 (0.017)	3.275 (0.017)	3.276 (0.019)	3.271 (0.027)	3.300 (0.032)	3.261 (0.032)
Games	2.872 (0.011)	2.874 (0.012)	2.892 (0.013)	2.828 (0.019)	2.864 (0.023)	2.872 (0.022)
Talk about nature	2.314 (0.019)	2.333 (0.023)	2.342 (0.024)	2.307 (0.029)	2.302 (0.032)	2.284 (0.026)
Build things	2.476 (0.013)	2.489 (0.015)	2.502 (0.016)	2.454 (0.031)	2.430 (0.029)	2.477 (0.024)
Play sports	2.811 (0.012)	2.801 (0.013)	2.805 (0.014)	2.791 (0.026)	2.837 (0.028)	2.816 (0.020)
Number of books	90.770 (2.720)	107.500 (3.103)	114.100 (3.499)	89.710 (3.996)	62.280 (3.627)	73.820 (3.483)
Frequency use CD player (1–6, never to daily)	5.464 (0.026)	5.472 (0.031)	5.482 (0.035)	5.445 (0.055)	5.392 (0.044)	5.488 (0.033)
Read books to child (1–4, not at all to every day)	3.392 (0.018)	3.477 (0.014)	3.517 (0.015)	3.370 (0.022)	3.274 (0.024)	3.292 (0.029)
Read picture books (1–4, not at all to every day)	3.318 (0.016)	3.383 (0.015)	3.420 (0.015)	3.285 (0.024)	3.198 (0.029)	3.256 (0.028)
Attend PTA/PTO meetings	0.365	0.383	0.387	0.373	0.347	0.339
Attended parent advisory group	0.125	0.124	0.123	0.128	0.131	0.124
Volunteered at school	0.595 (0.013)	0.687 (0.011)	0.730 (0.012)	0.571 (0.019)	0.447 (0.017)	0.497 (0.018)
Participated in fundraising	0.690 (0.008)	0.742 (0.010)	0.760 (0.010)	0.695 (0.020)	0.610 (0.015)	0.634 (0.013)
Parent depression scale (1–4)	1.372 (0.007)	1.336 (0.006)	1.326 (0.007)	1.362 (0.013)	1.459 (0.012)	1.395 (0.012)
Parent not stressed scale (1–4)	3.061 (0.010)	3.057 (0.010)	3.058 (0.011)	3.054 (0.022)	3.062 (0.020)	3.068 (0.018)
Child spanked in last week	0.165	0.138	0.126	0.172	0.225	0.184
Eat dinner together (no. days per week)	5.814 (0.027)	5.803 (0.037)	5.791 (0.042)	5.836 (0.048)	5.809 (0.043)	5.837 (0.034)
Eat dinner at regular time (no. days per week)	5.495 (0.033)	5.523 (0.041)	5.548 (0.045)	5.456 (0.064)	5.486 (0.052)	5.444 (0.038)
Child uses home computer	0.750	0.818	0.831	0.784	0.644	0.676
Hours TV watched on weekdays	1.597 (0.034)	1.343 (0.030)	1.256 (0.029)	1.575 (0.048)	2.048 (0.058)	1.845 (0.050)
Visited zoo, aquarium, or farm	0.455	0.447	0.461	0.411	0.473	0.462
Visited the library	0.601	0.630	0.654	0.565	0.580	0.559
Visited art, museum, or historical site	0.350	0.381	0.400	0.331	0.324	0.306
Attended play, concert, or show	0.413	0.445	0.457	0.415	0.377	0.369
Dance lessons	0.190	0.243	0.270	0.171	0.108	0.132
Organized athletic activities	0.533	0.650	0.692	0.536	0.386	0.388
Clubs or recreation programs	0.130	0.159	0.167	0.137	0.089	0.095
Music lessons	0.099	0.118	0.132	0.081	0.071	0.077
Drama classes	0.023	0.029	0.031	0.022	0.018	0.015
Art classes or lessons	0.089	0.105	0.111	0.090	0.073	0.068
Performing arts programs	0.159	0.179	0.191	0.147	0.146	0.127
Craft classes or lessons	0.114	0.129	0.133	0.117	0.092	0.096
Neighborhood quality scale (1–3)	2.780 (0.010)	2.825 (0.008)	2.846 (0.009)	2.768 (0.016)	2.686 (0.015)	2.744 (0.015)
N	10,500	5,950	4,430	1,520	1,560	2,990

Table A.2. Coefficients and Standard Errors from Regressions Predicting Spring of Kindergarten Standardized Science Achievement and Fall of Kindergarten Teacher Ratings of Science Ability from Preschool Participation Interacted with Student Race

	Spring of Kindergarten Science Achievement (standardized)	Sense	Explain	Classify	Predict	Communicate	Physical Science	Life Science	Earth/ Space Science	Composite
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Preschool (center-based or state-sponsored)	3.21e–05	0.0681	0.0759	0.0889^{+}	0.0681	0.0796	0.0377	0.0712	0.0728	0.136^{*}
	(0.0337)	(0.0419)	(0.0536)	(0.0492)	(0.0492)	(0.0559)	(0.0495)	(0.0451)	(0.0616)	(0.0623)
Preschool*Black	0.137^{+}	0.0601	0.0962	0.0710	0.0479	0.0298	0.121	−0.00392	0.0680	0.0552
	(0.0811)	(0.0971)	(0.107)	(0.111)	(0.108)	(0.115)	(0.0940)	(0.0945)	(0.115)	(0.120)
Preschool*Hispanic	−0.0422	0.0220	−0.0222	−0.0630	−0.0244	0.00752	0.0399	0.0334	0.0138	−0.0348
	(0.0657)	(0.0723)	(0.0846)	(0.0816)	(0.0815)	(0.0842)	(0.0751)	(0.0734)	(0.0953)	(0.0947)
Preschool*Asian	−0.0698	−0.0199	−0.140	0.00956	−0.195	−0.113	−0.0286	0.0571	−0.157	−0.152
	(0.116)	(0.133)	(0.137)	(0.146)	(0.135)	(0.149)	(0.146)	(0.123)	(0.183)	(0.183)
Black	-0.439^{**}	-0.249^{**}	-0.282^{**}	-0.181^{*}	-0.194^{*}	-0.184^{*}	-0.203^{**}	-0.221^{**}	-0.198^{*}	-0.176^{+}
	(0.0700)	(0.0775)	(0.0899)	(0.0893)	(0.0812)	(0.0832)	(0.0744)	(0.0763)	(0.0935)	(0.0948)
Hispanic	-0.153^{**}	-0.176^{**}	-0.200^{*}	−0.104	-0.156^{*}	-0.195^{*}	-0.172^{*}	-0.136^{*}	-0.183^{+}	−0.119
	(0.0573)	(0.0672)	(0.0777)	(0.0764)	(0.0747)	(0.0811)	(0.0708)	(0.0673)	(0.0932)	(0.0936)
Asian	−0.0928	0.0681	0.175	0.0561	0.152	0.149	0.0272	0.0137	0.134	0.209
	(0.104)	(0.117)	(0.117)	(0.130)	(0.114)	(0.130)	(0.130)	(0.111)	(0.162)	(0.165)
Income controls	X	X	X	X	X	X	X	X	X	X
Child, family, and contextual controls	X	X	X	X	X	X	X	X	X	X
Classroom fixed effects	X	X	X	X	X	X	X	X	X	X
Observations	10,500	7,500	6,490	6,050	6,320	5,960	6,510	6,770	4,270	3,390

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. Sample sizes vary across this table as teachers had the option of not answering the question and instead noting they had not had the opportunity to observe the skill. Models include binary indicators of race and interactions with preschool for all racial groups. All interaction terms are interpretable compared with the coefficient on center-based preschool for white students.

$^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.

Table A.3. Coefficients and Standard Errors from Regressions Predicting Spring of Kindergarten Standardized Science Achievement and Fall of Kindergarten Teacher Ratings of Science Ability from Preschool Participation Interacted with Student Gender

	Spring of Kindergarten Science Achievement (standardized)	Sense	Explain	Classify	Predict	Communicate	Physical Science	Life Science	Earth/ Space Science	Composite
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Preschool (center-based or state-sponsored)	0.00169	0.119^{**}	0.116^{*}	0.115^{*}	0.116^{*}	0.130^{*}	0.0936^{+}	0.138^{**}	0.149^{*}	0.204^{**}
	(0.0363)	(0.0442)	(0.0559)	(0.0537)	(0.0525)	(0.0559)	(0.0505)	(0.0474)	(0.0633)	(0.0653)
Preschool*Female	0.00217	−0.0736	−0.0750	−0.0454	-0.103^{+}	−0.0822	−0.0588	-0.104^{+}	-0.125^{+}	-0.141^{+}
	(0.0457)	(0.0525)	(0.0605)	(0.0639)	(0.0608)	(0.0654)	(0.0592)	(0.0568)	(0.0744)	(0.0747)
Female	-0.100^{**}	0.113^{**}	0.101^{*}	0.0834	0.110^{*}	0.132^{**}	0.136^{**}	0.145^{**}	0.102^{+}	0.140^{*}
	(0.0380)	(0.0425)	(0.0503)	(0.0515)	(0.0494)	(0.0485)	(0.0471)	(0.0460)	(0.0592)	(0.0604)
Income controls	X	X	X	X	X	X	X	X	X	X
Child, family, and contextual controls	X	X	X	X	X	X	X	X	X	X
Classroom fixed effects	X	X	X	X	X	X	X	X	X	X
Observations	10,500	7,500	6,490	6,050	6,320	5,960	6,510	6,770	4,270	3,390

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. Sample sizes vary across this table as teachers had the option of not answering the question and instead noting they had not had the opportunity to observe the skill. Models include a binary indicator gender. All interaction terms are interpretable compared to the coefficient on center-based preschool for male students. The omitted category for the preschool variable is students who were not in a formal preschool setting—namely, those who were cared for by relatives, nonrelatives, or parents, and were not in a center-based, state-sponsored, or Head Start program.

$^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.

Table A.4. Coefficients and Standard Errors from Regressions Predicting Spring of Kindergarten Standardized Science Achievement and Fall of Kindergarten Teacher Ratings of Science Ability from Preschool Participation Interacted with Family Income Bracket

	Spring of Kindergarten Science Achievement (standardized)	Sense	Explain	Classify	Predict	Communicate	Physical Science	Life Science	Earth/ Space Science	Composite
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Preschool (center-based or state-sponsored)	0.0116 (0.0598)	0.0630 (0.0755)	0.00810 (0.0865)	0.0805 (0.0891)	0.0290 (0.0855)	0.0905 (0.102)	0.0270 (0.0871)	0.112 (0.0817)	0.0674 (0.115)	0.157 (0.103)
Preschool*Income quartile 1	0.0732 (0.0791)	0.0386 (0.0939)	0.0770 (0.114)	−0.0361 (0.110)	0.0436 (0.107)	−0.0359 (0.119)	0.0622 (0.103)	−0.0922 (0.100)	0.0591 (0.137)	−0.0918 (0.127)
Preschool*Income quartile 2	−0.0101 (0.0755)	0.0308 (0.0936)	0.133 (0.105)	0.0133 (0.107)	0.0602 (0.104)	−0.0157 (0.119)	0.0314 (0.103)	0.0140 (0.0981)	−0.0176 (0.131)	0.0114 (0.124)
Preschool*Income quartile 3	−0.0630 (0.0706)	0.00795 (0.0858)	0.0498 (0.100)	0.0431 (0.106)	0.0224 (0.0987)	0.0341 (0.115)	0.0367 (0.0996)	−0.0267 (0.0947)	0.0198 (0.135)	−0.0389 (0.126)
Income quartile 1	-0.121^{+} (0.0675)	−0.0687 (0.0866)	−0.162 (0.101)	−0.00698 (0.111)	−0.161 (0.0988)	−0.124 (0.104)	−0.0719 (0.0910)	−0.0221 (0.0941)	−0.0687 (0.126)	−0.0409 (0.120)
Income quartile 2	0.0218 (0.0660)	−0.0661 (0.0820)	-0.176^{+} (0.0936)	−0.00481 (0.0983)	−0.137 (0.0932)	−0.0748 (0.1000)	−0.0337 (0.0872)	−0.0518 (0.0909)	−0.0192 (0.118)	−0.00655 (0.114)
Income quartile 3	0.0971 (0.0631)	−0.0112 (0.0781)	−0.0891 (0.0932)	−0.0113 (0.0985)	−0.0489 (0.0915)	−0.0415 (0.102)	−0.0162 (0.0886)	0.0110 (0.0887)	−0.0180 (0.123)	0.0693 (0.118)
Income controls	X	X	X	X	X	X	X	X	X	X
Child, family, and contextual controls	X	X	X	X	X	X	X	X	X	X
Classroom fixed effects	X	X	X	X	X	X	X	X	X	X
Observations	10,500	7,500	6,490	6,050	6,320	5,960	6,510	6,770	4,270	3,390

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. Sample sizes vary across this table as teachers had the option of not answering the question and instead noting they had not had the opportunity to observe the skill. All interaction terms are interpretable compared to the coefficient on preschool for students in the highest income quartile ($100,000+). The omitted category for the preschool variable is students who were not in a formal preschool setting—namely, those who were cared for by relatives, nonrelatives, or parents, and were not in a center-based, state-sponsored, or Head Start program.

$^{+}p < 0.1$.

Table A.5. Coefficients and Standard Errors from Regressions Predicting Spring of Kindergarten Standardized Science Achievement and Fall of Kindergarten Teacher Ratings of Science Ability from Indicators of Preschool Location

	Spring of Kindergarten Science Achievement (standardized)	Sense	Explain	Classify	Predict	Communicate	Physical Science	Life Science	Earth/ Space Science	Composite
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Preschool in K–12 school	−0.0331	0.0602	0.0291	0.0593	0.0530	0.0800	0.0448	0.0455	0.0403	0.0712
	(0.0377)	(0.0451)	(0.0574)	(0.0501)	(0.0510)	(0.0536)	(0.0501)	(0.0461)	(0.0619)	(0.0602)
Preschool not in K–12 school	0.0222	0.0948^{*}	0.108^{*}	0.111^{*}	0.0714	0.0953^{+}	0.0763^{+}	0.112^{**}	0.118^{*}	0.173^{**}
	(0.0312)	(0.0379)	(0.0461)	(0.0446)	(0.0440)	(0.0499)	(0.0437)	(0.0399)	(0.0557)	(0.0571)
Income controls	X	X	X	X	X	X	X	X	X	X
Child, family, and contextual controls	X	X	X	X	X	X	X	X	X	X
Classroom fixed effects	X	X	X	X	X	X	X	X	X	X
Observations	10,490	7,500	6,490	6,050	6,320	5,960	6,510	6,770	4,270	3,390

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. Sample sizes vary across this table as teachers had the option of not answering the question and instead noting they had not had the opportunity to observe the skill. Sample sizes vary slightly from primary models due to missing data on location variables. Models include binary indicator of Head Start, so the omitted category is students who were not in a formal preschool setting—namely, those who were cared for by relatives, nonrelatives, or parents, and were not in a center-based, state-sponsored, or Head Start program.

$^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.

Table A.6. Coefficients and Standard Errors from Regressions Predicting Spring of Kindergarten Standardized Science Achievement and Fall of Kindergarten Teacher Ratings of Science Ability from Indicators of Full- and Part-Time Participation in Preschool

	Spring of Kindergarten Science Achievement (standardized)	Sense	Explain	Classify	Predict	Communicate	Physical Science	Life Science	Earth/ Space Science	Composite
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Preschool full time	0.00187	0.0536	0.0777	0.114*	0.0397	0.0950+	0.0881+	0.0852+	0.0765	0.161*
	(0.0339)	(0.0432)	(0.0556)	(0.0498)	(0.0515)	(0.0532)	(0.0470)	(0.0440)	(0.0622)	(0.0640)
Preschool part time	0.00312	0.0999**	0.0790+	0.0750+	0.0826+	0.0854+	0.0457	0.0877*	0.0958+	0.109*
	(0.0328)	(0.0378)	(0.0455)	(0.0438)	(0.0441)	(0.0497)	(0.0452)	(0.0399)	(0.0540)	(0.0521)
Income controls	X	X	X	X	X	X	X	X	X	X
Child, family, and contextual controls	X	X	X	X	X	X	X	X	X	X
Classroom fixed effects	X	X	X	X	X	X	X	X	X	X
Observations	10,490	7,500	6,490	6,050	6,320	5,950	6,500	6,770	4,270	3,390

Notes: Robust standard errors in parentheses. All estimates account for the complex survey design of Early Childhood Longitudinal Study through the use of survey setting and weighting. Sample sizes vary across this table as teachers had the option of not answering the question and instead noting they had not had the opportunity to observe the skill. Sample sizes vary slightly from primary models due to missing data on time variables. Models include binary indicator of Head Start, so the omitted category is students who were not in a formal preschool setting—namely, those who were cared for by relatives, nonrelatives, or parents, and were not in a center-based, state-sponsored, or Head Start program.

$^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.