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Executive Function Skills and Academic Achievement Gains in Prekindergarten: Contributions of Learning-Related Behaviors

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Although research suggests associations between children's executive function skills and their academic achievement, the specific mechanisms that may help explain these associations in early childhood are unclear. This study examined whether children's (N = 1,103; M age = 54.5 months) executive function skills at the beginning of prekindergarten (pre-K) predict their learning-related behaviors in the classroom and whether these behaviors then mediate associations between children's executive function skills and their pre-K literacy, language, and mathematic gains. Learning-related behaviors were quantified in terms of (a) higher levels of involvement in learning opportunities; (b) greater frequency of participation in activities that require sequential steps; (c) more participation in social-learning interactions; and (d) less instances of being unoccupied, disruptive, or in time out. Results indicated that children's learning-related behaviors mediated associations between executive function skills and literacy and mathematics gains through children's level of involvement, sequential learning behaviors, and disengagement from the classroom. The implications of the findings for early childhood education are discussed.

Keywords: academic achievement, executive function, learning-related behaviors, structural equation modeling

Recent comprehensive definitions of school readiness emphasize a multifaceted construct consisting of not only language development, academic knowledge (including early literacy, mathematics, and scientific skills), and physical well-being motor development but also children's ability to regulate their behavior intentionally in the service of learning, including the modulation of attention, emotion, and cognition (Office of Head Start, 2011). A focus on children's ability to self-regulate is not new, as these elements of school readiness were originally addressed over 30 years ago (Zigler & Trickett, 1978). Included in the broader domain of self-regulation are executive function skills or the ability to regulate thoughts and cognition in the service of planning, problem-solving, and goal-directed actions (Miyake et al., 2000). Executive function skills have garnered particular interest as measures of school readiness because of their positive associations with academic achievement (e.g., Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Fuhs, Nesbitt, Farran, & Dong, 2014; McClelland et al., 2007), but empirical evidence to explain why such an association exists is limited. In this study, we examined the relations among assessments of prekindergarten (pre-K) children's entering executive function skills; direct observations of learning-related behaviors assessed over the course of the school year; and children's gains in literacy, language, and mathematics achievement. We tested whether learning-related classroom behaviors mediate the association between executive function skills and academic achievement gains in pre-K.

Executive Function Skills and Academic Achievement

Executive function skills include shifting actions and attention in response to changing situational demands (i.e., attention shifting; Zelazo, Frye, & Rapus, 1996), holding and manipulating information in the mind (i.e., working memory; Baddeley & Hitch, 1974) and suppressing a prepotent response or ignoring interfering stimuli or information (i.e., inhibitory control; Diamond, 1990). Although these skills are conceptually distinct and differentiated in adults, assessments of executive function skills in pre-K and kindergarten tend to be represented by a unitary factor in children this age (Hughes, Ensor, Wilson, & Graham, 2009; Wiebe, Espy, & Charak, 2008; Willoughby, Blair, Wirth, & Greenberg, 2010).

Children's executive function skills emerge during early childhood, improve markedly by the time children enter kindergarten (Johnson, 2001), and continue to develop through middle childhood and adolescence. The co-occurrence of the development of executive function skills with children's transition to formal education settings has led researchers to investigate questions regarding the role of executive function skills in children's successful

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adjustment to formal learning environments. Research indicates that young children's executive function skills are related to children's literacy, language, and mathematics achievement (e.g., Allan & Lonigan, 2011; Clark, Pritchard, & Woodward, 2010; Weiland, Barata, & Yoshikawa, 2014). Moreover, these relations are still apparent when controlling for prior academic achievement (Fuhs et al., 2014; Ponitz, McClelland, Matthews, & Morrison, 2009; Welsh, Nix, Blair, Bierman, & Nelson, 2010) and general intelligence (Blair & Razza, 2007; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011). Relations, however, tend to be stronger for mathematics achievement (Blair & Razza, 2007; Bull et al., 2008; Fuhs et al., 2014).

That executive function skills are connected to academic achievement may be of particular importance for children from economically disadvantaged backgrounds who are most typically served by pre-K programs and are more likely than their more affluent peers to enter school with lower executive function skills (Blair et al., 2011; Noble, McCandliss, & Farah, 2007) as well as academic achievement (Arnold & Doctoroff, 2003; Mistry, Benner, Biesanz, Clark, & Howes, 2010). In fact, associations between family socioeconomic status and literacy and mathematic achievement have been found to be mediated by children's executive function skills (Nesbitt, Baker-Ward, & Willoughby, 2013). Questions still remain, however, as to how children's executive function skills contribute to their early academic achievement.

Learning-Related Classroom Behaviors as Mediators

Recent accounts suggest that one mechanism through which executive function skills and academic achievement are linked is through learning behaviors in the classroom. Specifically, executive function skills may allow children to adapt successfully to early learning environments that are increasingly requiring children to become active seekers and appliers of knowledge (Blair & Diamond, 2008; Eisenberg et al., 2010; McClelland & Cameron, 2011). Executive function skills may work to promote learning-related behaviors, which in turn facilitate academic achievement gains. Moreover, children's executive function skills and learning-related behaviors may be reinforced through positive feedback loops, including positive interactions with teachers and peers and better academic performance. Such learning-related behaviors could include but are not limited to the ability to (a) attend to and be involved in learning-related activities, (b) engage in sequential learning-related activities that require remembering and enacting multiple steps, (c) cooperate and interact with peers and teachers on learning-related activities, and (d) refrain from unoccupied and disruptive behaviors that reduce learning opportunities. Each of these behaviors will be described in more detail in the following sections.

Level of Involvement

As early as pre-K, children's involvement and participation are positively associated with their concurrent and future achievement as rated by teachers (DiPerna, Lei, & Reid, 2007; McClelland, Acock, & Morrison, 2006; Neuenschwander, Röthlisberger, Cimeli, & Roebers, 2012; Portilla, Ballard, Adler, Boyce, & Obradović., 2014; Sasser, Bierman, & Heinrich, 2015) and as observed directly (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009). For example, Brock et al. (2009) found that both teacher ratings of kindergarteners' self-directed learning and observer ratings of kindergarteners' engagement in learning were positively associated with children's reading and mathematics achievement at the beginning and end of kindergarten. Teacher ratings and direct assessments of children's level of involvement in learning have also been linked to executive function skills (Brock et al., 2009; Neuenschwander et al., 2012; Portilla et al., 2014; Rimm-Kaufman, Curby, Grimm, Nathanson, & Brock, 2009; Sasser et al., 2015). Using teacher ratings, researchers have found that level of involvement in learning mediates the relation between young children's executive function skills and academic achievement (Neuenschwander et al., 2012; Portilla et al., 2014; Sasser et al., 2015).

Sequential Learning Behaviors

Executive function skills may facilitate participation in cognitively demanding activities that typically require the completion of a series of steps or operations (Blair & Diamond, 2008; Blair et al., 2007). An illustrative example of a cognitively demanding sequential activity is patterning, which requires the systematic recognition, description, extension, and creation of repeating patterns. Research indicates that early childhood classrooms that provide cognitively demanding instruction, including instruction to promote higher order thinking skills, are associated with greater academic achievement (Mashburn et al., 2008) and that practicing cognitively demanding activities strengthens children's mathematic achievement (Blair et al., 2007).

Social-Learning Interactions

Children who have strong executive function skills may also be more able to take part in social interactions with peers and teachers that contribute to learning. Throughout the day in early childhood classrooms, children are engaged in shared learning experiences with peers and teachers that contribute to academic success (Ladd, 1990; Montroy, Bowles, Skibbe, & Foster, 2014; Wentzel, 1999); hence, successful adaptation to the classroom includes children's ability to engage in learning-related behaviors with others. Social competencies at the onset of pre-K are predicted by executive function skills (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Denham et al., 2012; Montroy et al., 2014); those skills appear to contribute to children's ability to engage in social-learning interactions. Montroy et al. (2014) found that not only were preschool children's executive function skills related to teacher ratings of social competence but also that social competence mediated associations between children's fall executive function skills and fall to spring literacy gains.

Unoccupied and Disruptive Behaviors

In addition to behaviors that promote learning, another possible mediator of the association between executive function skills and academic achievement could be through children's ability to abstain from unoccupied (i.e., off-task behavior) and disruptive behaviors and avoid the resulting isolation that can result from such behaviors (i.e., time out). These problem behaviors are typically more extreme than low involvement in a learning opportunity and include negative behaviors that not only interrupt the child's

learning but also disturb other members of the learning environment. Children who engage in unoccupied and disruptive behaviors, as observed directly or reported by teachers, tend have lower levels of academic achievement and lower levels of executive function skills (Bierman, Torres, Domitrovich, Welsh, & Gest, 2009; Denham et al., 2012; Montroy et al., 2014; Sasser et al., 2015). Moreover, teacher ratings of problem behaviors indicate that the relation between young children's executive function skills and literacy achievement may be facilitated by children's ability to remain occupied and inhibit disruptive behaviors (Montroy et al., 2014; Sasser et al., 2015).

The Present Study

Although research suggests associations between children's executive function skills and their academic achievement, the specific mechanisms that may help explain these associations are unclear. Initial evidence supports hypotheses that children's executive functioning skills at the onset of school afford children the ability to adapt to the demands of early childhood classrooms and exhibit positive learning-related classroom behavior, which in turn allows them to make academic gains. Much of this work, however, has relied on teacher ratings of children's behaviors. Although teachers are in a unique position to report more globally on average behaviors of children, retrospective ratings can be potentially influenced by teachers' own perceptions and judgments of their children's competencies (Odom et al., 2008). Consequently, we examined whether direct observations of pre-K children's behavioral responses to the demands of the classroom—or learning-related behaviors—mediate the established associations between executive function skills and gains in literacy, language, and mathematic achievement.

This study is unique in that we had high consent rates (84.3% of eligible children) and direct observations of children over the course of three full-day observations spread out over the year. These stable classroom estimates afforded us the opportunity to control for differences among pre-K classrooms that might confound the children's opportunities to engage in learning-related behaviors (e.g., variation in learning opportunities provided by the teacher); we could examine individual children's skills and behaviors relative to their consented classmates.

On the basis of prior theoretical and empirical work, learning-related behaviors examined included (a) level of involvement in learning activities, (b) engagement in sequential learning behaviors, (c) social-learning interactions, and (d) refrainment from unoccupied and disruptive behaviors that reduce learning opportunities. The inclusion of children's participation in sequential behaviors and social-learning interactions extends prior observational work by examining the potential impact of not only children's engagement or disengagement in the classroom but also specific types of interactions that are posited to facilitate learning.

The study extends prior work through the investigation of three research questions. First, do children who enter pre-K with higher levels of executive function skills relative to their classmates (i.e., controlling for classroom-level effects) engage in more learning-related behaviors? Second, do children, relative to their classmates, who demonstrate more learning-related behaviors make greater gains in literacy, language, and mathematic achievement over the pre-K year? Third, is the relation between children's entering executive function skills and their pre-K achievement gains in literacy, language, and mathematics mediated by their learning-related behaviors?

Method

Participants

Data for the present study come from a sample of children who participated in a large-scale evaluation of a pre-K curriculum. The original study consisted of 1,145 consented children who were nested in 80 pre-K classrooms that were situated in 57 schools across six school districts in North Carolina and Tennessee. We restricted the analytic sample to the 1,103 children who completed at least one individual assessment measure at the beginning and end of pre-K and who were observed for at least one of the three in-class observations. Of the 1,103 children in the analytic dataset, 1,054 had complete data at the beginning and end of pre-K on all measures. The primary reason children were excluded was a result of the child moving during the course of the pre-K year. On average, each classroom had 13.8 children (SD = 3.4) in the analytic sample.

On average, the children (45.7% female) in the analytic sample were 54.5 months (SD = 3.63 months) at their first assessment. Approximately 33.6% of children were identified by their schools as English language learners (ELL), and 12.9% of the sample had an active individualized education program (IEP). Study children were also diverse with regard to ethnicity; 40.9% of children were identified as Caucasian, 25.7% African American, 24.5% Hispanic/Latino, 5.3% Asian, 2.4% multiracial, and 1.2% identified by other classifications. Because of the Family Educational Rights and Privacy Act, individual children's Free and Reduced Price Lunch (FRPL) status was not provided by all of the school systems. All study children, however, attended public pre-K programs that targeted children from economically disadvantaged backgrounds (i.e., first priority eligibility was based on family income).

Measures

Academic achievement. Academic achievement was measured with seven subscales of the Woodcock–Johnson III Achievement Battery (WJ-III; Woodcock, McGrew, Mather, 2001). Letter-Word Identification measured children's ability to identify and pronounce alphabet letters and read words by sight. The Spelling subtest measured children's ability to draw simple shapes and write orally presented letters and words. Academic Knowledge measured children's factual knowledge of science, social studies, and the humanities. Oral Comprehension measured children's ability to listen to and provide a missing key word to an orally presented passage. Picture Vocabulary tested children's expressive vocabulary. Applied Problems measured children's ability to solve numerical and spatial problems accompanied by pictures. Quantitative Concepts measured children's understanding of number identification, sequencing, shapes, and symbols and in a separate section to manipulate the number line.

Executive function skills. The Dimensional Change Card Sort (DCCS; Zelazo, 2006) required children first to sort a set of cards according to one dimension (red vs. blue color) and then according to another (star vs. truck shape). If children were able to

make the switch between sorting rules successfully, they were given a set of cards that had either a black border around the card or no border. If the card had a border, children were required to sort cards by color; if the card had no border, they were required to sort by shape. Sort rules were taught by both verbal instruction and demonstrations. On the basis of Zelazo's (2006) coding of the task, children received a score of 0 if they did not pass the initial color sort task, a 1 if they passed the color sort but not the shape sort, a 2 if they passed the shape sort, and a 3 if they also passed the advanced border version. The DCCS is a standardized measure in the National Institutes of Health Toolbox (Zelazo et al., 2013). DCCS test–retest reliability following a 2- and 3-week delay with preschoolers has been established at $r = .48$ (Lipsey et al., 2014) and .44, respectively (Müller, Kerns, & Konkin, 2012).

The Copy Design task (Osborn, Butler, & Morris, 1984) required children to copy eight increasingly more complex geometric shapes from a printed model. Although the Copy Design task taps children's visual and motor integration, the task also requires children to sustained attention to detail. Children had two attempts to replicate a design. If an attempt met a defined set of criteria (e.g., should be approximately symmetrical; cannot be rotated) each received a score of 1; if it did not, the attempt received a score of 0. Total scores could range from 0 to 16. Interrater reliability for the scoring of the Copy Design task's eight shapes was Cohen's $\kappa = 0.79$. Test–retest reliability has been established with 4-year-olds at $r = .72$ (Lipsey et al., 2014).

The Corsi Blocks task (Corsi, 1972) required children to point to a series of blocks fixed to a board in an irregular order. This visual–spatial task required children to first repeat the pattern exactly as the examiner demonstrated (i.e., forward), then to reverse the pattern given by the examiner (i.e., backward). The task began with a two block span and continued by asking children to repeat increasingly longer block patterns. Children had two attempts to complete each pattern within a given trial, and there were two trials for both the forward and backward parts of the task. The total score was the longest backward pattern a child could correctly repeat. Although we could not locate test–retest reliability estimates for the backward span portion of the task, reliability for the forward span has been established at $r = .83$ (Alloway, Gathercole, & Pickering, 2006) with children ages 4 to 6. Reliability for a verbal variation of the task (i.e., backward digit span) has been established at $r = .73$ (Lipsey et al., 2014) with 4-year-olds.

The Peg Tapping task (Diamond & Taylor, 1996) required children to tap once with a wooden dowel when the examiner tapped twice and to tap twice when the examiner tapped once. Children received two practice trials with feedback for incorrect responses followed by eight opportunities to successfully demonstrate the rules. If successful, 16 test trials without feedback were given; if unsuccessful, the task was terminated. Test trials were scored 0 for incorrect responses and 1 for correct. A score of -1 was assigned for the total score if the task was aborted if a child could not complete the practice trials. Final scores therefore ranged from -1 to 16. Test–retest reliability for peg tapping has been established with 4-year-olds at $r = .80$ (Lipsey et al., 2014).

Head-Toes-Knees-Shoulders (HTKS; Ponitz et al., 2009) required children to touch their toes when instructed to "touch your head" and to touch their heads when instructed to "touch your toes." Six practice trials with feedback were given followed by 10 test trials. For children who responded correctly to five or more of the test trials, two new prompts were added. Children were also required to touch their knees when instructed to "touch your shoulders" and to touch their shoulders when instructed to "touch your knees." Four practice trials with feedback were given followed by 10 test trials. Each trial was scored 0 if the child made an incorrect response, 1 if the child self-corrected an incorrect response, and 2 if the child made a correct response. Final scores for the task were the sum of children's performance on the six practice items and the 20 testing items (range = 0 to 52). HTKS test–retest and interrater has been established with 4-year-olds at $r = .80$ (Lipsey et al., 2014) and Cohen's $\kappa = 0.79$ (McClelland et al., 2014), respectively.

Learning-related behaviors. The Child Observation in Preschool (COP; Farran & Son-Yarbrough, 2001) is an observation protocol designed to quantify child behaviors particular to early grades classrooms. The COP uses a systematic behavior-sampling procedure—also known as a "snapshot" procedure—to capture information regarding listening and verbalizations, learning setting–schedule, proximity to and interaction state with teacher and peers, activity–task demands, level of involvement in learning activities, and the materials and focus of activities.

Each child in the classroom is located and then observed for approximately 3 s, after which the observer enters codes across nine categories. Observers proceed by coding each child in the classroom before returning to a previously observed and coded child. A full round of coding the behaviors of the members of the classroom is called a sweep. A maximum of 20 separate instances, or sweeps, was coded across the school day. On average, across all three observations 47.80 sweeps ($SD = 11.47$) were coded for each child.

Because of its structure, COP categories can be combined to examine the joint occurrence of behaviors of interest. In our case, we were interested in behaviors that co-occurred with children's learning opportunities. In early childhood classrooms, learning opportunities are defined broadly and include any activities in which there is a defined task or set of materials to which children attend. Sometimes those activities are clearly academic in focus, that is, storybook reading, mathematics puzzles, and so forth. Other times the activities are ones associated with play such as blocks, art, music, and drama. The four behaviors used in this study were all summarized as they co-occurred with learning activities defined in this broad manner.

First, children's level of involvement was coded based on a 5-point scale ranging from 1 (*low*; off task, not attending to instruction) to 5 (*high*; intense focus, serious pursuit of activity, cannot be distracted from task) involvement. Level of involvement was only coded if a child was engaged in a learning activity; thus, for this study, level of involvement was quantified as a child's average level of involvement during learning activities. All observers achieved interrater reliability with an experienced anchor observer at each time point. Across the three observations, interrater reliability for involvement in learning was Cohen's $\kappa = .69$.

Second, we were interested in examining children's participation in sequential learning behaviors, defined as behaviors that involved a sequence of steps or organization. Sequential behaviors could include children examining a book while turning the pages, working on a puzzle or craft project (with a specific model to follow), and make-believe play if the children were clearly enacting roles. A code of sequential required that children be actively

participating in the activity; therefore, passively attending to a teacher reading a book in a large group would not be coded as sequential. The sequential behavior variable was computed as a proportion of sweeps in which the behavior occurred out of the total number of sweeps across the three observation time points. Sequential learning behaviors were coded under the category of type task, which captured the type of learning engagement children were displaying. Interrater reliability for the category of type task was established at Cohen's $\kappa = .85$.

Third, we characterized children's participation in social-learning interactions using the COP protocol. Social-learning interactions were defined as instances in which children (with or without the teacher) were working together in the context of a learning activity. The activity could include cocreating products (e.g., whole group brainstorming, pretending together in dramatic play, playing with blocks) or following predetermined rules to accomplish a goal (e.g., formal games, scripted play). As with the sequential behavior variable, the social-learning interactions variable was computed as the proportion of sweeps in which the behavior occurred. Social-learning interactions were coded under the category of interaction state, which captured the types of interactions in which children engaged. Interrater reliability for the category of interaction state was established at Cohen's $\kappa = .86$.

Last, in addition to quantifying children's behaviors while they were participating in learning activities, we used three codes from the COP protocol to quantify children's disengagement from these activities. Unoccupied was coded when a child was not attending to a learning-related activity though one was available. Brief glances away from an activity were not coded as unoccupied; nor were children coded unoccupied when there was no potential learning opportunity. Disruptive was coded when children were observed either acting in a manner that drew other classroom member's attention off task, or deliberately misusing or destroying materials. Time out was coded when children were isolated by the teacher from the rest of the class because of behavior. The three codes were compiled to create an unoccupied–disruptive variable that was expressed as the proportion of sweeps in which these behaviors occurred. The codes that contributed to the unoccupied–disruptive variable were coded through the categories of type task and interaction state, which had interrater reliability of Cohen's $\kappa = .85$ and .89, respectively.

Procedures

Children were assessed individually in the fall (September and October) and spring (March to May) of pre-K, further referred to as Time 1 and Time 2, respectively. At both Time 1 and 2, measures were administered in English in a quiet area away from the classroom; each testing sessions lasted approximately 30 min. Although all self-regulation measures were administered in English, verbal directions were accompanied with demonstrations and practice trials with feedback. Measures were administered in a fixed order within each session; however, the order of the two sessions varied. One session included the administration of Peg Tapping, HTKS, Copy Design, Oral Comprehension, Applied Problems, Quantitative Concepts, and Picture Vocabulary, whereas the other session consisted of DCCS, Corsi Blocks, Letter-Word Identification, Academic Knowledge, and Spelling. The direct assessments of EF skills were always administered first in each session. The average interval between fall and spring sessions was 7.38 months ($SD = 0.55$ months).

Classrooms were observed at three time points during the year: in the fall (October to November), midyear (January and February), and in the spring (March and April). Observations lasted the duration of the school day and only occurred within the teacher's individual classroom (not including time outside, meals in the cafeteria, or special classes in other areas of the school).

Missing Data

Aggregating across multiple visits, complete data were available for 95.5% of the sample ($n = 1{,}053$). Children who were missing data were not significantly different from children without missing data on any variable included in the study. Following best practice to avoid bias associated with listwise deletion (Enders, 2010), full information maximum likelihood estimation (i.e., the ML estimator was implemented) was used with the final sample of 1,103 for path analyses conducted in Mplus 7.0 (Muthén & Muthén, 2012).

Results

Data Reduction

Descriptive statistics for all variables are presented in Table 1. For all analyses, academic achievement was quantified as WJ-III

Table 1
Descriptive Statistics for Observed Variables

Variable	*M*	*SD*	Range
T1 executive function			
Backward Digit Span	1.17	1.16	0–5
Copy Design	0.93	1.45	0–10
Dimensional Change Card Sort	1.38	0.62	0–3
Head-Toes-Knees-Shoulders	11.61	13.67	0–52
Peg Tapping	5.38	5.85	−1–16
T1 academic achievement			
Academic Knowledge	436.26	15.76	366–478
Applied Problems	390.50	25.16	318–449
Letter-Word Identification	318.85	24.49	264–423
Oral Comprehension	445.46	13.40	418–482
Picture Vocabulary	462.10	12.83	374–491
Quantitative Concepts	406.23	12.47	386–452
Spelling	336.89	23.35	277–405
T2 academic achievement			
Academic Knowledge	449.16	13.33	394–479
Applied Problems	411.87	18.61	332–453
Letter-Word Identification	348.16	22.40	264–446
Oral Comprehension	456.45	13.11	418–492
Picture Vocabulary	468.80	9.93	374–491
Quantitative Concepts	422.75	14.57	386–455
Spelling	369.96	26.77	277–432
Learning-related behaviors averaged across observations			
Level of involvement (rating)	2.36	0.26	1.50–3.03
Sequential behaviors	0.24	0.09	0.00–0.53
Social learning interactions	0.10	0.06	0.00–0.36
Unoccupied–disruptive	0.05	0.05	0.00–0.31

Note. T1 = Time 1, assessed at the beginning of prekindergarten (pre-K). T2 = Time 2, assessed at the end of pre-K. Woodcock–Johnson III W-Scores are reported for academic achievement. Level of involvement Likert ratings range from 1 (*low involvement*) to 5 (*high involvement*). Descriptives for other learning-related behaviors are the proportion of observed sweeps characterized by the given behavior.

equal-interval scaled W scores. For descriptive purposes, WJ-III normed standard scores are described below. At the beginning of pre-K, standard score means ranged from 79.35 ($SD = 12.52$) for the Spelling subtest to 100.65 for the Picture Vocabulary subtest ($SD = 11.45$). At the end of pre-K, standard score means ranged from 86.35 ($SD = 15.23$) for the Spelling subtest to 101.03 for the Picture Vocabulary subtest ($SD = 9.65$). Mean scores for direct assessments of executive function skills are presented in Table 1 in raw scores while the learning behaviors are presented in proportions except for ratings of involvement.

For young children, measures of executive function skills tend to load on a single factor. Zero-order correlations were consistent with previous research with statistically significant ($p < .001$) correlations ranging from .19 (association between Copy Design and Backward Digit Span) to .53 (association between HTKS and Peg Tapping). Given the amount of variance shared among the measures and prior work indicating a unitary construct, subsequent analyses were conducted with an executive function total pretest score that provided equal weight to each measure (i.e., transforming scores into standardized *z*-scores and aggregating across the obtained *z*-scores).

Measures of academic achievement in pre-K also tend to be highly interrelated. Zero-order correlations supported the aggregation of the WJ-III subtests across the content domains of literacy, language, and mathematics. The two literacy subtests, Letter-Word Identification and Spelling, exhibited significant ($rs < .42$, $ps < .001$) concurrent correlations at both the beginning and end of pre-K. Concurrent correlations among the three language subtests, Oral Comprehension, Picture Vocabulary, and Academic Knowledge, were also significant and robust ($rs < .52$, $ps < .001$). Large concurrent correlations were also found between Applied Problems and Quantitative Concepts ($rs < .64$, $ps < .001$). On the basis of the conceptual and empirical link between these three groups of subtests, we created and analyzed equally weighted total scores for literacy, language, and mathematics skills (i.e., aggregated *z*-scores).

Preliminary Analyses

This study was concerned with the testing of mediation in data that are organized within hierarchical levels, namely children nested within classrooms. Examination of the intraclass correlation coefficients (ICCs) indicated that at the end of pre-K, 13.7% of the variance in academic achievement was accounted for by between-classroom differences. With regard to learning-related behaviors, 47.5%, 50.2%, 43.4%, and 15.2% of the variance in level of involvement, sequential behaviors, social-learning interactions, and unoccupied–disruptive were accounted for by between-classroom differences, respectively. Therefore, to address our specific research questions, it was essential that we control for the variation between pre-K classroom environments. As such, all analyses were conducted with group-mean centered learning-related classroom behaviors and academic outcomes (see Raudenbush & Bryk, 2002). Standard errors were adjusted using the complex command in Mplus to further account for interdependency among observations (children within classrooms).

As a preliminary step to modeling direct and indirect effects between executive function skills, learning-related behaviors, and academic achievement, we first calculated the zero-order correlations among the study variables. As seen in Table 2, results indicated a strong relation between entering executive function skills and literacy, language, and mathematics achievement, which were related to achievement at the end of pre-K. The four measures of children's learning-related behaviors were significantly interrelated in the expected directions, and all four were associated with beginning of pre-K executive function and mathematics skills and end of pre-K literacy, language, and mathematics skills. Children's entering literacy skills were related to their level of involvement in learning tasks, sequential behaviors, and unoccupied and disruptive behaviors; entering language skills were related to sequential behaviors and social-learning interactions. Age was related to executive function skills at the beginning of pre-K and to literacy, language, and mathematics skills at the beginning and end of

Table 2
Zero-Order Correlation Among and Observed Variables

Variable	1	2	3	4	5	6	7	8	9	10	11
Independent variable											
1. Executive function T1	—										
Mediators											
2. Level of involvement	.18	—									
3. Sequential behaviors	.14	.47	—								
4. Social learning interactions	.11	.30	.28	—							
5. Unoccupied–disruptive	−.19	−.48	−.25	−.16	—						
Dependent variables											
6. Literacy achievement T2	.42	.19	.21	.09	−.22	—					
7. Language achievement T2	.42	.08	.09	.12	−.06	.37	—				
8. Mathematics achievement T2	.67	.17	.16	.09	−.16	.66	.60	—			
Covariates											
9. Literacy achievement T1	.56	.13	.15	.05	−.15	.58	.39	.54	—		
10. Language achievement T1	.51	.03	.07	.11	−.02	.25	.76	.44	.47	—	
11. Mathematics achievement T1	.66	.09	.12	.08	−.11	.46	.63	.64	.63	.77	—
12. Age at T1	.25	.05	.03	.02	−.03	.18	.14	.23	.24	.11	.23
13. Gender (0 = female)	−.13	−.08	−.13	−.07	.17	−.22	−.01	−.05	−.15	−.02	−.06
14. ELL Status (0 = non-ELL)	−.20	.06	.02	−.02	−.05	.01	−.47	−.12	−.19	−.70	−.43

Note. T1 = Time 1, assessed at the beginning of prekindergarten (pre-K). T2 = Time 2, assessed at the end of pre-K. ELL = English language learners. Mediators and dependent variables were centered at the classroom group mean. Correlations greater than .08 are significant at $p < .01$. Correlations greater than .06 are significant at $p < .05$.

pre-K, such that older children had larger scores on the tasks and achievement tests. Age was not related to any of the learning-related classroom behaviors.

Zero-order correlations also indicated that on average females tended to perform better on the literacy and mathematics and executive function tasks at the beginning of pre-K and on the literacy tasks at the end of pre-K compared with their male counterparts. They were also more likely to have higher levels of involvement, more likely to engage in sequential in activities, and less likely to be observed as unoccupied or in time out. On average children identified as ELL tended to have lower performance on measures of executive function, literacy, language, and mathematics skills at the beginning of pre-K compared with their non-ELL peers, and differences were still seen at the end of pre-K for language and mathematics. Children identified as ELL were likely to be observed as more involved in learning opportunities.

Although children's entering executive function skills were related to children's entering and end of pre-K academic achievement, the focus of our study was to examine whether children's learning-related classroom behaviors mediated the relation between children's executive function skills and pre-K achievement gains. As an initial step, we estimated the total direct effect of children's entering executive function skills on end of pre-K literacy, language, and mathematics achievement after controlling for entering academic achievement, gender, age, and ELL status. Results indicated that there were significant positive relations between children's entering executive function skills and residualized gains in their literacy ($\beta = .149$, $SE = 0.029$, $p < .001$) and mathematics skills ($\beta = .158$, $SE = 0.030$, $p < .001$) over the pre-K year; however, relations were not found for children's residualized gains in language ($\beta = .006$, $SE = 0.024$, $p = .796$). Because of the lack of relations with language gains, subsequent analyses focus on the dependent variables of children's literacy and mathematics gains.

Mediation Models

To investigate if the effects of executive function at the beginning of pre-K on residualized academic achievement gains (i.e., controlled for entering academic achievement) were mediated by children's learning-related behaviors, we estimated direct and indirect effects through path analysis in Mplus. Separate models were conducted for the content areas of literacy and mathematics. Significance testing of the indirect effects was conducted in accordance with standard error and confidence limit procedures advocated by MacKinnon (MacKinnon, Fairchild, & Fritz, 2007). Because of the possible correlations among mediators, models were initially tested with a single mediator at a time. If multiple learning-related behaviors were found to mediate the effects of children's classroom behaviors on an academic outcome, these mediators were then tested simultaneously in a multiple mediator model. We used this strategy to prevent issues of collinearity among mediators and to reduce the possibility of spurious relationships among variables.

Literacy. The first series of models estimated the direct effects of the independent variable of children's entering executive function skills on the mediator of children's learning-related behaviors after accounting for their gender and age (Path a), the direct effect of the mediator of children's learning-related behaviors on the dependent variable of children's pre-K literacy gains after accounting for their gender and age (Path b), and the direct effect of the independent variable of children's entering executive function skills on the dependent variable of children's pre-K literacy gains after accounting for the mediator of children's learning-related behaviors, gender, and age (Path c′). Estimates of the indirect effect of children's entering executive function skills on their literacy gains through their learning-related behaviors were also calculated.

Results of the indirect effects indicated that children's level of involvement during learning activities (Figure 1A; model fit comparative fit index [CFI] = 1.00; root-mean-square error of approximation [RMSEA] 90% confidence interval [CI] [0.00, 0.05]), sequential learning behaviors (Figure 1B; CFI = 0.99; RMSEA 90% CI = [0.01, 0.08]), and unoccupied or disruptive behaviors (Figure 1D; CFI = 0.99; RMSEA 90% CI [0.00, 0.06]) partially mediated the relationship between children's entering executive function skills and growth in literacy skills across the pre-K year. Children who entered pre-K with greater executive function skills were more like to be observed as having higher levels of involvement and exhibiting more sequential learning behaviors and were less likely to be observed as unoccupied, disruptive, or in time out.

In turn, children who were observed with higher levels of involvement and performing more sequential learning behaviors and who were less likely to be observed as unoccupied, disruptive, or in time out made greater literacy gains in pre-K. With regard to children's participation in social-learning interactions (Figure 1C; CFI = 1.00; RMSEA 90% CI [0.00, 0.05]), whereas greater entering executive function skills were associated with engaging in more social-learning interactions, social-learning interactions were not related to greater literacy gains and did not indirectly influence the relation between children's entering executive function skills and literacy gains.

To estimate the magnitude of the indirect effects, we divided the indirect effect estimate by the total direct effect between children's entering executive function skills and literacy gains (Path c). Results indicated that the indirect effect through children's level of involvement in learning activities accounted for 11.4% of relation between children's entering executive function skills and pre-K literacy gains, whereas the indirect effect through children's sequential learning behaviors accounted for 8.7% of the total effect and the indirect effect through children's being unoccupied, disruptive, or in time out accounted for 12.8% of the total effect.

With the identification of children's level of involvement, sequential behaviors, and being unoccupied or disruptive as significant mediators of the relation between children's entering executive function skills and pre-K literacy gains, a multimediator model that simultaneously entered the three variables and their covariances was conducted to estimate their total indirect effect (CFI = 0.99, RMSEA 90% CI [0.00, 0.06]). Combined, the three learning-related behaviors partially mediated the relation between children's entering executive function skills and pre-K literacy gains, $\beta_{EF \rightarrow TotalIndirect \rightarrow Lit} = .029$, $SE = .009$, $p = .001$, 95% CI [.012, .046]. The magnitude of the indirect effect relative to the total direct effect between children's entering executive function skills and literacy gains indicated that in total the three learning-related behaviors accounted for 19.5% of relation between children's entering executive function skills and pre-K literacy gains. The unique indirect effect of the individual learning-related behaviors on lit-

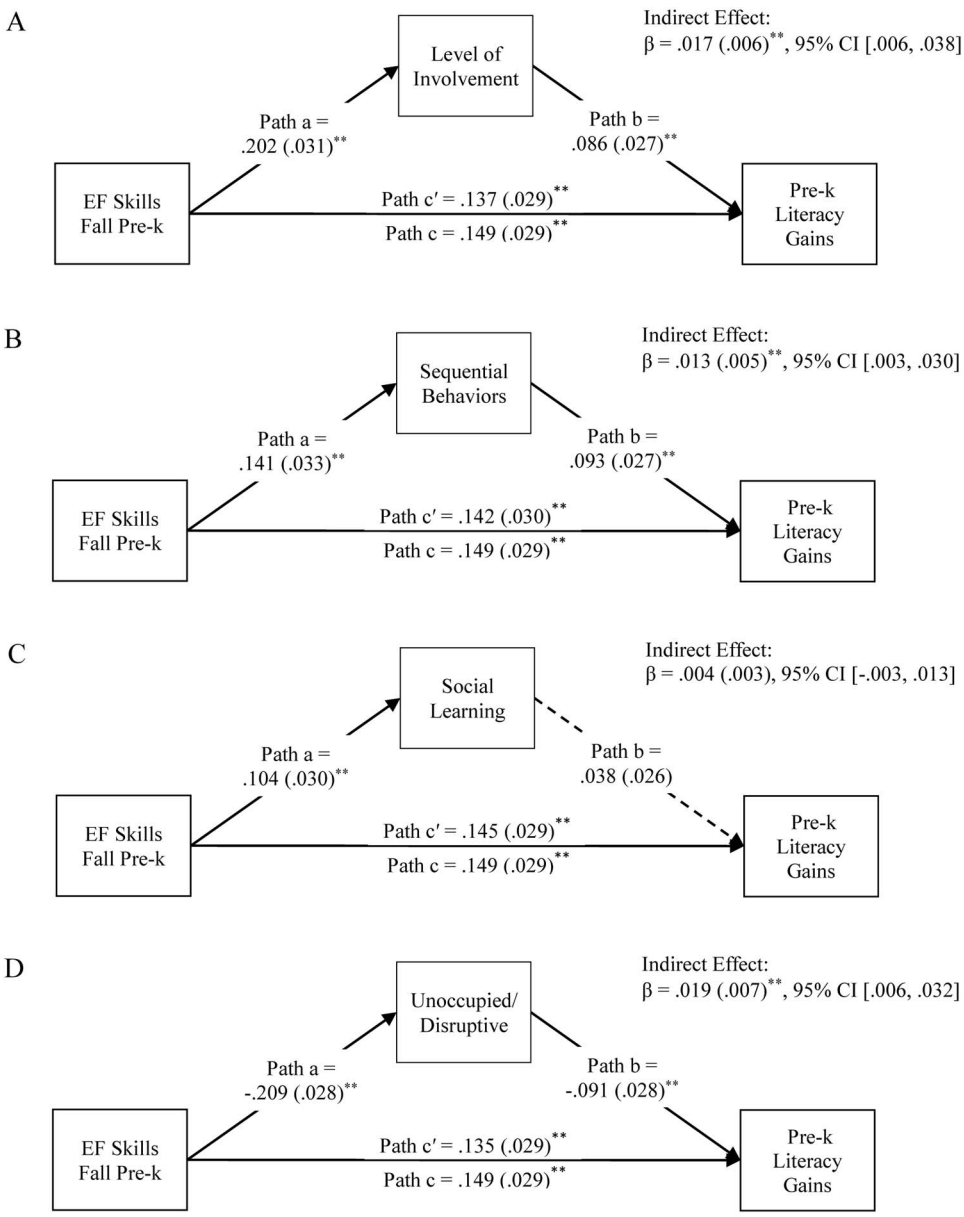

Figure 1. Path analysis of direct effects among children's executive function (EF) skills at the beginning of prekindergarten (pre-K), their (A) level of involvement, (B) sequential behaviors, (C) social-learning interactions, and (D) disengagement from learning opportunities (i.e., unoccupied, disruptive, or in time out), and their end of pre-K literacy achievement gains. For simplification the covariates of beginning of pre-K achievement, English language learners status, gender, and age are not reported in this figure. Standardized path coefficients (*SE*s) are provided on the straight, single-headed arrow. CI = confidence interval. † $p < .10$. * $p < .05$. ** $p < .01$.

eracy gains were $\beta_{EF \rightarrow Involvement \rightarrow Lit} = .005$, $SE = .007$; $\beta_{EF \rightarrow Sequential \rightarrow Lit} = .010$, $SE = .005$; $\beta_{EF \rightarrow Unoccupied \rightarrow Lit} = .014$, $SE = .007$.

Mathematics. Results of models predicting children's pre-K mathematics gains indicated that children's level of involvement during learning activities (Figure 2A; CFI = 1.00; RMSEA 90% CI [0.00, 0.04]) and being unoccupied, disruptive, or in time out (Figure 2D; CFI = 1.00; RMSEA 90% CI [0.00, 0.05]) partially mediated the relationship between children's entering executive function skills and growth in mathematics skills across the pre-K year. Children who entered pre-K with greater executive function skills were more like to have higher levels of involvement in learning activities and were less likely to be unoccupied, disruptive, or in time out, which, in turn, contributed to greater gains in mathematics achievement.

Results also indicated that children's sequential learning behaviors were related to children's pre-K mathematics gains

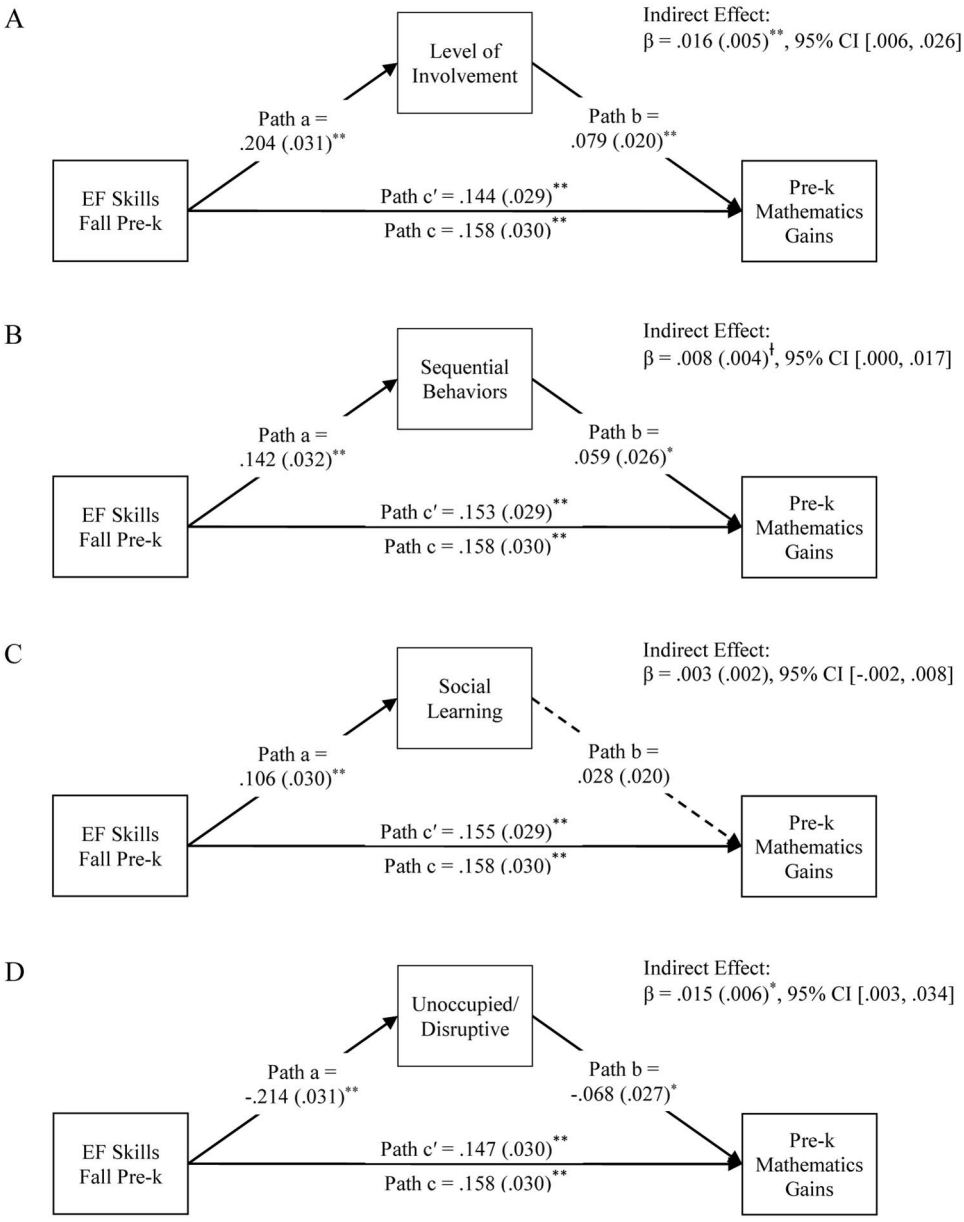

Figure 2. Path analysis of direct effects among children's executive function (EF) skills at the beginning of prekindergarten (pre-K), their (A) level of involvement, (B) sequential behaviors, (C) social-learning interactions, and (D) disengagement from learning opportunities (i.e., unoccupied, disruptive, or in time out), and their end-of-pre-K literacy achievement gains. For simplification the covariates of beginning of pre-K achievement, English language learners status, gender, and age are not reported in this figure. Standardized path coefficients (*SE*s) are provided on the straight, single-headed arrow. CI = confidence interval. † $p < .10$. * $p < .05$. ** $p < .01$.

(Figure 2B; CFI = 1.00; RMSEA 90% CI [0.00, 0.07]), and there was a marginal effect for children's sequential behaviors mediating the relation between children's executive function skill and math gains ($\beta_{EF \rightarrow Sequential \rightarrow Math} = .008$; $p = .056$). Last, as with literacy gains, social-learning interactions were not related to greater mathematics gains (Figure 2C, CFI = 1.00; RMSEA 90% CI [0.00, 0.05]) and did not indirectly influence the relation between children's entering executive function skills and mathematics gains.

The indirect effect through children's level of involvement in learning activities accounted for 10.1% of relation between children's entering executive function skills and pre-K mathematics gains, whereas the indirect effect through children's sequential learning behaviors accounted for 5.1% of the total effect and the indirect effect through children's being unoccupied, disruptive, or in time out accounted for 9.5% of the total effect.

With the identification of children's level of involvement, sequential behaviors, and being unoccupied or disruptive as signif-

icant mediators of the relation between children's entering executive function skills and pre-K mathematics gains, the total indirect effect of the three behaviors was estimated by simultaneously entering the three variables and their covariances into a single multimediator model (CFI = 0.99, RMSEA 90% CI [0.00, 0.05]). Combined the three learning-related behaviors partially mediated the relation between children's entering executive function skills and pre-K mathematics gains, $\beta_{EF \rightarrow TotalIndirect \rightarrow Math} = .023$, $SE = .007$, $p = .001$, 95% CI [.009, .036]. The magnitude of the indirect effect indicated that in total the three learning-related behaviors accounted for 14.6% of relation between children's entering executive function skills and pre-K mathematics gains. The unique indirect effect of the individual learning-related behaviors on mathematics gains were $\beta_{EF \rightarrow Involvement \rightarrow Math} = .010$, $SE = .006$; $\beta_{EF \rightarrow Sequential \rightarrow Math} = .004$, $SE = .005$; $\beta_{EF \rightarrow Unoccupied \rightarrow Math} = .008$, $SE = .007$.

Discussion

The goal of this study was to explore the relations between executive function skills, learning-related classroom behaviors, and achievement gains across the pre-K year. Specifically, we tested whether children's learning-related behaviors provided a pathway through which executive function skills enabled literacy, language, and mathematics learning. Our work yielded three important findings. First, greater executive function skills in children when they began pre-K were associated with higher levels of involvement during learning opportunities, more displays of sequential learning behaviors, more participation in social-learning interactions, and less demonstrations of unoccupied and disruptive behaviors. Second, children's involvement in learning interactions; participation in sequential learning behaviors; and abstention from being unoccupied, disruptive, or in time out were related to making greater pre-K gains in literacy and mathematics. Third, children's learning-related behaviors in the classroom were a mechanism through which children's executive function skills at the beginning of pre-K facilitated their pre-K literacy and mathematics gains. It appears that children who enter pre-K with less well-developed executive function skills find it harder to be involved in learning opportunities, including participating in fewer sequential behaviors and refraining from unoccupied and disruptive behaviors, which in turn is associated with making less gain in literacy and math across the pre-K year.

Executive Function Skills and Learning-Related Behaviors

Our results provide support for current theory regarding how executive functions skills influence children's readiness for school and are consistent with prior work demonstrating that the regulatory skills with which children enter pre-K are associated with their involvement in learning-related activities in the classroom. Namely, the results indicate that relative to their classmates, children with greater executive function skills at the onset of pre-K were more likely to participate in behaviors that are consistent with successful adaptation to the classroom environment and to engage in behaviors that facilitate academic achievement in the form of greater involvement in learning opportunities, more displays of sequential learning behaviors, more participation in social-learning interactions, and less demonstrations of unoccupied and disruptive behaviors.

The study extended prior research in several key ways. First our approach to examining how children behaved in classrooms is quite different from teacher ratings. To quantify learning-related behaviors, we used a snapshot protocol that codes specific classroom behaviors that with the exception of involvement were behavioral counts. Learning-related behaviors were also aggregate values from three full-day observations that were distributed across the course of the pre-K year. This approach to assessing children's in-classroom behaviors provided the opportunity to assess children's behaviors across various classroom contexts (e.g., whole group, centers, small groups) and reduce measurement issues (i.e., greater reliability) that can emerge from relying on a one-time assessment of a complex construct like children's learning-related classroom behaviors. Another strength of this study was the use of an analytic approach that controlled for between-classroom effects that have the potential to conflate results if left unadjusted. In particular, by centering the variables of children's learning behaviors and literacy, language, and mathematics achievement at the classroom mean, we are able to account for the difference in achievement gains and learning-related behaviors that might be attributed to differences in the types of classroom opportunities provided to children by the teachers and peers. Controlling for contextual effects allowed us to understand more clearly how a child's entering skills relative to his or her peers affected the types of behaviors demonstrated and the amount of academic growth.

Direct effects between children's executive function skills at the onset of pre-K and pre-K literacy and mathematics gains were consistent with prior work. The lack of association with language gains, although not hypothesized, is actually consistent with a growing body of work indicating that while children's executive function skills facilitate development of children's cognitively demanding reading, literacy, and mathematical skills, vocabulary development may rely less on children's executive function skills (e.g., Blair et al., 2007; Fuhs et al., 2014). It is also possible, however, that because pre-K classrooms do not facilitate language growth to the same degree, there was less to explain.

Learning-Related Behaviors and Academic Achievement

We also addressed the question of whether children who are observed engaging in more learning-related behaviors relative to their classmates made greater gains in literacy, language, and mathematic achievement over the pre-K year. Consistent with prior research, we found that compared with their classroom peers, children who were more involved in learning opportunities; engaged in more cognitively demanding sequential activities; and were able to refrain from being unoccupied, disruptive, or in time out tended to make larger gains in literacy and mathematics. On the other hand, we found that although zero-order correlations between the observations of children's participation in associative and cooperative social-learning interactions were related to children's end of pre-K literacy and mathematics achievement, after accounting for children's entering academic and executive function skills, the relations were no longer significant. Although prior studies have found relations between children's social-learning

behaviors and academic success (Ladd, 1990; Montroy et al., 2014; Wentzel, 1999), our quantification of social-learning behaviors as the frequency of teacher or peer-learning interactions could be contributing to the differential results. It is possible that more general ratings of children's social competence by either observers or teachers used by prior studies were also picking up on additional aspects of children's social competence that were facilitating academic growth.

Mediation Through Learning-Related Behaviors

The results from the mediation analyses indicated that children's executive functioning skills could contribute to their literacy and mathematics achievement through both positive and negative learning-related behaviors specific to the classroom environment. First, children with high executive function skills participated more often in more demanding activities and were more highly involved. Their participation and involvement in these positive learning-related behaviors mediated the relation between their executive function skills and gains in literacy and mathematics. More work is needed to determine the kinds of materials that might be included in classrooms to encourage learning-related classroom behaviors and push the boundaries of children's knowledge.

Second, children who entered pre-K classrooms with lower executive function skills were more often unoccupied, were more frequently disruptive and prompted their teachers more often to put them in time out. The consequence of this combination of skills and behavior was associated with lower achievement gains, which may be particularly problematic in a classroom environment in which a teacher has to spread attention across many children. More research is needed on how to engage children with these characteristics positively in the classroom. Otherwise, the children appear to be in a negative loop—their inattentiveness, low impulse control, and poorer working memory prevent them from engaging positively in learning behaviors in the classroom and consequently, the children learn less over the year.

Study Limitations and Future Directions

Several limitations should be mentioned. First, even though our tests of mediation concern speculation regarding cause and effect, the correlational design of the study still limits the ability to draw firm causal conclusions. Claims of causality could be substantially strengthened if children's learning-related behaviors were manipulated experimentally rather than simply observed. However, we believe that our conservative approach to analyses yielded important insights for future experimental work in real-world classroom settings.

It is important to remember that direct assessments of executive function may be tapping only a part of the broader construct of self-regulation. Self-regulation comprises such cognitive skills as attention shifting, inhibitory control, and working memory as we assessed directly but it also consists of such behaviors as effort and motivation that may only be determined in context. Although our composite executive function set of skills was related to observed classroom behaviors, the mediation was only partial. Other unmeasured skills or traits of the children likely also accounted for learning-related behaviors, skills likely related to the broader construct of self-regulation.

Partial mediation also indicates a need for future research to identify and examine the role of other child classroom behaviors that might contribute to academic success. This work could include establishing whether the learning-related behaviors quantified using a snapshot coding scheme replicate when observational systems that capture behavior over extend periods of time are used. Such knowledge will allow the field to understand the practical importance of the associations found among children's abilities, classroom behaviors, and academic success.

It is also important to note that our study provides no information about what accounts for differences in children's entering executive function skills. Entry-level executive function skills and achievement were relatively highly correlated, and executive function skills showed considerable variability across children. Although this study cannot address this variability, recent research suggests that variability in these skills could be explained in part by differences in family practices (e.g., Blair, Raver, & Berry, 2014). Future research on the origins of individual variability in these skills at the beginning of pre-K could inform teachers about ways to facilitate early learning for a diverse group of children.

Finally, to address the study's research questions, we were deliberate in isolating child-level effects from classroom contextual effects; however, our exclusive focus on child-level effects is not without its limitations. As evident from the ICCs of the study variables, there was considerable variation in the way these pre-K classrooms operated. Although the study design allows us to find that that when these classroom differences were controlled for, children's participation in learning behaviors appeared to relate to the different types of skills they brought into the classroom, it does not permit us to draw conclusions regarding the effect of different classroom contexts. It is important that future research examine the effects that alternative classroom contexts might have on the relations among children's executive function, their learning-related behaviors, and academic skills. Recent advances in multilevel structural equation modeling have made examining the dynamic interrelations among hierarchically structured variables feasible. Nonetheless, complex statistical techniques must always be matched by complex conceptualizations (Peugh & Ender, 2010); classrooms for young children are dynamic environments, hard to model well but very important to understand better.

Conclusion

The results of this study highlight the complexity of understanding learning environments for young children from at-risk circumstances and reinforce the notion that executive function skills are important for understanding how children respond to learning opportunities in classroom settings. The effects of entering skills are of particular importance given that pre-K is often children's first encounter with a formal learning environment. The question to investigate further is whether classrooms are providing the types of experiences that capitalize on children's executive function skills.

How children exert themselves in their environment is only half the picture. Children's ability to demonstrate learning-related behaviors is an attribute both of the child and the classroom context,

the latter of which is being established and provided by the pre-K teacher. In addition to making use of the positive executive function skills children bring to the classroom, teachers also have the responsibility for figuring out how to keep children with low executive function skills engaged and occupied. Enhancing the richness of the learning opportunities for children with higher skills while also providing access to learning for those with lower skills is the real challenge of pre-K programs for children from low-income families.

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