A Child by Environment Perspective on How Children's Executive Function Skills and the Classroom Environment Support Early Math Learning

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Abstract

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This dissertation includes three independent studies that advance a line of research exploring how children's executive function and aspects of their classroom experience support mathematics learning during the early years of school. In the first study, I examined how children's inhibitory control and the quality of their relationship with their preschool teacher was associated with their classroom engagement, and whether a close student-teacher relationship could serve as a protective factor for children with low inhibitory control. Results indicated that inhibitory control and the quality of the student-teacher relationship were associated with different domains of engagement. Rather than serving as a protective factor, a close student-teacher relationship served to amplify the positive association between children's inhibitory control and positive engagement with their teacher. In the second study, I explored the extent to which children's behavioral engagement mediated the association between their executive function and gains in mathematical knowledge and skills during preschool, and the extent to which the direct and indirect associations were moderated by the quantity and quality of math instruction in the classroom. Children's behavioral engagement partially mediated the association between their executive function and mathematical gains. The direct associations between executive function and mathematical gains were weaker in classrooms with a high dosage of instruction and in classrooms with higher quality instruction, while the indirect associations were stronger in classrooms with higher quality instruction. In the third study, I examined how children's executive function and math skills at kindergarten entry, as well as the content of math instruction during the school year, independently and jointly related to their math learning during kindergarten. Each of children's school-entry skills was associated with their math learning, and the association between working memory and math achievement gains was stronger for children who started kindergarten with lower math skills. More frequent math instruction focused on basic skills was associated with smaller math achievement gains during kindergarten, while instruction on more advanced skills was associated with larger gains; the latter association was larger for children who started kindergarten with low cognitive flexibility or math skills.

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APPROVAL OF THE DISSERTATION

This dissertation, A child by environment perspective on how children's executive function skills and the classroom environment support early math learning, has been approved by the Graduate Faculty of the Curry School of Education in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Rational and Conceptual Link: Using a Child by Environment Perspective to Understand How Children's Executive Function Skills and Classroom Environments Support Early Math Learning

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The Three-Manuscript Dissertation: Overview

In this dissertation I present a line of research exploring how children's executive function and aspects of their classroom experience support mathematics learning during the early years of school. The dissertation adheres to the manuscript-style dissertation option, as outlined in the Curry School of Education Ph.D. Dissertation Manual (2015). In accordance with these guidelines, I am the first author on all three of the studies. Additionally, Study 1 has been submitted and is in the revision process at *Early Childhood Research Quarterly*, and Study 2 is currently under review at the *Journal of Applied Developmental Psychology*. All three manuscript-style studies are conceptually linked while representing a unique contribution to the field. The remainder of this document discusses the rationale for the current line of research and the theoretical framework shared by the three studies. Following this document, each of the three manuscripts is presented in its entirety.

Conceptual Link: Using a Child by Environment Perspective to Understand How Children's Executive Function Skills and Classroom Environments Support Early Math Learning

Young children need to develop a variety of skills, including early academic, general cognitive, and social emotional skills to be ready to succeed in formal schooling (Claessens, Duncan, & Engel, 2009; National Research Council and Institute of Medicine, 2000). Policymakers have promoted high-quality preschool programs as a way to ensure that children have the readiness skills they need, and young children are spending increasing amounts of time in these programs (McFarland et al., 2017). Early education programs seek to provide enriched environments and interactions that support children's development (Yoshikawa et al., 2013). However, the extent to which a child is able to engage with and subsequently learn and develop from the people, materials, and resources in their classroom environment is dependent on the interplay between the early skills the child brings to the classroom and the affordances provided in that classroom (Brock, Rimm-Kaufman, & Wanless, 2014; Ladd, Birch, & Buhs, 1999; Sameroff & Mackenzie, 2003).

While young children undoubtedly need early skills across many domains, early mathematics skills may be especially important and serve as a bellwether of later academic achievement (Claessens et al., 2009; Duncan et al., 2007). Among both early academic and socioemotional skills, children's mathematical skills at school entry are the strongest predictor of later academic performance in not only math, but also reading (Duncan et al., 2007). The importance of children's early math knowledge and skills as an indicator for their later academic success highlights the need to understand children's characteristics and skills that are related to math learning. Research indicates that children's early executive function skills are especially important for their math learning.

Executive function is a cognitive construct that encompasses higher order processes such as planning and problem solving, and is composed of: working memory, cognitive flexibility or shifting, and inhibitory control (Diamond, 2006; Hughes, 1998; Welsh, Pennington, & Groisser, 1991). Executive function is important for a variety of school readiness skills, both social emotional and academic (Blair, 2002; Heckman, 2006; Raver, 2012), but is particularly strongly linked to math performance and learning as compared to other subjects like language and literacy (Best & Miller, 2010; Blair, Ursache, Greenberg, & Vernon-Feagans, 2015; Bull, Espy, & Wiebe, 2008; Stipek & Valentino, 2015; Vandenbroucke, Verschueren, & Baeyens, 2017). Furthermore, neuropsychological research suggests a deep connection between executive function and math, as they tend to activate the same areas of the brain and both undergo rapid development in early childhood (Best & Miller, 2010; Espy et al., 2004). The strong links between executive function and math call for a deeper understanding of the mechanism underlying this association.

Research suggests that executive function may be directly to children's math skills, as they both draw upon children's cognitive processes (Nesbitt, Farran, & Fuhs, 2015; Clements, Sarama, & Germeroth, 2016). One such explanation highlights the inherent unity of math proficiencies, including conceptual understanding, strategic competence, procedural fluency, and reflective reasoning (National Research Council, 2001, p. 116), and higher order executive function skills including conceptual reasoning, strategic organization, efficient and fluent information processing, and feedback utilization (Anderson, 2002; Clements et al., 2016). Additionally, executive function is proposed to be central to mathematical processing (see Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2014 for a detailed description of a mathematical processing network with executive function at the center).

Other research suggests an indirect relation between EF and math, with behavioral engagement as a hypothesized mediator between the two. Some research suggests that children's EF skills, specifically their inhibitory control, is associated with their ability to engage positively in the classroom and attend to content, which in turn, is related to the development of math knowledge and skills (Clements et al., 2016; McClelland, Acock, & Morrison, 2006). This view of the association between executive function and academics implies that executive function would have effects on all domains of learning, not just math.

In addition to executive function being central to children's math learning, child by environment models of development suggest that features of the classroom environment will interact with the child's characteristics to influence their learning (Brock et al., 2014; Ladd et al., 1999).

Child by environment models posit that children's outcomes (e.g., math achievement) are the result of an interaction between a child's characteristics (e.g., executive function skills) and their social environment (e.g., instruction, relationship with their teacher; Sameroff & Mackenzie, 2003). Both risk and protective factors are present within the child as well as the environment (Brock et al., 2014; Ladd et al., 1999). For example, children with weak executive function may be considered "at risk" in regards to academic achievement because they may not have the skills to engage positively in the classroom or cognitively with the math content. However, elements of the classroom environment, such as strong instruction or positive student-teacher relationships, may be able to serve as protective factors and facilitate positive outcomes for those children despite that risk. The goal of this dissertation is to use a child by environment perspective to explore the ways in which young children's executive function and aspects of their classroom environments (e.g., quantity and quality of instruction) individually and jointly influence their behavior and math learning in the classroom.

Study 1: The Role of Inhibitory Control and Relationships with Teachers in Children's Engagement in the Classroom

The first study used a child by environment perspective to examine preschool children's behavioral engagement. In the early childhood classroom children interact or engage with their teachers, peers, and classroom activities and materials, and their engagement can be positive or conflictual (Downer, Booren, Lima, Luckner, & Pianta, 2010). Child characteristics, including inhibitory control, are associated with classroom engagement (Bohlmann & Downer, 2016; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Cadima, Doumen, Verschueren, & Buyse, 2015). Aspects of the environment, including the quality of a child's relationship with their teacher, are also related to the ways that children engage in the classroom (Birch & Ladd, 1997; Griggs, Gagnon, Huelsman, Kidder-Ashley, & Ballard, 2009; Palermo, Hanish, Martin, Fabes, & Reiser, 2007). Furthermore, a close student-teacher relationship can serve as a protective factor for children who otherwise may have difficulties in the classroom due to behavioral or academic risk factors. A close-student teacher relationship has changed the trajectory of children considered at risk due to externalizing behavior and low academic performance (Blair & McKinnon, 2016; Pianta, Steinberg, & Rollins, 1995; Sabol & Pianta, 2012; Silver, Measelle, Armstrong, & Essex, 2005). This relationship may similarly serve as an important support in the classroom for children who may be considered "at risk" for poor engagement due to low inhibitory control. For this reason, we examine whether a close student-teacher relationship moderates the association between inhibitory control and engagement.

Utilizing data from the *MyTeachingPartner-Math/Science* (*MTP-M/S*) efficacy trial, this study used a series of multiple regressions to examine how children's inhibitory control and the quality of their relationships with their teachers (both closeness and conflict in the relationship), as well as the interaction between children's inhibitory control and teacher-child closeness, were associated with their engagement with teachers, peers, and tasks. Results indicated that children with stronger inhibitory control had less conflictual engagement. Children with a close student-teacher relationship were observed to have more positive engagement with their teacher, while children with a conflictual student-teacher relationship were observed to engage in more conflict in the classroom. Additionally, a close student-teacher relationship and inhibitory control interacted such that the positive association between inhibitory control and positive engagement with teachers was stronger for children with a closer relationship with their teacher. Findings suggest that supporting children's inhibitory control and encouraging close student-teacher relationships may help promote young children's positive classroom engagement. In this study we examined the links between children's executive function and their classroom engagement, but did not examine how classroom engagement was related to children's academic outcomes. We explore this association in Study 2.

Study 2: Executive Function, Engagement, and Mathematical Achievement: Relations in Classrooms with Varying Math Instruction

In study 2, we examined the extent to which preschool children's behavioral engagement mediated the relation between executive function and math learning, and explored whether these associations were affected by the quantity and quality of classroom math instruction. Executive function is of central importance in supporting children's knowledge and skills in mathematics (Bull et al., 2008; Clark, Pritchard, & Woodward, 2010). However, the mechanisms underlying the relation between young children's executive function and mathematical skills are not fully understood. There is some evidence suggesting that children's classroom engagement may act as a mediator, however extant research has shown mixed results (Brock et al., 2014; Nesbitt et al., 2015). Taking a child by environment perspective led us to consider the ways classroom math instruction may provide different learning affordances to children based on their self-regulation skills (Brock et al., 2014). Specifically, we examined the ways in which the quality and quantity of math instruction in the classroom influenced both the direct association between executive function and math as well as the mediational pathways.

In this study, we again utilized *MTP-M/S* data, specifically direct assessments of children's executive function and math achievement, teacher reports of children's engagement, and observational data of the quality and quantity of math instruction. A path analysis model was used to test the mediation, and results indicated that children's behavioral engagement partially mediated the positive association between their executive function and math learning, however these associations were smaller than the direct associations between executive function and math learning. Next two more path analysis models were used to test for moderation by quantity and quality of math instruction, respectively. The quantity of math instruction in a classroom moderated the direct association between executive function and math, such that children's executive function was less strongly related to growth in math skills in classrooms with more math instruction. The quantity of math instruction did not moderate the indirect associations between executive function and math. Similar to the moderation of the direct association by quantity, children's executive function was less strongly related to growth in math skills in classrooms with higher quality math instruction. However, in contrast to the weaker direct association in classrooms with higher quality instruction, the indirect association between executive function and math through engagement was stronger in classrooms with higher quality math instruction. In summary, children's mathematics gains were directly associated less strongly with their executive function in classrooms with a higher dosage of math instruction and in classrooms with higher quality instruction. In other words, results indicated that when classrooms provide sufficient amounts of math instruction and when they provide instruction of adequate quality, children's math gains are more equal and less dependent on the executive function skills they bring to the classroom. Additionally, executive function was more positively linked to mathematics gains, due to more behavioral engagement, in classrooms with higher quality instruction. Specifically, the association between behavioral engagement and improved math outcome was stronger in classrooms with higher quality instruction than in classrooms with lower quality instruction. Results suggest the importance of providing sufficient dosage and quality of math instruction for equitable learning outcomes.

In this study, I examined how two aspects of math instruction, dosage and quality, impacted the relations among executive function, engagement, and math outcomes. Both the quantity and quality of math instruction in the classroom changed the association between children's executive function and their math gains. In classrooms with high dosage of instruction and in those with high quality instruction, children's executive function skills were not directly related to their math outcomes. These findings led me to consider whether other aspects of math instruction may also change the association between children's executive function and math outcomes. In Study 3, I sought to build upon this study by examining a different aspect of math instruction, what math skills are taught. Specifically, I examined how the frequency with which different skills are taught in kindergarten is associated with children's math outcomes and how this association may vary based on children's executive function and math skills at school entry using a large, nationally representative sample.

Study 3: Links Between Early Skills, Instruction, and Mathematics Achievement in Kindergarten

Although children's executive function is important for their math learning (Blair & Razza, 2007; Bull et al., 2008; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Nayfeld, Fuccillo, & Greenfield, 2013), their math skills at school-entry are the strongest predictors of their later math performance (Duncan et al., 2007; Watts, Duncan, Siegler, & Davis-Kean, 2014). Moreover, recent research suggests that these early skills may interact such that executive function skills act as a protective factor for children who start school with less advanced math skills (Blair, McKinnon, & The Family Life Project Investigators, 2016; Ribner, Willoughby, Blair, & The Family Life Project Key

Investigators, 2017). However, not just children's early skills, but also what math skills they are taught in kindergarten math instruction influences their math learning (Engel, Claessens, Watts, & Farkas, 2016). Moreover, children differentially benefit from math instruction based on the skills they bring to the classroom (Bodovski & Farkas, 2007; Chiatovich & Stipek, 2016; Engel, Claessens, & Finch, 2012), and exeuctive function skills are more closely associated with some math skills (Peng, Namkung, Barnes, & Sun, 2016; Vanbinst & De Smedt, 2016) than others. This led us to hypothesize that the association between which skills are taught in kindergarten and the gains children make in math during the school year may depend not only on their math skills at the start of the year, but also on their executive function, however, there is little research in this area.

Study 3 utilized a child by environment perspective to examine associations between children's executive function and math skills at school entry, classroom math instruction, and math achievement. We assessed the extent to which school-entry skills and math instruction independently and jointly related to math learning. Specifically, we used data from the kindergarten year of the Early Childhood Longitudinal Study Kindergarten Class of 2010-2011 in regression analyses to examine these associations. Children who started kindergarten with the strongest math skills had the highest math achievement at the end of the year, and the size of this association was larger than the association with any of children's other skills or demographic characteristics. Stronger cognitive flexibility and working memory were also associated with greater gains in math during kindergarten, with the working memory effect size being nearly twice the size of that of cognitive flexibility. Furthermore, working memory did serve as a protective factor for children starting kindergarten with lower math skills in that they experienced greater than expected math gains when they had strong working memory at school-entry. In terms of instruction, more frequently teaching Advanced Number Skills as well as Operation was associated with larger math gains, while more frequently teaching Basic Math Skills was associated with smaller gains. Additionally, the positive association between Advanced Number Skills and math gains was stronger for children who started kindergarten with low math skills or low cognitive flexibility. Findings from the study support teaching more advanced math skills during kindergarten to support children's critical early math learning.

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The Role of Inhibitory Control and Relationships with Teachers in Children's Engagement in the Classroom

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Introduction

The majority of young children now spend a portion of their day in a preschool setting (Kena et al., 2016) and the quality of children's engagement with teachers, peers, and tasks within the classroom is an important predictor of their academic and social-emotional development (Chien et al., 2010; Fantuzzo et al., 2007; Williford, Maier, Downer, Pianta, & Howes, 2013). Positive classroom engagement, such as shared positive interactions and affect with teachers and peers, and sustained and active engagement with classroom tasks, is linked to improved relationships, future engagement, and positive academic outcomes in language, literacy, and math (Bohlmann & Downer, 2016; Hughes, Luo, Kwok, & Loyd, 2008; Sabol, Bohlmann, & Downer, 2017). Conversely, children with more negative engagement in the classroom, including conflictual interactions with peers and teachers, tend to experience more exclusion by peers and psychosocial maladjustment (Crick, Casas, & Mosher, 1997; Gower, Lingras, Mathieson, Kawabata, & Crick, 2014; Palermo, Hanish, Martin, Fabes, & Reiser, 2007). Given the importance of children's classroom engagement, it is critical to understand what factors may lead children to be more or less engaged in the classroom.

Children may differ in how they approach interactions with teachers, peers, and tasks based on how regulated they are. Specifically, a child's ability to filter their thoughts and impulses to resist temptations and distractions, may play a particularly important role in their ability to positively engage in the classroom (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Cadima, Doumen, Verschueren, & Buyse, 2015). Although children's inhibitory control has been linked to their overall engagement in the classroom, less research has explored how children's ability to inhibit their impulses is specifically related to how they engage with teachers, peers, and tasks in the classroom. This is important because while a child may be rated by their teachers as having generally high levels of positive engagement in the classroom, this may mask difficulties within a particular domain, and children's engagement in specific domains can have unique impacts on their development.

Children who have difficulty with impulse control may need additional classroom supports to positively engage with teachers, peers, and classroom activities. A close teacher-child relationship has been found to be an important support for children who might otherwise have difficulties in the classroom due to demographic and behavioral risk factors (Burchinal, Peisner-Feinberg, Pianta, & Howes, 2002; Pianta, Steinberg, & Rollins, 1995; Silver et al., 2005). It is possible that a close student-teacher relationship may also improve classroom engagement for children with low inhibitory control, but this is an area that has yet to be studied in young children. In this study, we investigate associations between the quality of the teacher-child relationship and children's classroom engagement, and whether the student-teacher relationships may serve as a protective factor for children with low inhibitory control by supporting positive classroom engagement.

Importance of Children's Classroom Engagement

Children's engagement with the people and tasks in their environment is the driver of their development. Bronfenbrenner's (1994) developmental theory posits that development is facilitated through interactions with adults, peers, and the learning context and so provides a guiding framework to explore children's classroom engagement. Classroom engagement can be organized into interactions with teachers, peers, and classroom materials or tasks, all of which can have positive impacts on children's development (Downer, Booren, Lima, Luckner, & Pianta, 2010; Sabol et al., 2017). Children's positive and supportive interactions with teachers are associated with social-emotional and academic development (Burchinal et al., 2008; Downer et al., 2010; Yoshikawa et al., 2013). Similarly, children who positively engage with their peers, through cooperation, communication, and play, show greater school readiness skills (Coolahan, Fantuzzo, Mendez, & McDermott, 2000; Downer et al., 2010). Finally, positive task engagement is characterized by children remaining on-task, enthusiastically participating in classroom activities, and showing self-reliance by seeking out opportunities in the classroom (Downer et al., 2010). Children's positive engagement with school tasks is linked to the development of school readiness skills and greater academic learning (Bohlmann & Downer, 2016; Hofer, Farran, & Cummings, 2013; Portilla, Ballard, Adler, Boyce, & Obradovic, 2014). Considering the relevance of children's classroom engagement in predicting children's outcomes across domains, it is important to explore factors that are associated with classroom engagement.

Inhibitory Control and Classroom Engagement

Self-regulation includes a broad constellation of skills related to the ability to persist and delay gratification, plan one's actions, organize information, and control one's emotions, behavior, attention, and cognition (Ursache, Blair, & Raver, 2012); all of which are fundamental to a child's functioning and engagement in the classroom. Extant research shows that preschool and kindergarten children with greater self-regulation are more engaged with teachers, peers, and tasks in the classroom (Silva et al., 2011; Valiente, Swanson, & Lemery-Chalfant, 2012; Yang & Lamb, 2014). However, because self-regulation includes a cluster of skills, it is unclear which components are most important in fostering children's classroom engagement. This lack of precision limits our understanding of how to support children's regulatory skills in efforts to improve classroom engagement.

In this study, we specifically examine one aspect of self-regulation – inhibitory control. Inhibitory control has been conceptualized in different ways. Temperament researchers have operationalized it as part of effortful control and typically measure children's automatic emotional reactivity and regulation, as well as purposeful regulation. Developmental researchers define inhibitory control as a component of executive function, solely focused on deliberate cognitive control in situations without emotional valence (Blair & Razza, 2007; Zhou, Chen, & Main, 2012). In the present study, we use the second conceptualization.

The role inhibitory control plays in preschool children's classroom engagement is unclear. School-aged children with greater inhibitory control show more positive engagement in the classroom (Brock et al., 2009; Cadima et al., 2015). However, elementary classrooms are quite different from preschool classrooms in regards to the increased focus on formal academic instruction, interactions with the teacher, increased time in a large group, and expectations for autonomy (Rimm-Kaufman & Pianta, 2000). Therefore, it is unclear whether inhibitory control plays the same role in classroom engagement for preschool children. Furthermore, researchers have examined how inhibitory control relates to children's overall engagement in the classroom, but little research has examined whether the ability to inhibit impulses might be particularly important for some aspects of classroom engagement; for example, inhibitory control may be strongly associated with a child's engagement with peers, but less strongly related to a child's engagement with the teacher.

The limited research that does exist suggests that young children with stronger inhibitory control are more likely to be deeply engaged with learning tasks and less likely to be unoccupied and engaged in disruptive behavior (Bohlmann & Downer, 2016; Cadima et al., 2015). For children in first grade, parental reports of lower inhibitory control related to more teacher-initiated engagement with the child (both positive engagement, such as the teacher listening to the child read aloud or conversing with the child about their schoolwork, as well as conflictual engagement with the teacher, such as disciplining the child), but not child-initiated engagement with the teacher (Rudasill & Rimm-Kaufman, 2009). Both effortful control and executive function have been linked to more positive engagement and less social problems with peers (Fabes et al., 1999; Fahie & Symons, 2003; Nesbitt, Farran, & Fuhs, 2015) however, inhibitory control specifically has not been examined in regards to interactions with peers. In this study, we seek to better understand the links between children's inhibitory control and their engagement with teachers, peers, and tasks in the preschool classroom. In addition, we will consider how the quality of a child's relationship with their teacher relates to classroom engagement and whether it can serve as a protective factor for children with low inhibitory control.

Student-Teacher Relationship Quality and Children's Engagement

Positive teacher-child relationships are typically viewed by the child as providing a sense of security (Hartup, 1989). Children who have a close relationship with their teacher may feel more comfortable approaching the teacher, as well as using the teacher as a secure base from which they can explore tasks and materials in the classroom and engage with peers (Howes, 2000; Howes, Hamilton, & Matheson, 1994). In contrast, conflictual student-teacher relationships can have deleterious effects on children. Children with whom the teacher reports a close relationship are also reported to be more engaged in the classroom, while children with conflictual relationships are reported to be less engaged (Cadima et al., 2015; Hughes et al., 2008; Yang & Lamb, 2014). One drawback of this research is that these associations rely on teachers' reports of both their perceptions of relationships with children and their perceptions of children's engagement, though research shows that teacher ratings can be influenced by teacher characteristics (Mashburn, Hamre, Downer, & Pianta, 2006). We therefore build on previous findings by examining if the relation exists when children's engagement is measured by an outside observer using a standardized protocol.

While there is some evidence that the quality of student-teacher relationships is associated with children's general classroom engagement, the relations between the quality of the student-teacher relationship and engagement in specific domains (i.e., teachers, peers, tasks) is relatively unknown. It is expected that teachers would engage more positively with children with whom they perceive a close relationship and more negatively with children with whom they perceive a conflictual relationship, and there are small to moderate concurrent associations between teachers' reports of the quality of their relationship with a child and observed engagement with the child (r = .25 for reported close relationships and positive observed engagement; r = .53 for conflictual relationships and conflictual engagement; Downer et al., 2010). Children with as a close student-teacher relationship are reported by their teachers to engage in more prosocial behavior, while students with a conflictual student-teacher relationship are reported to engage in more disruptive play with their peers and less prosocial behaviors (Birch & Ladd, 1997; Griggs, Gagnon, Huelsman, Kidder-Ashley, & Ballard, 2009; Palermo et al., 2007). Finally, teachers who report close or low conflict relationships with a child also report that child to be more self-directed in their engagement with classroom tasks (Birch & Ladd, 1997). However, with the exception of the concurrent associations observed by Downer and colleagues (2010), these relations only reflect teachers' perceptions of the child's engagement. In this study, we will examine how teachers' perception of the quality of their relationship with a child relates to a child's observed classroom engagement later in the year. Furthermore, we examine whether a close relationship can serve as a protective factor by moderating the relationship between children's inhibitory control and their classroom engagement.

Student-Teacher Relationship as a Protective Factor

There is evidence that for children who are considered at-risk for maladaptive outcomes, a close student-teacher relationship may play an especially important role in changing their developmental and academic trajectory (Blair & McKinnon, 2016; Pianta et al., 1995; Sabol & Pianta, 2012; Silver et al., 2005). A close student-teacher relationship has been found to be important protective factor for children considered at risk for a number of reasons including behavior problems, poor effortful control, and low academic performance (Blair & McKinnon, 2016; Liew, Chen, & Hughes, 2010; Silver et al., 2005). For example, for children who had above average levels of externalizing behavior in kindergarten but also had a close student-teacher relationship, there were lower than expected age-related increases in externalizing behavior over time (Silver et al., 2005). Academically, first-graders at-risk for low academic performance performed equally well in reading and math in second grade despite low effortful control when they had a close student-teacher relationship (Liew et al., 2010). Similarly, preschoolers with low math skills but a close student-teacher relationship had higher math skills in kindergarten than were expected (Blair & McKinnon, 2016). However, there is very little evidence on whether a close relationship with their teacher can serve as a protective factor for children considered at-risk due to low inhibitory control or in regards to classroom engagement outcomes. In the present study, we examined whether a close student-teacher relationship moderates the association between preschool children's inhibitory control and their engagement with teachers, peers, and tasks.

Present Study

The present study sought to add to the existing literature on preschool children's self-regulation and student-teacher relationships as predictors of children's classroom engagement in three key ways. First, we sought to examine the relation between a specific component of self-regulation, inhibitory control, and classroom engagement. Second, we used an observational measure of children's engagement across domains rather than a teacher-report on children's general engagement. Finally, we examined how a close student-teacher relationship could serve as a protective factor in regards to facilitating classroom engagement for children with low inhibitory control. Specifically, we sought to answer the following research questions:

1. Do children with greater inhibitory control engage more positively with teachers, peers, and classroom tasks, and engage in less conflict?

2. Do children with higher levels of teacher reported closeness and lower levels of teacher reported conflict engage more positively with teachers, peers, and classroom tasks, and engage in less conflict?
3. Does a close teacher-child relationship serve as a protective factor in supporting engagement for children with low inhibitory control?

We hypothesized that children's inhibitory control would be positively associated with positive engagement with teachers, peers, and tasks, and negatively associated with conflictual engagement. Similarly, we hypothesized, based on previous research (Yang & Lamb, 2014), that a close student-teacher relationship would be associated with positive engagement with teachers, peers, and tasks, and negatively associated with conflictual engagement. We also hypothesized that a conflictual student-teacher relationship would be associated with less positive engagement with teachers, peers, and tasks and more conflictual engagement. Finally, we expected that student-teacher closeness would moderate the relationship between children's inhibitory control and their engagement across domains, such that children with lower inhibitory skills would benefit more from a close student-teacher relationship, with respect to their classroom engagement.

Method

Participants

Data from this study come from the first year of a randomized controlled trial of a curricular and professional development intervention, *MyTeachingPartner-Math/Science* (*MTP-M/S*), designed to support preschool teachers' mathematics and science instruction, and improve children's skills in these areas (for a description of the intervention, see

Kinzie, Whittaker, McGuire, Lee, & Kilday, 2015; for intervention effects see Whittaker et al., 2017).

Data for the study were collected across two sites. Site 1 classrooms (*n* = 116) implemented the *MTP-M/S* intervention during the 2013-2014 school year and included Head Start, state pre-k, and private for-profit and non-profit preschool classrooms in a Midwestern city. Site 2 classrooms (*n* = 40) implemented the intervention during the 2014-2015 school-year and consisted of state-funded pre-k classrooms in a Southeastern city.

The original sample included 156 teachers. There was some attrition over the course of the larger study due to teachers voluntarily withdrawing (*n* = 12), leaving the classroom or school (*n* = 38), or no longer meeting eligibility requirements (*n* = 8). To offset teacher attrition, an additional 15 teachers replaced some of the teachers who left the study, leading to 171 total study teachers. Teachers were majority female (97%) and the majority reported their race/ethnicity as White (72%), 20% as Black/African American, 3% as Hispanic/Latino, and the rest reported multiple races/ethnicities (4%). They had completed between 12 and 18 years of school (*M* = 15.25, *SD* = 1.83) and 24% had completed a major focused on early childhood. There were no significant differences in demographic characteristics of teachers from Site 1 and Site 2, with the exception of teacher education. Teachers from Site 2 completed significantly more education (*M* = 16.98 years) than those from Site 1 (*M* = 14.69 years).

A total of 913 students participated during the first year of the larger study (an average of 6 randomly selected students per classroom). There was some attrition at the student level. Initially, 841 children were selected to participate. Of these, 216 couldn't be assessed in the spring due to teacher or student withdrawal from the preschool. To offset child attrition due to student withdrawal, an additional 72 children were added to the sample prior to spring assessments. Participating students (*N* = 913) were all kindergarten eligible for the subsequent academic year and were an average of 53.88-months-old (*SD* = 3.72) at the start of the study. Of the children: 53% were reported to be White, 29% Black/African American, 6% Hispanic/Latino, 3% Asian, and 9% other or multiple races/ethnicities. Parents reported an average of 14.38 (*SD* = 0.20) years of education.

For the present study, because our focus was on children's classroom engagement, we only included classrooms in which at least one child's classroom engagement was observed (*N* = 123, see further information below about procedures). Descriptive statistics on the 123 participating classrooms and teachers are included in Table 1. Of the 156 original classrooms, 30 were no longer participating at the time of observations and three were unable to be observed due to extenuating circumstances in the classroom. We tested for differences between the original sample of classrooms and teachers and our included classrooms and teachers, and found that included classrooms were more likely to be from Site 2 and more likely to be state pre-k classrooms, as compared to Head Start or private pre-k. There were no differences in teacher characteristics between the original sample and the included sample of teachers.

The sample of children in the present study consists of a subsample of children who were randomly selected to be observed for classroom engagement (*N* = 366, see further information below about procedures). Children in the sample ranged from 47 months to 62 months (*M* = 53.91, *SD* = 3.72) at the beginning of the study. The sample was diverse: 51% were reported to be White, 32% Black/African American, 5% Hispanic/Latino, 3% Asian, 9% multiracial, and less than 1% other. Children from Site 2 were significantly younger (*M* = 52.96 months; *M* = 54.38 months at Site 1) and a higher percentage were reported to be a racial/ethnic minority (80% vs. 34% at Site 1). Descriptive statistics for children are presented in Table 1. Children in the subsample did not differ from children in the original sample on any descriptive characteristics.

Procedures

Participating classrooms were assigned, using block randomization based on preschool type and location, to the *MTP-M/S* intervention or business-as-usual. Teachers in the intervention condition received the math and science curricula, and associated online and in-person professional development supports. Teachers in the business-as-usual classrooms continued their normal instruction. Teachers who consented to participate attended an introductory workshop in the fall, during which they were oriented to the purpose of the study and given information about data collection requirements. Teachers completed a survey in the fall that included questions about demographics and professional experience, and rating scales on the quality of their relationships with students.

At the beginning of the school year, participating teachers sent home a consent form and family demographic survey to all parents or guardians of their students, with a request that these be completed and returned. Based on the parental consent received, we randomly selected six students per classroom for participation in direct assessments (see more on procedures below). Students were excluded from the study if they were reported by their teachers to have an Individualized Education Plan or limited English proficiency.

In the spring we conducted classroom observations of children's engagement (see more information on the observational protocol below). From the selected sample of six children per classroom, we randomly selected three on whom to conduct classroom observations of their engagement in the classroom (n = 366).

Child assessment training and protocol. Data collectors all had a Bachelor's degree and prior experience working with children. Prior to the fall assessment window they attended two full days of training on the administration of direct assessments. Data collectors were given extensive practice administering the assessments and were evaluated using a checklist to ensure they adhered to standardized administration and scoring. Direct assessments of children's inhibitory control were collected by trained data collectors at the beginning of the year in one-on-one sessions in a quiet area of the classroom or school.

Observation training and protocol. Prior to spring observations, data collectors attended two full days of training on an observational measure of children's engagement (Individualized Classroom Assessment Scoring System [inCLASS]; Downer et al., 2010). Training included viewing numerous video examples and practice coding five classroom videos. After completing the training, data collectors were given five videos to individually code. To be considered reliable, data collectors had to assign codes that were within one point of the expert-determined code 80% of the time and could not be more than one-point away on more than three out of the five videos for each dimension. Observations of children's classroom engagement were conducted in early spring. They were conducted for ten minutes at a time on a given student, followed by a five-minute coding period; this cycle was repeated in succession for each student being observed for as many cycles as class time permitted. Students were observed for an average of eight cycles (*M* = 7.55 cycles; *SD* = 2.18) across three consecutive days (*M* = 2.80; *SD* = 0.76) in early spring. Twelve percent of inCLASS cycles were double coded to calculate inter-rater reliability (*ICC*s = .50 -.84).

Measures

Inhibitory control. Children's inhibitory control was measured by direct assessment using *Pencil Tap* (Diamond & Taylor, 1996). In this task children are asked to tap once when the experimenter taps twice and tap twice when the experimenter taps once. Children receive a score of the percent of correct responses across 16 scored trials. *Pencil Tap* has shown good concurrent and construct validity (Smith-Donald, Raver, Hayes, & Richardson, 2007). The internal consistency is the current sample was excellent (α = .92).

Student-teacher relationship. Teachers' perceptions of their relationships with students were collected using the short form of the *Student-Teacher Relationship Scale* (STRS; Pianta, 2001). The STRS consists of 15 items rated on a 5-point Likert-type scale. Items from the STRS can be averaged into two subscales: conflict, which measures negativity in the relationship, and closeness, which measures warmth and affection. A validation study of the STRS with preschool and kindergarten children found support for the convergent and discriminate validity of the closeness and conflict scales (Doumen et al., 2009). The internal reliability in the present sample was good for both the closeness scale (α = .87) and conflict scale (α = .91).

Engagement. Children's classroom engagement was measured using the *Individualized Classroom Assessment Scoring System* (inCLASS; Downer et al., 2010), an observational assessment of children's engagement across ten dimensions, each rated on a seven-point scale, which can be aggregated up to engagement in four domains: Positive Teacher Engagement, Positive Peer Engagement, Task Engagement, and Conflictual Engagement. Positive Teacher Engagement is an aggregate of children's emotional connection to the teacher as observed by seeking and enjoying interactions with the teacher and their communication with the teacher, or the degree to which they initiate and sustain conversation with the teacher. Positive Peer Engagement is also comprised of an emotional connection and a communication dimension, and also a dimension measuring the child's ability to successfully initiate and lead interactions with other children. The Task Engagement domain consists of a dimension measuring the degree to which the child maintains focus on an appropriate task and the enthusiasm with which they complete the task, and a second dimension that measures the degree to which the child seeks out opportunities and resources. Finally, Conflictual Engagement measures tension, resistance and negativity in interactions with teachers and peers and a third dimension measuring how well the child meets behavioral expectations for the setting.

The instrument developers found the inter-rater reliability on dimensions of the inCLASS to be moderate to excellent (ICC = .53 - .84) and the dimensions show criterion validity with established teacher ratings of similar constructs (see Downer et al., 2010 for validation study). In the present study, 12% of cycles were double coded; inter-rater reliability for the domains ranged from fair to excellent (per guidelines set forth by Cicchetti, 1994; *ICC* = .73 for Positive Teacher Engagement; *ICC* = .77 for Positive Peer Engagement; *ICC* = .56 for Task Engagement; *ICC* = .63 for Conflictual Engagement).

Agreement between scores assigned by coders was within one point on each dimension 72% -98% of the time. Internal consistency for Positive Teacher Engagement was .79, Positive Peer Engagement was .89, Task Engagement was .40, and Conflictual Engagement was .62.

Data Analyses

Data were analyzed using linear regression analyses in *MPlus* version 7.31, with full information maximum likelihood to handle missing data. The nesting of children in classrooms was accounted for by including classroom as a random factor in all models and adjusting the standard errors of our estimates for covariance of children within classrooms. The analyses focused on predicting children's engagement in the four domains (teacher, peer, task, and conflict) from children's inhibitory control, and closeness and conflict in the student-teacher relationship. All outcomes and predictors were estimated simultaneously in a path-analytic model. Each of the regression models included child's age, child's gender, years of education completed by the child's primary caregiver, child race/ethnicity, teacher race/ethnicity, teacher's years of education, center type, site, and intervention condition as covariates. We did not hypothesize that the intervention would have effects on the relations between inhibitory control, teacher-child relationships, and engagement, and so include intervention condition as a covariate rather than a variable of interest. We performed two sets of analyses, one focusing on the main effects, and one adding an interaction term to examine whether student-teacher closeness moderated the association of inhibitory control with each of the engagement domains.

Results

Correlations

Table 2 presents bivariate correlations for the variables used in the analyses. All measures of positive engagement in the classroom (Positive Teacher Engagement, Positive Peer Engagement, and Task Engagement) were positively correlated with each other. Children's Conflictual Engagement was negatively correlated with their Task Engagement, and not significantly correlated with engagement with their teacher or peers. Inhibitory control was positively correlated with children's positive engagement with peers and negatively correlated with their Conflictual Engagement. Closeness in the student-teacher relationship was correlated with positive engagement with the teacher while conflict in the relationship was correlated with Conflictual Engagement in the classroom.

Regression Models

Inhibitory control and classroom engagement. The top of Table 3 presents results from the regression models examining the main effects of inhibitory control on the four engagement domains. Children with greater inhibitory control were observed to have lower levels of conflictual engagement in the classroom ($\Delta R^2 = .018$). There were no significant relationships between children's inhibitory control and positive engagement with teachers, peers, or tasks.

Quality of the student-teacher relationship and classroom engagement. The top of Table 3 presents results from the regression models examining the main effects of closeness and conflict in the student-teacher relationship on the four engagement domains. Children with a closer student-teacher relationship were observed to have more positive engagement with their teachers ($\Delta R^2 = .027$). Similarly, children with a more conflictual relationship with their teachers were observed to have more conflictual engagement in the classroom ($\Delta R^2 = .058$). Surprisingly, closeness in the student-teacher relationship was also associated with conflictual engagement in the classroom. However, the closeness of the student-teacher was not significantly associated with children's conflictual engagement when we removed conflict from the model ($\beta = .01$, $SE = .03$), suggesting that this finding is the result of a suppression effect (Ludlow & Klein, 2014).

Close student-teacher relationships as a protective factor. The bottom of Table 3 presents results from the regression models examining the inhibitory control by student-teacher closeness interaction on the four engagement domains, controlling for the main effects and covariates. Each regression was run again with the addition of an interaction term to test whether a close student-teacher relationship moderates the association between children's inhibitory control and their engagement. Analyses showed a small but significant interaction effect on positive engagement with the teacher ($\Delta R^2 = .009$). The positive coefficient indicates that the relation of inhibitory control with positive teacher engagement is stronger for children who have a closer relationship with their teacher. Figure 1 illustrates the conditional effects of children's inhibitory control on their positive engagement with their teacher at three levels of closeness in the student-teacher relationship. Further probing of the interaction (Preacher, Curran, & Bauer, 2003) revealed that children's inhibitory control was only significantly associated with positive engagement with their teacher when children were at least 0.37 standard deviations above the mean in the closeness of their relationship with their teacher.

Discussion

Positive classroom engagement is important to many aspects of children's social and academic development (Bohlmann & Downer, 2016; Chien et al., 2010; Fantuzzo et al., 2007; Hughes et al., 2008; Williford, Maier, et al., 2013), but as yet there has been little research examining how children's inhibitory control is linked to engagement, or whether children's relationships with teachers might contribute to engagement in important ways. This study aimed to add to this research in three key areas. First, we were interested in examining associations between children's inhibitory control and their classroom engagement. Second, we sought to expand on prior findings by using an observational measure – instead of a teacher report - that assesses children's engagement across four key domains. Finally, we were interested in understanding whether teacher-child relationships could serve as a protective factor in supporting classroom engagement for children with low inhibitory control. We expected that inhibitory control and positive teacher-child relationships would independently predict higher engagement, and that positive teacher-child interactions would buffer the effects of low inhibitory control. We found some limited support for these hypotheses, and identified some important directions for future work.

Inhibitory Control and Classroom Engagement

Findings from this study suggest that children's inhibitory control may be an important factor in conflictual engagement in the classroom, such that children with stronger inhibitory control at the start of the school year exhibited lower levels of conflictual engagement in the spring. The relation between children's inhibitory control and lower levels of conflictual engagement in the classroom later in the preschool year is consistent with most research examining associations between children's self-regulatory skills and engagement or behavioral problems in the classroom. Studies have found a positive relation between inhibitory control and more positive and less problematic engagement (Silva et al., 2011; Valiente et al., 2012; Yang & Lamb, 2014). Specifically, children reported by their teachers as exhibiting greater effortful control are more often seen as engaging in positive, constructive social interactions and less often seen in harmful, destructive interactions with peers (Fabes et al., 1999). Similarly, children with greater executive function less often engage in unoccupied, disruptive behavior (Nesbitt et al., 2015). This study builds on this work by linking a specific aspect of children's self-regulation, early inhibitory control, to their overall observed conflictual engagement later in the year.

Quality of the Student-Teacher Relationship and Classroom Engagement

Teacher reported closeness in the student-teacher relationship predicted more positive engagement with the teacher later in the school year. This finding is consistent with work showing that closeness in the student-teacher relationship is concurrently associated with higher levels of parent and teacher reported general engagement (Portilla et al., 2014). However, we were unable to find previous work that examined how the closeness a teacher reported in their relationship with a child related to later observed engagement or interaction with that child. These unique findings, suggesting that a close-student teacher relationship leads to more positive engagement between the teacher and child, could be explained a variety of ways. It is possible that teachers are interacting more with students with whom they have a close relationship. Hamre and Pianta (2001) proposed that a close student-teacher relationship might motivate a teacher to spend more time and energy on that child. Conversely, it's possible that students who feel they have a secure relationship base with the teacher feel more comfortable approaching and engaging with the teacher, or a combination of these may be at work. One study examining this question in third grade students found that a close student-teacher relationship was concurrently associated with increased engagement on the part of the child and also with decreased attention from the teacher and both were related to later academic achievement. However, positive and negative attention from the teacher were not measured separately and the researcher concluded that the increased attention to children with whom they had lower quality relationships was likely due to children's problematic behavior in the classroom (O'Connor & McCartney, 2007). Therefore, it is likely that a different mechanism could be at work in explaining the association between an early close student-teacher relationship and later positive interactions between the child and teacher. Another study found that a close student-teacher relationship predicted reports of greater sociability, increased extroversion and decreased introversion (Peisner-Feinberg et al., 2001). This suggests that children with a close relationship may be approaching teachers more, resulting in more positive engagement with their teacher, though we would also expect to see an increase in engagement with peers if increased child sociability was the reason for increased engagement with the teacher. Future work will need to examine more closely the association between a close student-teacher relationship and later interactions between the child and teacher in the classroom.

Teacher reported conflict in the student-teacher relationship predicted more observed conflict with peers and teachers and more problems meeting behavioral expectations. This finding is consistent with a body of work highlighting the detrimental outcomes associated with a conflictual student-teacher relationship. For example, a conflictual student-teacher relationship in early childhood is associated with aggressive behavior during preschool (Palermo et al., 2007) and less social competence and more externalizing behavior in elementary school (Pianta & Stuhlman, 2004). This study adds to this research by highlighting how a conflictual student-teacher relationship leads to conflict with teachers and peers, and failure to meet behavioral expectations in preschool.

Close Student-Teacher Relationships as a Protective Factor

A close student-teacher relationship was found to moderate the association between children's inhibitory control and positive engagement with the teacher such that when children had both strong inhibitory control and a close student-teacher relationship, the association of inhibitory control and positive engagement with the teacher was stronger. Thus, inhibitory control and a close student-teacher relationship interacted to amplify the positive effects of the other in regards to a child's positive engagement with the teacher. The amplifying effect of a close student-teacher relationship for children already on a positive trajectory because of strong inhibitory control was a surprising finding, as previous research has tended to focus on a close student-teacher relationship as a protective factor for children on a negative trajectory. However, in the present study a close student-teacher relationship was only related to improved engagement for children with at least average inhibitory control. Previous research found a close student-teacher relationship serves as a protective factor, changing the trajectory of children considered at-risk because of externalizing behavior, poor effortful control, or low academic ability (Blair & McKinnon, 2016; Silver et al., 2005; Wang, Brinkworth, & Eccles, 2013). However, these finding are still somewhat consistent with the work, finding that the student-teacher relationship was a protective factor for first-graders low on aspects of effortful control but not for those with low inhibitory control, in terms of their academic achievement (Liew et al., 2010). It seems that a close student-teacher relationship may not be able to be compensate for low inhibitory control in the same ways it helps to compensate for behavior or academic problems.

Limitations and Future Directions

This study examined how inhibitory control and early student-teacher relationships predicted later classroom engagement, however it is likely that these factors actually have complicated bidirectional relationships. While children with greater inhibitory control are able to avoid conflictual engagement in the classroom, children's classroom engagement also leads to later gains in inhibitory control related skills such as executive function and regulation (Williford, Whittaker, Vitiello, & Downer, 2013). Similarly, while the quality of a child's relationship with their teacher predicted later engagement with the teacher, children's classroom engagement also likely affects how the teacher views the quality of their student-teacher relationship. Children who exhibit aggressive behavior at the start of kindergarten tend to have conflictual relationships with their teachers later in the year, which in turn leads to increases in aggressive behavior at the end of kindergarten (Doumen et al., 2008). A similar self-perpetuating pattern could play out with children with positive classroom engagement and close student-teacher relationships. Future research should focus on examining the bidirectional relationships between all these factors.

In addition to exploring directionality in the relationships between these factors, future research should investigate these factors in a causal framework. Specifically, research could examine whether interventions like *Banking Time* (Pianta & Hamre, 2001) that improve student-teacher relationships lead to more positive engagement with the teacher and less conflictual engagement. And similarly, if interventions that improve children's inhibitory control result in decreased conflictual engagement. Additionally, future work could examine whether there are unexplored underlying factors that cause children to have both student-teacher relationships of a particular quality and also certain patterns of engagement in the classroom. For example, children with strong language skills may have a closer relationship with their teacher, because the teacher can communicate and better connect with the child, and they may also engage more positively in classroom because they can verbally engage with their teacher and peers, participate in cooperative and/or pretend play that requires dialogue, and avoid conflict by communicating their needs and problems.

Additional work is also needed to understand the mechanism through which student-teacher relationships may affect classroom engagement. One potential avenue to explore is whether a close student-teacher relationship leads the child to feel more comfortable seeking interactions with the teacher or if the teacher interacts more with children with whom she perceives a close relationship. Questions also remain about how a conflictual student-teacher relationship could lead to more conflictual engagement in the classroom. Future work could explore if the teacher acts differently towards children with whom she perceives a conflictual relationship or if a conflictual relationship provides a negative relational model, which the child brings to her classroom engagement. An additional challenge is that closeness and conflict in the student-teacher relationship seemed to behave differently when examined simultaneously as opposed to independently. The relation between closeness in the student-teacher and conflictual engagement in the classroom was not discussed here due to evidence that it is the result of a suppression effect (Ludlow & Klein, 2014) but further explanation of this finding is required.

Future work would also benefit from expanding the scope of engagement. Children's engagement with school has been conceptualized as including behavioral engagement, emotional engagement, and cognitive engagement (Fredricks, Blumenfeld, & Paris, 2004). The present study focused primarily on behavioral engagement and to some extent emotional engagement, leaving cognitive engagement unexamined.

Finally, further work is needed to understand whether children's classroom engagement is the mechanism through which student-teacher relationships and inhibitory control affect children's developmental outcomes.

Despite the need for further examination of these complex relationships, findings suggest some implications for supporting children's engagement in the classroom. Since strong inhibitory control was related to lower levels of conflict in the classrooms, supporting children's development of inhibitory control, and executive function more generally, during this crucial period of their development may be an important way to avoid a negative classroom environment. A number of classroom practices and interventions have been found to support children's development of self-regulation (Diamond, 2012; Raver et al., 2011). Similarly, interventions that support positive teacher-child relationships may help to improve children's classroom engagement. For example, *Banking Time* (Pianta & Hamre, 2001) aims to improve the quality of the student-teacher relationship by improving a child's feelings of security and attachment towards a teacher. A recent efficacy trial found that teachers assigned to implement

Banking Time exhibited lower negativity in their classrooms, and that children in *Banking Time* classrooms had significant reductions in externalizing behaviors (Williford et al., 2016).

Conclusion

In summary, this study provided evidence that children's inhibitory control as well as the quality of the student-teacher relationships are important predictors of children's classroom engagement. Greater inhibitory control was associated with less conflictual engagement in the classroom, while conflict in the student-teacher relationship was associated with greater conflictual engagement. Closer student-teacher relationships were associated with more positive engagement with the teacher, and this relation was even stronger when children also had greater inhibitory control. While more work is needed to understand causal mechanisms and the bidirectional relations between children's inhibitory control, student-teacher relationships, and classroom engagement, these findings suggest both supporting children's early self-regulatory skills and strengthening student-teacher relationships as possible avenues for promoting young children's positive classroom engagement.

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Table 1

Descriptive Statistics

	Total			
Variable	%	*N*	*M* (*SD*)	Range
Age (months)		358	53.92 (3.71)	47-62
Gender (boy = 1)	51			
Child racial/ethnic minority	49			
Parent's years of education		349	14.19 (2.45)	11-20
Pencil Tap (percent correct)		357	67.07 (31.72)	0-100
Student-Teacher Closeness		328	4.36 (0.64)	1.43-5.00
Student-Teacher Conflict		328	1.75 (0.88)	1.00-4.86
Positive Teacher Engagement		366	2.80 (0.85)	1.00-5.76
Positive Peer Engagement		366	2.82 (0.81)	1.00-6.33
Task Engagement		366	4.08 (0.70)	1.94-6.50
Conflictual Engagement		366	1.42 (0.34)	1.00-3.26
Classroom Variables				
Condition (Treatment)	49			
State Pre-kindergarten	29			
Head Start	8			
Private for-profit	37			
Private non-profit	25			
Teacher's years of education				
Teacher's race/ethnicity				
Black/African American	20			
White	65			
Latino/Hispanic	2			
Multiracial or other	3			

Note: Percentages may not total 100% due to rounding and non-report.

Table 2

Bivariate Correlations Between Variables of Interest

	1	2	3	4	5	6
1. Pencil Tap (percent correct)						
2. Student-Teacher Closeness	.13*					
3. Student-Teacher Conflict	-.08	-.37**				
4. Positive Teacher Engagement	.06	.17**	.02			
5. Positive Peer Engagement	.13*	.07	.00	.17**		
6. Task Engagement	.08	.06	-.08	.32**	.47**	
7. Conflictual Engagement	-.22**	-.07	.26**	-.02	-.03	-.33**

Note: * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed)

Table 3

Results of Regression Analyses Predicting Children's Classroom Engagement from Children's Inhibitory Control and Closeness and Conflict in the Student-Teacher Relationship

	Positive Teacher Engagement	Positive Peer Engagement	Task Engagement	Conflictual Engagement
Variable	*B(SE)*	*B(SE)*	*B(SE)*	*B(SE)*
(Constant)	2.378 (1.147)	2.481 (0.963)	2.373 (0.846)	1.448 (0.430)
Inhibitory Control (IC)	0.074 (0.058)	0.034 (0.049)	0.052 (0.057)	-0.153** (0.052)
Closeness	0.186** (0.063)	0.043 (0.058)	0.012 (0.064)	0.114* (0.057)
Conflict	0.101 (0.066)	0.020 (0.058)	-0.068 (0.062)	0.266*** (0.076)
Site	0.596* (0.266)	0.493** (.179)	-0.179 (0.185)	0.190 (0.268)
Condition	0.040 (0.139)	-0.043 (0.122)	-0.036 (0.132)	-0.120 (0.116)
State pre-K	0.335 (0.338)	0.017 (0.231)	-0.495* (0.245)	0.451 (0.275)
Private (for profit)	-0.307 (0.337)	0.093 (0.275)	-0.435 (0.296)	0.385 (0.249)
Private (non-profit)	-0.339 (0.327)	0.223 (0.280)	-0.299 (0.301)	0.243 (0.236)
Teacher years of education	-0.018 (0.095)	0.037 (0.099)	0.190* (0.097)	0.017 (0.091)
Teacher race/ethnicity				
Black/African American	-0.323 (0.220)	-0.113 (0.099)	-0.068 (0.097)	-0.251 (0.193)
Latino/Hispanic	0.699 (0.435)	0.671 (0.371)	0.967** (0.320)	0.196 (0.239)
Multiracial or other	-0.210 (0.446)	0.239 (0.254)	-0.142 (0.243)	0.177 (0.402)
Child age	-0.034 (0.054)	0.011 (0.050)	-0.012 (0.052)	-0.043 (0.052)
Child gender	-0.004 (0.106)	-0.201 (0.104)	-0.121 (0.103)	0.307** (0.090)
Child racial/ethnic minority	0.096 (0.151)	-0.039 (0.137)	-0.100 (0.152)	0.065 (0.117)
Parent years of education	0.061 (0.068)	0.043 (0.067)	0.211** (0.069)	-0.134* (0.059)
IC x Closeness	0.095* (0.044)	-0.002 (0.054)	0.023 (0.066)	0.016 (0.044)

Note: All non-binary variables standardized to improve interpretation. ****p*< .001 (two-tailed), ***p*< .01 (two-tailed), **p*< .05 (two-tailed)

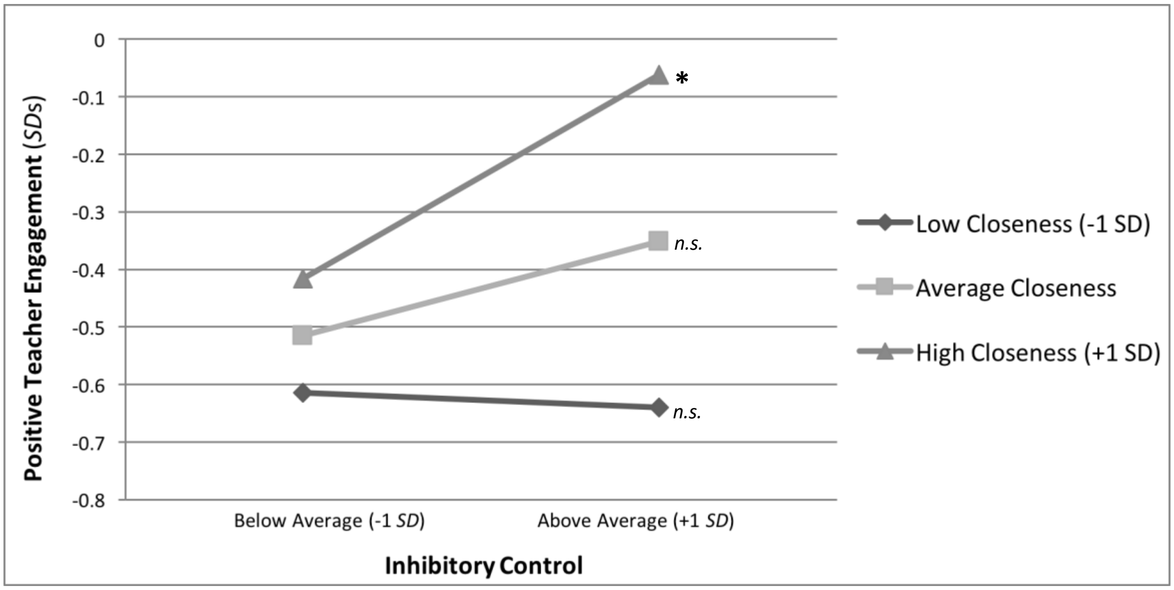

Figure 1. Simple slopes of children's inhibitory control predicting positive engagement with their teacher for children with 1 *SD* below the mean level of closeness in the student-teacher relationship, average closeness, and 1 *SD* above the mean level of closeness. *slope significant at $p < .05$ (two-tailed); *n.s.* simple slope was not significant

Executive Function, Engagement, and Mathematical Achievement: Relations in Classrooms with Varying Math Instruction

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Executive function (EF) is a cognitive construct that encompasses higher order processes like planning and problem solving, as well as cognitive functions like inhibition, working memory, and cognitive flexibility (Diamond, 2006; Hughes, 1998; Welsh, Pennington, & Groisser, 1991). EF undergirds both academic and social-emotional skills (Blair, 2002) and is a key predictor of children's school readiness skills (Heckman, 2006; Raver, 2012). It is of central importance in supporting mathematics achievement (Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010). However, the mechanisms underlying the association between young children's EF and mathematical skills are not fully understood. There is some evidence suggesting that children's classroom engagement, including how well children stay on task and pursue their activities, mediates the association between EF and math (Nesbitt, Farran, & Fuhs, 2015), but more research in this area is needed. Additionally, classroom math instruction, specifically the quantity (dosage) and quality of math instruction being delivered, likely affects the associations between EF, classroom engagement, and children's math learning. In this study, we examine the extent to which children's classroom engagement mediates the association between EF and math achievement and how this association may change depending on the quantity and quality of math instruction in the classroom in a sample of pre-kindergarten children and their teachers.

Executive Function and Math Achievement

EF is thought to underlie many of the skills necessary for academic achievement (e.g., McClelland, Acock, & Morrison, 2006) and has been linked to both concurrent and future academic performance. Children with stronger EF at the beginning of preschool perform better in language, literacy, and math both at the start and end of preschool

(McClelland et al., 2007). The association between preschool children's EF and math performance is especially strong (Bull et al., 2008) and neuropsychological research suggests a deep connection between the two, as they tend to activate the same areas of the brain (Best & Miller, 2010). Additionally, during early childhood, both EF and mathematical abilities undergo rapid development in children, suggesting a possible shared ontogenesis (Best & Miller, 2010). EF skills broadly and especially the individual components of EF (i.e., working memory, inhibition, and cognitive flexibility), underlie the cognition necessary to learn math. Children's EF skills are thought to potentially influence their performance in math both directly through unobserved underlying cognitive processes and indirectly through their association with children's classroom behavior (Clements, Sarama, & Germeroth, 2016; Nesbitt et al., 2015).

Direct association. Explanations directly linking EF and math stress the role EF plays in supporting the underlying cognitive processes needed for math learning. Inhibition allows children to refrain from providing initial incorrect responses and instead work on finding a solution, and cognitive flexibility allows children to switch between problem-solving strategies (e.g., Clements et al., 2016). Working memory helps children to hold multiple pieces of information in their mind which is necessary for solving multi-step problems and manipulating representations (e.g., shapes; Clark et al., 2014). Domain-general and domain-specific cognition theories postulate that cognitive resources specific to the learning domain, for example initial approximate number sense in math, and general cognitive skills, for example working memory capacity, are necessary to develop new math knowledge and skills (Geary & Moore, 2016). Through this process, a child's initial math and EF proficiencies interact and through a mutually supportive boot-strapping process, the child is able to use those early proficiencies in each domain to learn new skills and gain new knowledge (Clements et al., 2016; Cragg & Gilmore, 2014). For example, engaging in complex math such as problem solving requires children to use their EF skills in addition to their existing math skills (Fuhs, Nesbitt, Farran, & Dong, 2014; Schmitt, Geldhof, Purpura, Duncan, & McClelland, 2017). These theories suggest that children's EF skills will play a role in their math learning over the preschool year by providing cognitive resources necessary to do math.

Indirect association. An additional explanation stresses the indirect role EF plays in children's math learning. This conceptualization focuses on the ways in which EF supports children's learning behaviors in the classroom and how improved learning behaviors subsequently lead to the development of math knowledge and skills. In this view, children's EF skills, which include the abilities to control their thoughts and behavior, allow them to meet classroom expectations and attend to and subsequently benefit from interactions and instruction in the classroom (Clements et al., 2016; McClelland et al., 2006). For example, inhibitory control is necessary to avoid distractions in the classroom and stay focused on instruction (Clements et al., 2016). This explanation suggests that preschool children with stronger EF may display greater behavioral engagement with instructional math activities, which would be subsequently linked to improved math learning over the course of the year. However, this requires consistent exposure to high quality math instruction in the classroom.

Classroom Math Instruction

Transactional models of development call for consideration of the interplay between the classroom context and individual characteristics (Sameroff & Mackenzie, 2003). It is especially important to consider children's exposure to math instruction in the classroom when trying to understand the development of children's skills in this area. A teacher's choice of math activities, the frequency with which children are exposed to them, and the quality with which teachers engage in instruction and interactions around math content may provide different affordances for learning depending on a child's self-regulatory capabilities (Brock, Rimm-Kaufman, & Wanless, 2014). We specifically consider how the direct and indirect associations between children's EF skills and their math learning may vary depending on the quantity and quality of math instruction in a classroom.

Quantity of math instruction. Children's early math skills develop rapidly during the preschool years (Baroody, 1992; Starkey & Cooper, 1995), but are very much dependent upon the amount and type of math experiences to which they are exposed. Despite young children's developmental readiness and the considerable long-term benefits of rigorous mathematics instruction in early grades, mathematics instruction is often under-emphasized relative to reading in preschools: preschool teachers often spend only 6% to 8% of their day on math content (Bachman et al., 2017; Early et al., 2010; La Paro et al., 2009). An increased focus on math in the preschool classroom improves children's math learning (Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Klein, Starkey, Clements, Sarama, & Iyer, 2008; Klein, Starkey, Deflorio, & Brown, 2011; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006). However, transactional models of development predict that some children are likely to benefit more than others from a greater focus on math (Dearing, McCartney, & Taylor, 2009; Riggs & Greenberg, 2004). For example, children with weaker EF skills may learn more in classrooms with more math instruction because they may require teacher-facilitated instruction to engage in math thinking and processes (Fuhs et al., 2014; Schmitt et al., 2017). However, children with strong EF may make similar gains in their math achievement regardless of the amount of math instruction provided by the teacher because they are hypothesized to be able to both benefit from the teacher's instruction in classrooms consistently providing math instruction, or draw on their cognitive resources to participate in math learning independently (e.g., using math manipulative during free choice times) in classrooms without consistent instruction (Fuhs et al., 2014). In other words, children with weak EF may depend more heavily on math instruction in order to learn mathematics, whereas the math learning of children with strong EF may be relatively less affected by instruction. There is some evidence this may be the case. In a study of 288 low-SES children attending private preschool centers, Bachman and colleagues (2017) found that exposure to any math instruction (as compared to no math instruction) is most beneficial for children with low initial levels of self-regulation and cognitive ability. Furthermore, children's self-regulation was only related to math achievement for children not exposed to math instruction, and was unrelated to math outcomes for children exposed to math instruction.

At the same time, the indirect association between EF and math learning, through children's classroom engagement, may be weaker in classrooms with little math instruction. Children with stronger EF skills may be able to draw on those skills to better engage in learning behaviors (Bohlmann & Downer, 2016; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Cadima, Doumen, Verschueren, & Buyse, 2015). However, math achievement is linked to a higher dose of math instruction (Bodovski & Farkas, 2007; Klibanoff et al., 2006; Pianta, Belsky, Vandergrift, Houts, & Morrison, 2008) so children's higher levels of engagement are only expected to result in math gains to the extent that there is math instruction provided. In classrooms with a high dosage of math instruction, children with stronger EF who are better engaged in learning are more equipped to benefit from that instruction than their less engaged peers.

Quality of math instruction. The quality of math instruction may also differentially impact the relations among children's EF, engagement, and math learning. The National Council of Teachers of Mathematics (2000) has called for a move away from instruction based in rote memorization and towards instruction that supports conceptually deep mathematics learning. One of the only instruments available to measure the quality of the math instruction in the preschool classroom, the Classroom Observation of Early Mathematics Environment and Teaching (COEMET; Sarama & Clements, 2007), is grounded in these principles (Kilday & Kinzie, 2009). Children in classrooms with higher quality math instruction, as measured by the COEMET, on average show greater gains in their math knowledge over the course of the preschool year (Clements & Sarama, 2008). Yet transactional models of development suggest that children would differentially benefit from the quality of math instruction provided by the teacher based on their EF competencies. Low quality math instruction can be described as less focused on supporting and scaffolding children's conceptual understanding (Sarama & Clements, 2007). Researchers have hypothesized that, irrespective of engagement, children with stronger EF skills may be more able to benefit despite lower quality math learning opportunities, as compared to their peers with lower EF skills, by drawing on their EF-based cognitive resources (Schmitt et al., 2017). Conversely, children with weaker EF may require higher quality instructional practices, such as scaffolding, to make gains in their math achievement. For example, a child with weaker EF who struggles with problem solving and planning may require a teacher to scaffold them through a multi-step math process like addition, while children with stronger EF may be able to draw on their working memory and planning skills to independently work through the steps of the process. Likewise, because higher quality math instruction leads to greater math learning (Clements & Sarama, 2008), children who are more behaviorally engaged in learning because of their EF skills are likely to benefit more from that instruction, resulting in stronger indirect effects in classrooms with better quality instruction.

Present Study

In the present study, we build upon extant literature which demonstrates a strong link between children's EF and math achievement (Blair & Razza, 2007; Bull et al., 2008; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Nayfeld, Fuccillo, & Greenfield, 2013) by exploring the association between children's EF skills at the start of the school year and gains in their math achievement across the pre-k year. Previous research has drawn mixed conclusions on whether this association is mediated by children's behavioral engagement (Brock et al., 2014; Nesbitt et al., 2015). We add additional evidence to this question by examining whether behavioral engagement in the classroom acts as a mechanism through which EF is associated with children's math development. Finally, we consider child by environment interactions through investigating how these associations vary under different classroom math instruction.

Specifically, we explore how direct and indirect associations vary by the quantity and quality of math instruction in the classroom. We seek to answer the following questions:

1. What is the association between children's fall EF skills and gains in math achievement over the preschool year?
2. To what extent does positive engagement mediate the association between children's EF and math achievement?
3. To what extent do the direct and mediational associations vary by the dosage of math instruction in the preschool classroom?
4. To what extent do the direct and mediational associations vary the quality of math instruction in the preschool classroom?

Based on previous research we hypothesize that children with stronger EF skills at the start of preschool will make greater gains in their math achievement across the year (Nayfeld et al., 2013; Schmitt et al., 2017). We expect that the association between children's EF and math achievement will be partially mediated by their classroom engagement (Nesbitt et al., 2015). Based on prior findings (Bachman et al., 2017), we hypothesize the direct association between children's EF and math gains will be stronger in classrooms with low math dosage because children in those classrooms may need to independently engage in math activities to learn math since the teacher provides few opportunities and children with stronger EF may be more equipped to independently engage in math learning activities (Fuhs et al., 2014). Additionally, we expect the association between children's classroom engagement and math outcomes will be stronger in classrooms with higher math dosage, leading to a stronger overall mediation effect for children in classrooms with higher math dosage. Finally, we hypothesize the direct association between EF and math will be weaker for children in classrooms with higher quality math instruction because children may have less of a need to draw on their pre-existing EF skills to cognitively engage in, and benefit from, the instruction (Fuhs et al., 2014; Schmitt et al., 2017). Finally, we expect the association between children's behavioral engagement and math learning will be stronger for children in classrooms with higher quality math instruction because higher quality instruction is linked to improved math outcomes (Clements & Sarama, 2008).

Method

Participants

Data from this study come from a randomized controlled trial of a curricular and professional development intervention, *MyTeachingPartner-Math/Science* (*MTP-M/S*), designed to support preschool teachers' mathematics and science instruction, and improve children's skills in these areas (for a description of the efficacy trial, see Whittaker et al., 2018). The trial was implemented in two sites, with teachers participating for two years with two consecutive cohorts of children at each site. Data for the present study are from teacher's first year of participation. Site 1 included Head Start, state pre-k, and private for-profit and non-profit preschool classrooms in a Midwestern city. Site 2 consisted of state-funded pre-k classrooms in a Southeastern city.

One hundred and fifty-six teachers were initially recruited to participate in the study (116 from Site 1, 40 from Site 2). There was some attrition over the course of the larger study, and to offset teacher attrition an additional 15 teachers replaced some of the teachers who left the study, leading to 171 total study teachers. Of the 171 teachers, 59 left the study during their first year of participation. Teacher attrition was due to teachers voluntarily withdrawing (n = 12), leaving the classroom or school (n = 40), no longer meeting eligibility requirements (*n* = 4), or the classroom or center closing (*n* = 3). Teachers were majority female (97%) and the majority reported their race/ethnicity as White (72%), 20% as Black/African American, 3% as Hispanic/Latino, and the rest reported other or multiple races/ethnicities (4%).

At the start of the study an average of six children (*M* = 5.88, *SD* = 0.80, *min* = 2, *max* = 9) per classroom were randomly selected from among consented children to participate (*n* = 841). Children were eligible to participate if they were four-years-old and eligible to attend kindergarten the following year, had no IEP (other than an IEP for speech), and were English speaking. There was some attrition over the course of the study due to teacher attrition (*n* = 85), the child no longer being eligible to participate (*n* = 7), the child leaving the classroom or school (*n* = 2), or for unknown reasons (*n* = 103). An additional 72 children were added to the sample to replace children who had left the study, resulting in a full sample of 913 children (474 treatment, 439 control) in 143 different classrooms. The sample was 49% male. Children in the sample ranged from 46 months to 65 months (*M* = 53.89, *SD* = 3.76) at the beginning of the study. The sample was diverse: 53% were reported to be White, 29% Black/African American, 6% Hispanic/Latino, 3% Asian, 9% multiracial, and less than 1% other. The education level of the children's parents ranged from less than high school to an advanced degree (*M* = 14.38 years of education, *SD* = 2.46).

Procedures

Data Collection.

Video observations. Teachers were asked to film all of the math lessons they taught during the school year. Treatment teachers were asked to film all *MTP-M/S* math lessons (2 per week across 33 weeks) as well as any other math activities they taught; control teachers were asked to film all math lessons. Math teaching quality was coded from teachers' videos. We selected one tape per month across 6 months (in an effort to obtain an adequate sample of teachers' practice across the year, video from September, October, November, February, March, April were coded) for each teacher. We purposefully alternated each month between selecting whole group and small group math activities. On average, 3.74 (*SD* = 1.96) math tapes were coded per teacher (range 1 – 6 each year).

***Live classroom observations*.** The quantity of math instruction was coded during live classroom observations. Coders observed each classroom for three mornings in the spring (*M* = 3.19 days, *SD* = 0.81). To determine the quantity of math instruction, data collectors completed the Classroom Snapshot (adapted from Ritchie, Howes, Kraft-Sayre, & Weiser, 2001) across multiple 15-minute observation periods (range 1-10 per day, *M* = 4.78, *SD* = 2.07) during the morning; the proportion of the period devoted to math were averaged across the observations. Data collectors were trained on the measure in conjunction with training for another observation measure over the course of two full days.

***Child assessments*.** Direct child assessments of mathematics achievement and EF were conducted in the fall and spring of each study year. Data collectors completed a two-day training to learn the measures prior to assessing children. Children were assessed in a quiet space, outside of the classroom when possible.

Teacher and parent questionnaires. Parents and teachers completed demographic questionnaires at the start of the school year. Teachers were asked to complete rating scales about participating children's engagement at the end of the school year.

Measures

Teacher and child demographic characteristics. Participating teachers and parents completed demographic questionnaires. Teachers reported their teaching experience. Parents reported their education, and their child's age, gender, and race/ethnicity.

Math achievement. Children's math achievement was directly assessed in the fall and spring using the Short Tools for Early Assessment in Mathematics (STEAM; Weiland et al., 2012). It assesses a range of math skills including counting, sequencing, and number recognition. The STEAM has been validated for use in pre-k and has shown sensitivity to individual child differences (Weiland et al., 2012). Internal consistency was good ($\alpha = .82$).

Executive function. An overall EF score was obtained by compositing standardized scores from three direct assessment measures of children's EF, Pencil Tap, Backward Digit Span, and Head-Toes-Knees-Shoulders, described below. Recent research suggests that compositing individual EF measures to create a mean score represents EF better than creating a latent EF factor score (see Willoughby, Blair, & The Family Life Project Investigators, 2016 for a discussion of conceptual, pragmatic, and statistical evidence for compositing EF measures). Internal consistency of the composite was .72.

Pencil Tap. Children's inhibitory control was measured using Pencil Tap (Diamond & Taylor, 1996). In this task children are asked to tap once when the experimenter taps twice and tap twice when the experimenter taps once. Children receive a score of the percent of correct responses across 16 scored trials. Pencil Tap has shown good concurrent and construct validity (Smith-Donald, Raver, Hayes, & Richardson, 2007). The internal consistency in the current sample was excellent ($\alpha = .92$).

Backward Digit Span. Backward Digit Span is a measure designed to assess children's executive function and particularly target the components of inhibition and working memory (Carlson, 2005). In this task children are given a number series and asked to repeat the number series in reverse order. The length of the longest digit span correctly repeated in reverse is the child's score. The internal consistency is the current sample was good ($\alpha = .82$).

Head-Toes-Knees-Shoulders. This direct child assessment tests multiple aspects of EF including working memory, attention, cognitive flexibility, and inhibitory control of children between 4- and 8-years-old (McClelland et al., 2014; McClelland & Cameron, 2012). The assessment uses no materials and is structured like a short game in which children are first instructed to touch their head and toes, or touch their shoulders and knees, and then instructed to do the "opposite" of what is instructed (e.g., touch their toes when asked to touch their head). Internal consistency was good ($\alpha = .86$).

Engagement. Teachers reported on children's classroom engagement using the Task Orientation subscale from the Teacher-Child Rating Scale (TCRS; Hightower et al., 1986). The TCRS is a teacher report of children's competencies and problem behaviors that has demonstrated excellent psychometric properties in young children (Bryant et al., 2002). The Task Orientation subscale includes items about a child's ability to complete work, such as "functions well even with distractions." The internal consistency of the Task Orientation scale in the current study was excellent (α = .90).

Amount of math instruction. The amount of math instruction was observed using the Emergent Academic Snapshot (Ritchie et al., 2001). The Emergent Academic Snapshot is a time sampling observation measure of the academic instruction occurring in the classroom. In the present study, observers tracked the content (e.g., math, literacy, social studies) occurring in the classroom using an iPad timing application during fifteen minute cycles. The proportion of the cycle devoted to math was calculated, and then proportions were averaged across observation days. In the current study, 6.4% of cycles were double coded and inter-rater agreement was acceptable (using rules of thumb set forth by Cicchetti et al., 2006; proportion of mathematics, ICC = .66).

Quality of math instruction. Math teaching quality was rated from teachers' video using an adapted version of the Classroom Observation of Early Mathematics Teaching (COEMET; Sarama & Clements, 2007). The adapted measure included five items rating the quality of math teaching on a 5-point scale. The quality items assess the extent to which teachers: supported children's conceptual understanding and the associated skills; engaged children in discussion about math through the use of open-ended questions which prompted children to share, clarified or justified their math ideas; supported children's learning at an appropriate level through the use of scaffolding; built and elaborated on children's math ideas and strategies; provided a review of the content covered and connected the math they taught to children's real-lives. In the current study

100% of videos were double coded and interrater reliability (ICC average measures = .78) and internal consistency ($\alpha = .72$) were acceptable.

Data Analyses

Data were analyzed using path analyses in *MPlus* version 7.31, with full information maximum likelihood to account for missing data. Maximum likelihood estimation was used to calculate all paths and bootstrap resampling with 10,000 samples was used to compute the standard errors of the model parameter estimates reported in the results. The use of bootstrap resampling to compute standard errors is preferable the Sobel (1982) method because the latter presumes that the estimates of the regression of the dependent variable on the mediator and of the mediator on the independent variable are independent, and that the sample distribution for the estimate of the indirect effect is normally distributed. However, the bootstrap estimates failed to account for the nesting of children within classrooms so standard errors were also computed using the Sobel method and including classroom as a random factor in all models and adjusting the standard errors of our estimates for covariance of children within classrooms each year, as a robustness check. Results were not sensitive to the method used to compute standard errors and the pattern of results was the same. All non-dichotomous variables were standardized prior to analysis. Each of the regression models included child's age, child's gender, years of education completed by the child's primary caregiver, a dummy variable indicating if the child was an ethnic/racial minority, the child's score on the math assessment in the fall, the teacher's years of experience teaching children in preschool, site, and intervention condition as covariates/blocking factors. The first path analysis model predicted children's spring math achievement from their EF, and examined mediation through behavioral engagement. A second path analysis model examined the same mediation but allowed each path to vary as a function of the dosage of math instruction in the child's classroom. A third path analysis model examined the mediation model allowing each path to vary as a function of the quality of math instruction in the child's classroom. We further probed the conditional effects when moderation was significant by graphing the conditional effects and their 95% confidence interval and identifying regions in which the conditional association between EF and children's gains in math achievement were statistically significant.

Results

Direct and Indirect Associations Between EF and Math

Figure 1 presents results from the path analysis model examining the direct and indirect association between EF and children's spring math achievement. Children's EF had a significant direct association with their math achievement (B = 0.20, $p < .001$). Additionally, children's EF was positively related to their classroom engagement (B = 0.18, $p = .003$) and their classroom engagement to their math achievement (B = 0.12, $p < .001$). The total indirect association of EF with children's math achievement was also significant (B = 0.02, 99% CI = 0.003, 0.053), although smaller than the direct association. Overall the total association between EF at the start of the year and gains in math achievement (B = 0.22, 99% CI = 0.111, 0.331), was 90.9% direct and not fully mediated through children's classroom engagement.

Moderation by the Quantity of Math Instruction

The next path analysis model examined moderation of the direct and indirect associations by the amount of math instruction occurring in the classroom (shown in

Figure 2). There was significant moderation of the direct association (*B* = -0.09, *p* = .005), such that the relation between children's EF and their math achievement was weaker in classroom with more math instruction. The weaker association between EF and math in classrooms with more math instruction is illustrated in Figure 3. Probing of the moderation revealed that the direct association between children's EF and their math outcomes was significant when math dosage in the classroom was less than 1.21 *SD*s (18.68% of the day) above the mean. In classrooms where math instruction occurred for at least 18.68% of the day children's EF was not directly associated with the gains they made in math during the school year. Furthermore, the total association between EF and math gains (including both the indirect and direct association) was not significant when the quantity of math instruction was 1.44 *SD*s (20.07% of the day) or more above the mean (see Figure 3). There was not significant moderation of the mediation as neither the association between EF and classroom engagement (*B* = 0.05, *p* = .242), nor classroom engagement and math achievement (*B* = -0.02, *p* = .533) were moderated by the amount of math instruction in the classroom.

Moderation by the Quality of Math Instruction

The final path analysis model (see Figure 4) examined moderation of the direct and indirect association of EF and math achievement by the quality of math instruction occurring in the classroom. There was significant moderation of the direct association (*B* = -0.14, *p* < .001). The direct association between children's EF and math achievement was weaker in classrooms with higher quality math instruction (the pattern was similar to moderation by quantity shown in Figure 3) and probing of the moderation revealed that children's EF was not directly associated with the gains they made in math when the quality of the math instruction they received was at least 0.65 SDs above the average quality observed. The association between children's EF and their classroom engagement was not moderated by the quality of math instruction (*B* = -0.02, *p* = .593). However, the relation between children's classroom engagement and their math achievement was moderated by the quality of math instruction (*B* = 0.10, *p* = .024), such that children who were more engaged showed greater gains in their math learning in classrooms with higher quality instruction, resulting in a moderation of the overall indirect effects. Probing of the moderation revealed that the indirect association between children's EF and math through their engagement was significant when the quality of instruction was between 0.35 *SD*s below the mean quality and 0.71 *SD*s above it. Furthermore, the total association between EF and math achievement was not significant when the quality of math instruction in the classroom was 0.81 *SD*s or more above the average observed quality.

Discussion

The purpose of this study was to explore the association between children's EF at the start of their preschool year and gains in math achievement across the year. First, we sought to examine the extent to which children's EF was directly associated with their math learning and the extent to which children's behavioral engagement in the classroom mediated that association. Next, we explored how the quantity and quality of math instruction in the classroom moderated both the direct and indirect associations between EF and math.

Direct and Indirect Associations Between EF and Math Achievement Gains

Children who started preschool with stronger EF skills made greater gains in their math achievement over the course of the school year. This finding is consistent with a large and growing body of research (e.g., Blair & Razza, 2007; Bull et al., 2008; Fitzpatrick et al., 2014). However, there is less evidence regarding the mechanisms through which EF skills may support math learning. In this study we hypothesized that children's behavioral engagement in the classroom may serve as one mechanism linking EF and improved math outcomes. We found that although children's engagement did partially mediate the association between EF and math, it accounted for less than 10% of the total association. Only a small number of previous studies have examined behavioral engagement's role in mediating the relation between EF and math, and results were mixed with one study finding that children's learning behaviors partially mediated the association between EF and math gains (Nesbitt et al., 2015), and another finding only a direct relation between EF and math (Brock et al., 2009). The study by Brock and colleagues (2009) utilized EF measures that primarily measured inhibitory control (Pencil Tap and Balance Beam), while the present study and the study from Nesbitt and colleagues (2015) used measures thought to tap into multiple components of EF. This distinction may account for the difference in findings. Although this study adds to the evidence base suggesting children's learning behaviors in the classroom partially mediate the relation between EF and math, children's engagement accounted for only a small portion of the relation between EF and math and further research is needed to uncover other mechanisms that may play an even stronger role, including the extent to which EF is supporting children's math learning through underlying cognitive processes. Findings suggest the children may be drawing on their EF resources to do math more so than they are drawing on EF to engage in positive learning behaviors in the classroom.

Moderation by the Amount of Math Instruction

The quantity of math instruction in a classroom moderated the direct association between EF and math but not the indirect association through behavioral engagement. Children's EF was less strongly related to how much math they learned in classrooms with more math instruction. In fact, in classrooms where the teacher spent more than 18.68% of the day on math, children's EF was not directly related to their growth in math achievement, and in classrooms that spent at least 20.07% of their day on math there was no association (considering both direct and indirect associations) between EF and math. These findings suggest that when teachers spent more than 20.07% of their class time on math activities, all children grew equally in their math skills, regardless of their EF skills. Children with weak EF skills are at increased risk of academic difficulties in math during later elementary school (Fitzpatrick et al., 2014; Morgan et al., 2017; Stipek & Valentino, 2015) and children's number competence in kindergarten is a strong predictor of mathematical achievement throughout early elementary school (Jordan, Kaplan, Ramineni, & Locuniak, 2009). An increased focus on math in the preschool classroom may be an important part of helping to ensure children with weaker EF skills enter kindergarten with strong mathematics skills and knowledge. Unfortunately, many children are likely not getting sufficient amounts of math instruction as this domain is often under-emphasized relative to reading and many preschools spend only a small portion of their day on math (Early et al., 2010; La Paro et al., 2009).

Contrary to expectations, the amount of math instruction did not moderate either the association between children's EF and behavioral engagement nor between their engagement and growth in math achievement. These findings reveal some interesting information about EF, engagement, and children's math learning. Surprisingly, the association between children's EF and behavioral engagement did not vary as a result of the amount of math instruction in the classroom. Since children with low EF tend to struggle more with math (e.g., Becker, Miao, Duncan, & McClelland, 2014; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014) one could expect they would be less engaged in a classroom spending more time on a subject they find challenging. However, since results indicate the amount of math instruction can be increased without changing children's engagement and results in greater learning for children with low EF, there is evidence to support policies requiring more time devoted to math instruction in the classroom.

Moderation by the Quality of Math Instruction

Similar to quantity, the quality of math instruction in a classroom moderated the direct association between EF and math, however it also moderated the indirect association. In classrooms with lower quality instruction, children's EF skills played a greater role in math learning, such that children with weaker EF skills learned less than their peers with stronger EF. This may be because strong EF skills served as a protective factor for children in classroom with poor quality instruction, while children with weaker EF needed the supports provided during high quality instruction. In contrast, in classrooms with higher quality math instruction, children's EF skills were less strongly related to their growth in math achievement during preschool. In classrooms with above average quality (≥ 0.65 *SD*s above the mean), children's growth in math achievement was not directly associated with their EF skills at the start of school, and in classrooms that were at least 0.81 *SD*s above the mean quality, there was so association between EF and math gains. Again, these findings suggest that improving the quality of math instruction may be an avenue to help close the disparity in math achievement between children with stronger and weaker EF skills (Becker et al., 2014; Blair & Razza, 2007; Verdine et al., 2014). A number of promising interventions have been shown to be efficacious approaches for improving the quality of preschool teachers' math instruction (Clements et al., 2011; Whittaker et al., 2018). Results provide support for policies requiring preschool classrooms to employ curricula and professional development that are known to improve the quality of math instruction as an avenue to support children with low EF who may be at risk for academic difficulties.

In contrast to the direct association between EF and math achievement, the indirect association was stronger in classrooms with higher quality math instruction. Specifically, in classrooms with higher quality math instruction children's behavioral engagement was more strongly related to their growth in math achievement during the year. However, the region of significance for the indirect effect is only within approximately one standard deviation of the mean quality. That is, for classrooms outside of that region (those with above and below average quality of math instruction) children's EF was not indirectly related to their growth in math through behavioral engagement. These findings suggest that in classrooms with low quality instruction, even when children are engaged in learning behaviors they do not benefit much more from instruction than children who are not engaged. Conversely, in classroom with high quality instruction even those children who are less engaged in learning behaviors are able to benefit as much as children who engage more in positive learning behaviors. This may be because high quality math instruction, which includes elements such as directly explaining the math skill and concept being taught and providing repetition and review of the content (Sarama & Clements, 2007), provides enough exposure that even those children who are not engaged as consistently throughout the activity are able to receive the information since it is delivered clearly and repeatedly.

Limitations and Future Directions

There are a number of limitations in the data used in the present study. First, children's behavioral engagement was reported by teachers rather than directly observed. While teachers can draw on a broader span of time to rate children's engagement (i.e., the teacher sees the child in the classroom everyday rather than on a few specific instances) and the danger of children changing their behavior because an outsider is present in the classroom is avoided, teacher ratings are less standardized and may be influenced by other information the teacher has about a child. Furthermore, teachers reported on children's general engagement in learning behaviors, not specifically on their behavioral engagement in math learning which may have reduced our sensitivity to detect engagement.

The associations between children's EF, engagement, and their gains in math achievement were examined in a path analytic model but causality cannot be inferred from the results. Future work examine should examine these associations in a causal framework. For example, an intervention designed to increase children's EF, could be leveraged to get an estimate of the causal effect of EF on children's math achievement and behavioral engagement in the classroom, which could then be used to obtain estimates of direct and indirect effects of EF on math.

In accordance with being unable to make causal conclusions, it is likely that the associations between some factors examined here have more complicated, bidirectional relations which could be examined in future work. For example, we examined the influence of EF on children's engagement in the classroom but children's classroom engagement also leads to gains in self-regulatory skills like executive function (Williford, Whittaker, Vitiello, & Downer, 2013). Additionally, the causal direction between children's EF and their math learning has recently come under question with researchers suggesting that engaging in math learning may actually improve children's EF skills (Clements et al., 2016), suggesting a possible bidirectional relation between EF and math. Future research could explore what aspects of math instruction may actually improve children's EF.

Future work is also needed to further explore the mechanism linking children's EF to their improved math learning and achievement. Our results suggest that the link is partially due to children's EF skills supporting their behavioral engagement in the classroom but a large portion of the association remains unexplained. One reason contributing to this weak link may be that teachers reported on children's general engagement. Future research should examine if a more closely aligned assessment of children's behavioral engagement in math specifically yields different results. It is also important that future work explore the ways in which children's EF supports other types of engagement in math learning, specifically their cognitive engagement in math. Much of the theory directly linking EF and math stresses the ways in which EF skills support cognition to engage in math (Clements et al., 2016; Cragg & Gilmore, 2014; Geary & Moore, 2016) but the links remain empirically unexplored. For example, working memory is hypothesized to support children in completing subtraction when using a "counting back" strategy because children must maintain the goal of the problem and the part-whole relation in mind, while counting back and keeping track of how many counts have been completed (Clements et al., 2016). This theorized explanation can be empirically tested by using an active dual-task method, which requires children to perform the subtraction problem while they perform another task that requires the use of their working memory, but there is a dearth of this research in young children (Cragg & Gilmore, 2014).

Conclusion

In summary, this study provided evidence that children's EF is an important predictor of growth in their math achievement, and that only a small portion of the association can be accounted for through greater behavioral engagement relative to the direct association between EF and math. Both the quantity and quality of math instruction in the classroom moderated the direct association between EF and math, such that EF was less closely linked to math achievement gains in classrooms with more math instruction and in those with higher quality instruction. The quality of math instruction also moderated the indirect association between EF, behavioral engagement, and math achievement gains; behavioral engagement was more closely associated with math gains in classrooms with higher quality instruction, leading to overall stronger indirect associations in those classrooms. While more work is needed to understand causal mechanisms and the bidirectional associations between children's EF, behavioral engagement, math instruction, and achievement, these findings suggest supporting children's EF skills is important for both their behavioral engagement and achievement outcomes.

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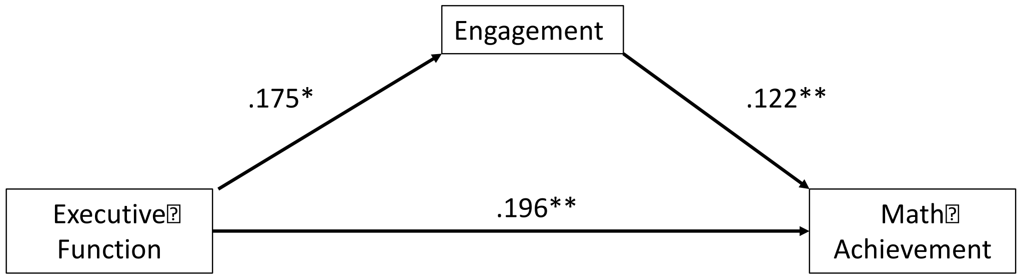
Table 1

Descriptive Statistics

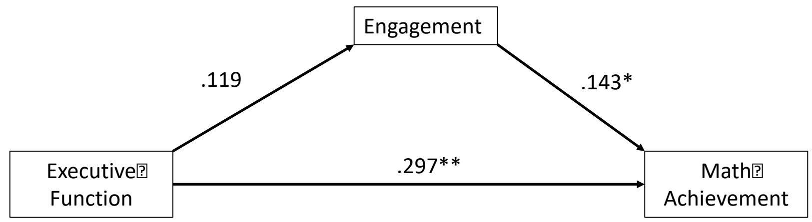
Variable	%	*N*	*M* (*SD*)	Range
Age (months)		899	53.89 (3.76)	46-65
Gender (boy = 1)	49	892		
Child racial/ethnic minority	47	859		
Parent's years of education		867	14.38 (2.46)	11-20
Executive function composite		785	0.00 (0.80)	-1.23-2.22
Pencil Tap (%)		814	67.39 (31.47)	0-100
Backward Digit Span		789	1.45 (0.80)	1-5
Head-Toes-Knees-Shoulders		813	16.97 (17.09)	0-59
Task Orientation		632	3.74 (0.95)	1-5
Fall Short TEAM (Math)		807	10.52 (4.36)	0-22
Spring Short TEAM (Math)		685	13.10 (3.61)	1-22
Classroom Variables				
Quantity of Instruction (proportion)		111	0.09 (0.08)	.00-.40
Quality of Instruction		106	1.85 (0.44)	1.00-2.87
Condition (Treatment)	72	143		
Teacher's years of experience		160	6.66 (7.00)	0-37



Effects	*B* (*S.E.)*
Direct	0.196 (0.043)
Indirect	0.021 (0.009)
Total	0.217 (0.043)

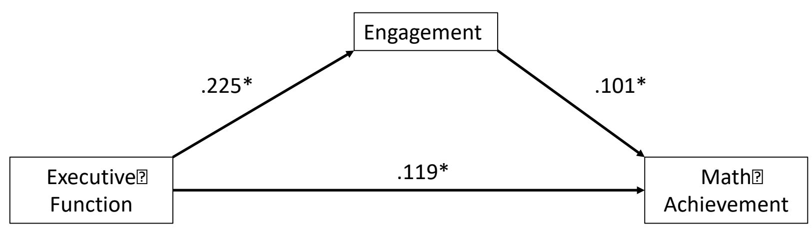
Figure 1. Regression coefficients for the relationship between EF and math achievement as mediated by classroom engagement. All variables are standardized. Covariates are not represented to simplify the presentation.
*p < .05; **p < .001

Mediation in classroom with below average dosage



Effects	*B* (*S.E.)*
Direct	0.297 (0.060)
Indirect	0.019 (0.012)
Total	0.316 (0.061)

Mediation in classroom with above average dosage



Effects	*B* (*S.E.)*
Direct	0.119 (0.048)
Indirect	0.026 (0.014)
Total	0.144 (0.046)

Figure 2. Regression coefficients for the relationship between EF and math achievement as mediated by classroom engagement for classrooms with dosage of math instruction 1 SD below the mean (top figure) and 1 SD above the mean (bottom figure). All variables are standardized. Covariates are not represented to simplify the presentation.
*p < .05; **p < .001

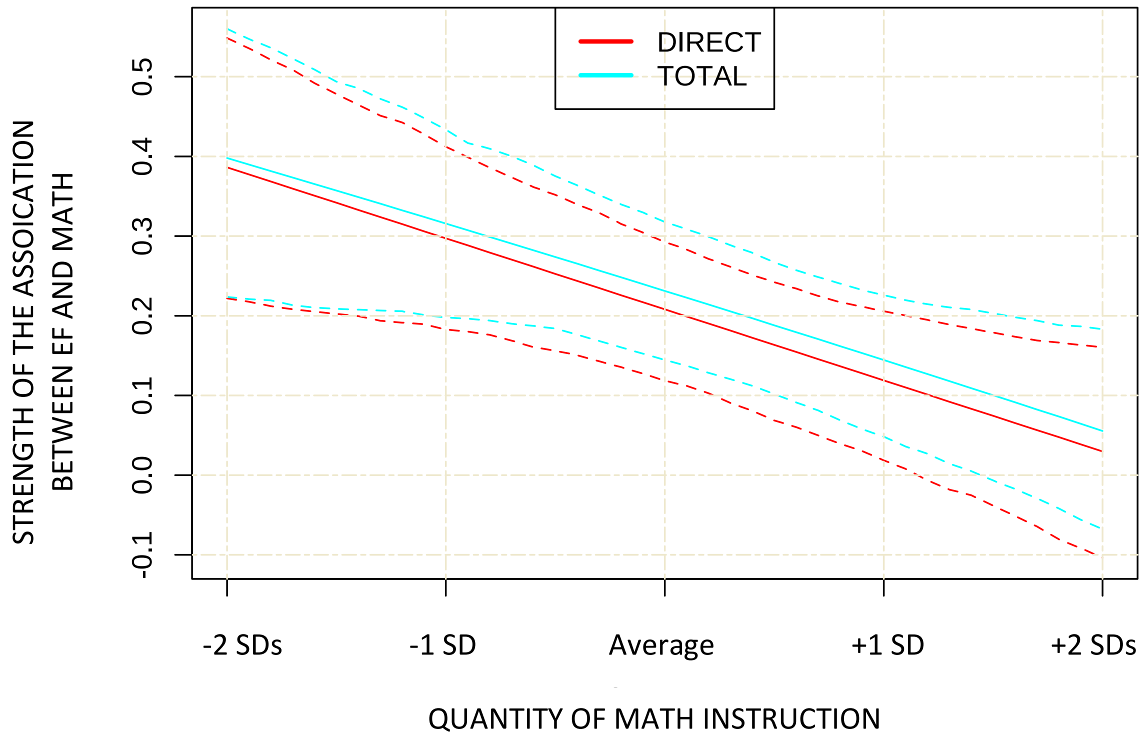
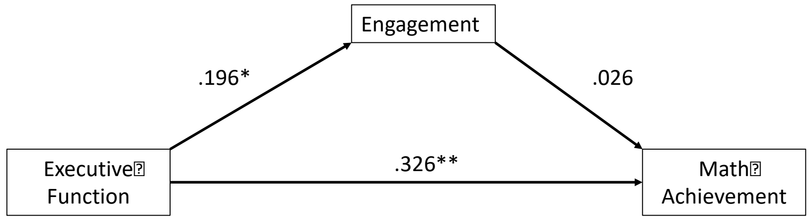


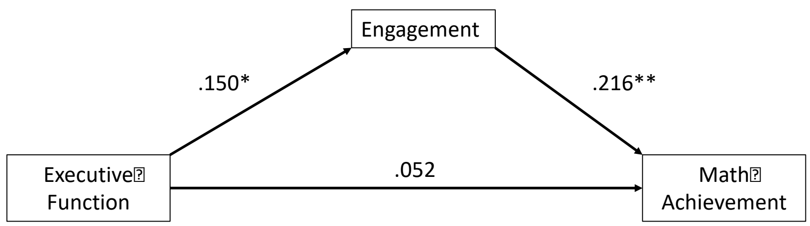
Figure 3. Moderation of the direct and total association between EF on math achievement (solid lines) by the amount of math instruction occurring in the classroom. The dotted line represents a 95% confidence interval of the estimate.

Mediation in classroom with below average quality



Effects	*B* (*S.E.)*
Direct	0.326 (0.053)
Indirect	0.005 (0.011)
Total	0.332 (0.053)

Mediation in classroom with above average quality



Effects	*B* (*S.E.)*
Direct	0.052 (0.060)
Indirect	0.033 (0.019)
Total	0.084 (0.061)

Figure 4. Regression coefficients for the relationship between EF and math achievement as mediated by classroom engagement for classrooms with quality of math instruction 1 SD below the mean (top figure) and 1 SD above the mean (bottom figure). All variables are standardized. Covariates are not represented to simplify the presentation.
*p < .05; **p < .001

Links Between Early Skills, Instruction, and Mathematics Achievement in Kindergarten

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Children who demonstrate strong math skills and knowledge during early childhood have more positive academic trajectories throughout their schooling than their peers with weaker early math skills (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007). Therefore, it is important to understand factors that promote the development of young children's math knowledge and skills. Children's math skills at school-entry are the strongest predictor of their later math performance (Duncan et al., 2007; Watts, Duncan, Siegler, & Davis-Kean, 2014). However, children's executive function (EF), a construct that encompasses children's cognitive self-regulatory skills, is also strongly predictive of math performance (Best & Miller, 2010; Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Ursache, Blair, & Raver, 2012). The limited research that has examined the interplay between early math and EF skills suggests that strong EF skills may act as a protective factor for children who enter preschool with less advanced math skills (Blair, McKinnon, & The Family Life Project Investigators, 2016; Ribner, Willoughby, Blair, & The Family Life Project Key Investigators, 2017).

Children's math outcomes are not just determined by their early skills, but are also influenced by the math content being taught in the classroom (Bachman et al., 2017; Engel, Claessens, & Finch, 2013). In particular, children learn more math during kindergarten when they are taught more advanced math skills (Engel, Claessens, Watts, & Farkas, 2016). Yet, the impact of instruction varies based on the math skills and knowledge children bring to the classroom. Specifically, children who enter kindergarten with less advanced math skills do benefit from exposure to instruction focused on basic math skills, while children who enter with more advanced skills benefit more from instruction focused on advanced skills (Engel et al., 2013). It is likely that the impact of EF on math learning varies similarly, such that children who start school with strong EF benefit more than their peers from instruction on advanced skills, because EF is hypothesized to be more important for challenging skills (Clements, Sarama, & Germeroth, 2016). However, there is little research in this area to date.

The current study addresses these gaps in knowledge by examining 1) how early math and EF skills individually and jointly predict children's math learning across the kindergarten year, and 2) whether the association between the math instruction children receive and their math gains during kindergarten vary based on children's math and EF skills at the start of the year. We use data from a recent nationally-representative sample of kindergarten students to examine our research questions.

Development of Early Math Skills

Beginning from a very young age, children develop knowledge and skills in a variety of math content areas: number and operations, algebra and patterns, geometry, measurement, and data analysis and probability (Clements & Sarama, 2014; The National Council of Teacher of Mathematics, 2000). Before children start formal school, during preschool or experiences in their everyday lives, they start to master early informal math skills including counting and comparing small sets, naming simple shapes, and duplicating or extending patterns (Clements & Sarama, 2014). These skills provide the building blocks upon which children develop more advanced math skills and understandings once they are in kindergarten. However, a variety of factors contribute to children's development of early math skills, not only their early, informal, domain-specific mathematical understandings, but also domain-general skills such as EF (Clark, Sheffield, Wiebe, & Espy, 2013; Geary & Moore, 2016; Gray & Reeve, 2016; Lefevre et al., 2010; Prager, Sera, & Carlson, 2016).

Executive Function and Math Achievement

Children's EF is critical to their math achievement and underlies many of the learning behaviors necessary for growth in math knowledge and skills (e.g., McClelland, Acock, & Morrison, 2006). Specific EF skills support children's math learning in unique ways. Children's inhibitory control allows them to avoid distractions in the classroom and attend to and subsequently benefit from interactions and instruction (Clements et al., 2016; McClelland et al., 2006). Their working memory allows maintenance and manipulation of representations (e.g., shapes, numbers, digits, words) which is necessary for a number of mathematical procedures including shape transformations and calculations (Clark et al., 2014). Cognitive flexibility allows children to switch problem-solving strategies or count by different units (Clements et al., 2016). Research has generally found that each component of EF has a unique association with children's math outcomes (Bull & Scerif, 2001; Purpura, Schmitt, & Ganley, 2017). However, working memory has demonstrated a stronger association with later math as compared to cognitive flexibility (Bull & Scerif, 2001; Purpura et al., 2017), and some studies have found that working memory is the only predictive component when accounting for the other EF components (Vandenbroucke, Verschueren, & Baeyens, 2017). Although children's early math and EF skills have both been found to be important predictors of later math achievement, few studies have examined how the interaction between these two sets of skills are related to children's math outcomes.

Children's Math Achievement as a Product of School Entry Math and EF Skills

Domain-general and domain-specific learning theories posit that children need both resources specific to the learning domain (e.g., initial approximate number sense in math), as well as general learning resources (e.g., working memory capacity) to successfully gain new knowledge and skills in the domain. In this view, a child's domain-specific math skills interact with domain-general EF skills, and through a mutually supportive boot-strapping process, the child is able to use skills in both areas to progress academically (Clements et al., 2016; Cragg & Gilmore, 2014). Empirical evidence bears this out, as there is ample evidence that EF and other academic skills are correlated throughout preschool and into the early elementary years (Becker, Miao, Duncan, & McClelland, 2014; Best, Miller, & Naglieri, 2011; Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Blair & Razza, 2007; Bull et al., 2011; Gathercole & Pickering, 2000; McClelland et al., 2014; Welsh, Nix, Blair, Bierman, & Nelson, 2010).

Additionally, recent work with a sample of children from low-income, rural families found that children's early EF skills served as a protective resource for children who had lower early math skills (Blair et al., 2016; Ribner et al., 2017). Children who were performing weakly in math prior to kindergarten entry, but had strong EF skills, had more positive math outcomes at the end of kindergarten and into fifth grade. We only know of research examining the potential protective role of strong EF skills for children with weaker early math skills in this single study, with a sample that can't be generalized to the larger population. In the present study, we examined whether this potential protective role of strong EF skills for children who start school with weaker math skills holds true for a nationally representative sample of kindergartners.

Although children's early skills are clearly important for early math achievement, transactional theories of child development (Brock, Rimm-Kaufman, & Wanless, 2014; Ladd, Birch, & Buhs, 1999; Sameroff & Mackenzie, 2003) suggest that the role of early skills in math learning are also influenced by environmental factors. One particularly important environmental factor influencing math learning is the type of math skills that are the focus of instruction in the classroom (Engel et al., 2016).

Early Math Instruction

Children are taught a number of different math skills in kindergarten, and during recent decades there have been some shifts in which skills are the focus of instruction. The National Council of Teachers of Mathematics (NCTM) released guidance on standards for mathematics to help direct states and districts development of math standards (NCTM, 2000, 2006). The NCTM standards for kindergarten include a number of basic skills across mathematical sub-domains including identifying shapes in geometry, and sorting and ordering objects by size in measurement and data (NCTM, 2000, 2006). Prior studies suggest that during the 1998-1999 school year kindergarten teachers tended to spend the most time, approximately 13 days per month, teaching this basic content that most of their students have already mastered (Engel et al., 2013). However, the standards also include more advanced numeracy concepts such as place value and multi-digit numbers, to which teachers devoted approximately nine days per month (Engel et al., 2013; NCTM, 2000, 2006). Finally, the standards also included operation skills like addition and subtraction, on which teachers only spent about four days per month (Engel et al., 2013; NCTM, 2000, 2006). Encouragingly, a more recent examination of children attending kindergarten during the 2010-2011 school years indicates that time spent on these more complex skills has increased more than the time spent on basic skills, but teachers continue to focus on complex skills less frequently (Engel et al., 2016).

Differential benefit of instruction by school entry math skills. While evidence suggests that focusing on more advanced skills during math instruction is effective in supporting math learning for children overall, the impact of instruction is dependent on children's math skills at kindergarten entry (Engel et al., 2013). Spending more time instructing kindergartners on advanced topics, including computation, advanced numbers/counting, and operations results in greater gains on a broad measure of math achievement, while a focus on basic counting and shape results in fewer gains (Bodovski & Farkas, 2007; Chiatovich & Stipek, 2016; Engel et al., 2013; Guarino, Hamilton, Lockwood, & Rathbun, 2006). However, instructional time spent on basic numbers and shapes is associated with mathematical achievement gains for kindergartners entering with the lowest initial math skills (Bodovski & Farkas, 2007; Engel et al., 2013). This research was conducted with children attending kindergarten in the 1990s, but the question has not been examined in the new context of increased overall math instruction, and an increased focus on more advanced skills. Thus, in the present study we used a more recent sample to examine how an instructional focus on more basic or advanced math skills differentially related to math gains across the year for children who started kindergarten with varying math skills.

Most prior work in this area has focused on children's math skills at kindergarten entry as the child factor that may determine whether or not a particular instructional strategy is most effective; however, the strong connection between children's EF skills and math learning suggests that children's entry level EF skills may also be important.

Differential benefit of instruction by EF at school entry. A teacher's instructional choices provide different affordances for learning depending on a child's self-regulatory capabilities (Brock et al., 2014). While EF shows strong links to children's math performance, the EF demands are not equally strong across all math skills. For example, more advanced skills like operations, call on children's higher order EF processes such as planning and problem solving in a way that simpler skills, like rote counting, do not. EF has been more closely linked with some of these skills than others, and thus, instruction focused on certain math skills is likely to benefit children in different ways dependent on their EF skills. For example, working memory is more strongly linked to operations than other mathematical sub-domains (e.g., numeracy, measurement; Peng, Namkung, Barnes, & Sun, 2016; Vanbinst & De Smedt, 2016). Despite the wealth of research linking children's EF skills and math outcomes, relatively little is known about how math instruction focused on more basic or advanced skills benefits children with different EF skills. This understanding might inform how to differentiate instruction for children who can be considered at risk for academic difficulties because of low EF skills. In the present study, we explored this unexamined question of how children who entered kindergarten with a range of EF skills differentially benefitted from an instructional focus on certain subsets of math skills.

Present Study

In the current study, we used a child by environment perspective to examine children's math gains during kindergarten. We first sought to examine the ways in which children's EF and math skills at kindergarten entry are individually and jointly associated with math gains. Furthermore, we explored whether cognitive flexibility and/or working memory can act as a compensatory factor for children who enter kindergarten with low math skills. We are only aware of the potential compensatory role of EF being examined in one previous sample (Blair et al., 2016; Ribner et al., 2017) and are not aware of any studies that have examined individual EF skills. Next, we examined which math skills kindergarten children were taught and how this instruction related to their math learning, as well as how that association varied based on a child's EF and math skills at school entry. While prior research (Bodovski & Farkas, 2007; Chiatovich & Stipek, 2016; Engel et al., 2013) found that kindergarten math instruction differentially benefited children based on children's math skills at school entry, this research has not been conducted in children attending kindergarten in new instructional math contexts. Furthermore, despite strong links between children's EF and math learning, the question of how math instruction differentially benefits children based on their EF remains unexplored. We examined this question by exploring whether the association between the types of math skills taught in the classroom and math gains varied based on children's EF skills at kindergarten entry.

We specifically sought to answer the following research questions.

1. What are the associations between children's cognitive flexibility, working memory, and math skills at kindergarten entry and their gains in math during the year?
    1a. To what extent does this association between EF and math gains vary based on children's school entry math skills?

We hypothesized that school-entry math skills and each EF skill would have a unique association with math outcomes, but expected the strength of the association between entry math skills and outcomes to be strongest. Furthermore, we hypothesized that the association between math gains and working memory would be stronger than the association between cognitive flexibility and gains (Bull & Scerif, 2001; Purpura et al., 2017). Finally, we hypothesized that EF skills would be more strongly associated with math gains for children with weaker math skills at school entry (Blair et al., 2016; Ribner et al., 2017).

2. What is the association between the frequency of instruction in Basic Math Skills, Advanced Numeracy Skills, and Operations and children's math gains during kindergarten?
    - 2a. To what extent does this association vary based on children's math skills at school entry?
    - 2b. To what extent does this association vary based on children's EF at school entry?

We expected that, on average, instruction more focused on advanced skills would be related to greater math gains, while instruction focused on basic skills would have null or potentially negative associations with gains (Bodovski & Farkas, 2007; Chiatovich & Stipek, 2016; Engel et al., 2013, 2016; Guarino et al., 2006). However, we expected that a focus on more basic skills would be beneficial only for children who entered kindergarten with lower math skills, while advanced skills instruction would benefit children who entered kindergarten with more advanced math skills (Engel et al., 2013). Although this question has not been explored in prior research, we hypothesized that children with stronger EF would benefit more than their peers with lower EF from a focus on more advanced math topics, as EF has been more strongly linked to more advanced topics like operations (Peng et al., 2016; Vanbinst & De Smedt, 2016).

Methods

Data for this study come from a nationally representative, longitudinal dataset, the Early Childhood Longitudinal Study, Kindergarten Class of 2010-2011 (ECLS-K:2011). The dataset, which is collected by the U.S. Department of Education's, National Center for Education Statistics (NCES), includes 18,174 children attending kindergarten in 1,352 schools during the 2010-2011 school year. It contains extensive information about children in the sample, their families, classrooms, teachers, schools, and other care settings. Data for the present study come from parent and teacher surveys, as well as direct child assessments, conducted during the first and second wave of data collection (the fall and spring of children's kindergarten year).

The ECLS-K:2011 includes weight variables to correct for oversampling and differential response rates. In this study, the W12AC0 weight was used. A portion of children in the full sample have zero weights, resulting in a sample of 14,368 children. Additionally, children who changed teachers during kindergarten (n = 594) will be excluded since the math instruction they experienced during the school year cannot be accurately determined. This resulted in a final analytic sample of 13,774 children.

Measures

Math achievement. Children's math achievement was individually assessed by trained and certified data collectors, using a computer-assisted interviewing program, at kindergarten entry and in the spring of kindergarten. Each assessment period included math and EF assessments and lasted for approximately one hour. The ECLS-K:2011 math assessment measured children's conceptual and procedural math knowledge, and problem solving. The math assessment is based on the National Assessment of Educational Progress (NAEP) math framework extended down to the kindergarten level and items were reviewed by an expert panel. It includes questions on number sense, properties, and operations; measurement; geometry and spatial sense; data analysis, statistics and probability; and patterns, algebra, and functions (Tourangeau et al., 2015). Questions are related to images presented to the child on a small easel and children can respond verbally or by pointing. The Item Response Theory (IRT) Scale Score provided in the dataset, which allows an examination of longitudinal growth in children's math achievement, is used in the present study. IRT scale scores in the full sample ranged from 0 to 135 (weighted M = 33.20, SD = 11.39 in the fall; weighted M = 46.98, SD = 12.53 in the spring). Reliability for the assessment scores were excellent (α = .92 in the fall, α = .94 in the spring).

EF. Children's EF assessment scores from the fall of kindergarten entry were used as independent variables in analysis. EF was directly assessed in the same session as the math assessment.

Cognitive flexibility was assessed using the Dimensional Change Card Sort (Zelazo, 2006). In this task children sort 22 cards, each with a picture of a red rabbit or blue boat. Children first sort based on the color of the picture (Color Game) and then by the shape of the picture (Shape Game). If children sort at least 4 of 6 cards correctly during the Shape Game, children play the Border Game. In the Border Game, children sort by color if the card has a border and by shape if it does not. Following recommendations from the developers, a single total score for Dimensional Change Card Sort was created by summing the score of each game; children who did not complete the Border Game due to a lower score on the Shape Game were assigned a score of 0 for the Border game. Scores for Dimensional Change Card Sort in the full sample ranged from 0-18 (weighted *M* = 14.18, *SD* = 3.34).

Working memory was assessed using the Number Reversed subtest of the Woodcock-Johnson III Tests of Cognitive Abilities (Mather & Woodcock, 2001). In this task children are given a sequence of numbers and asked to repeat the sequence in reverse order. Children begin with 5 two-number sequences and the length of sequence increases by increments of one up to 5 eight-number sequences. If during 5 sequences of any length children provide three consecutive incorrect responses, they do not progress to the next length sequence. The *W*-Ability score provided in the dataset has the most complete data and is used in the proposed analysis. The *W* score ranged from 393 to 603. The weighted mean for the full sample of children in the fall of kindergarten was 432.56 (*SD* = 30.03).

Math skills taught. Teachers reported on the math skills they taught in their classroom over the course of the kindergarten year on the spring ECLS-K:2011 teacher survey. A multi-part question asked teachers to report on the frequency with which they taught 25 different math skills (see Appendix A). Teachers chose from the response options: never; once a month or less; two or three times a month; once or twice a week; three or four times a week; daily.

Analysis

Data were screened for missing data, multivariate and univariate outliers, and normality prior to analysis. All variables of interested were presented in a descriptive and in a correlation table.

Prior to addressing the research questions, a confirmatory factor analysis (CFA) was conducted to reduce the amount of data representing math instruction. We fit a CFA to the math instruction variables indicated by Chiatovich and Stipek (2016) in their examination of math instruction factors using the ECLS-K:1998-1999 sample. We evaluated the fit of the CFA using a number of criteria: the root mean square error (RMSEA; Browne & Cudek, 1993) less than .05, and the comparative fit index (CFI; Bentler, 1990) and Tucker and Lewis index (TLI; Tucker & Lewis, 1973) greater than .95. The CFA demonstrated acceptable fit on two of three criteria (RMSEA = .08, CFI = .86, TLI = .95). Furthermore, each item loading was statistically significant ($p < .001$) and standardized loadings ranged between .62 and .90 (see Table 1). Since, we were interested in the role of the difficulty of skills being taught in instruction we only used the factors focusing on progressively more difficult skills (i.e., Basic Math Skills, then Advanced Number Skills, and finally Operations). We created composites by averaging the skills composing each factor because the composite score, as opposed to a factor score, allowed us to retain meaningful information about how often the skills were taught in the classroom. Each composite demonstrated good internal consistency (Basic Math Skills, α = .82; Advanced Number Skills, α = .71; Operations α = .84).

We answered each research question using a regression analysis. Each of the regression models included a series of covariates including: child's fall math score, so gains in math were being predicted; basic demographics of children, teachers, and schools included in most educational and developmental research including child's age, child's sex, household socioeconomic (SES) status (a composite of each parent's education and occupational prestige score, and household income), and teacher's years of experience teaching children in first grade or younger, and school type; and the number of hours the class spends on math each day and the number of days each week, to disentangle the effects of the content of instruction from the overall dosage of math instruction. All analyses were conducted in MPlus version 5.2. Missing data were accounted for using full information maximum likelihood. To address our first research questions on the association between children's skills at school entry and math gains, and how the association between EF and gains varied based on children's school entry math skills, regression analyses were performed, with the later including an interaction term between school-entry EF and math skills. We answered the second research question using all three instructional skill composites to predict math gains. In the final two models, we added an interaction term between each instructional skill composite and children's skills at school entry (either math skills or EF skills, respectively) to examine how the association between instruction and gains varied dependent on children's entry skills.

Results

Descriptive statistics for variables of interest are presented in Table 1. The loading for each skill on to its skill composite is also included in the table. Teachers of children in the sample reported providing instruction on Basic Math Skills (M = 4.08), Advanced Numbers Skills (M = 4.02), and Operations (M = 4.15) with similar frequency. They reported teaching these skills once or twice a week, or approximately six days per month (6.12 days of Basic Math Skills, 6.03 days of Advanced Numbers Skills, 6.23 of Operations). However, there was more variability in the frequency of teaching Advanced Number Skills (*SD* = 1.23) and Operations (*SD* = 1.28), as compared to Basic Math Skills (*SD* = 0.96).

Table 2 presents correlations between the variables included in the regression models. All of the instructional skill composites had a small to moderate positive correlation with each other (*r*s = .23 - .35), indicating that teachers tended to more (or less) frequently teach all the skills rather than sacrificing time spent instructing on some skills in favor of others. Basic Math Skills had a small negative correlation with children's cognitive flexibility, working memory, and math skills at school entry ($r = -.04$, $r = -.06$, $r = -.06$, respectively); teachers tended to teach Basic Math Skills more frequently when their students entered with less strong skills. Conversely, Advanced Number Skills had a small but positive correlations (*r*s = .04 - .09) with children's entry skills.

Executive Function Associated with Math Gains

Model 1 in Table 3 presents the results of the regression model predicting children's spring math scores from their EF and math skills at kindergarten entry. The model presents the association of each entry skill, accounting for the others in addition to other covariates, with children's math outcomes. Children's school entry math skills were the strongest predictor of their math outcome ($\beta = .71$, $b = .77$, $SE = .01$, $p < .001$). Both cognitive flexibility and working memory were associated with math gains. Notably, the association between working memory and math gains ($\beta = .12$, $b = .05$, $SE = .00$, $p <$

.001) was about twice as large as the association between cognitive flexibility (β = .06, *b* = .21, *SE* = .02, *p* < .001) and gains.

Math skills at kindergarten entry moderated the association between working memory and math gains. Model 2 in Table 3 presents the results of the regression model examining whether children's math skills at kindergarten entry moderated the associations between children's EF skills (cognitive flexibility and working memory) and their math gains. Children's school entry math skills did not moderate the association between their cognitive flexibility and math gains over the kindergarten year (β = -.01, *b* = -.11, *SE* = .08, *p* = .200). However, their math skills at school entry did moderate the association between working memory and math gains (β = -.07, *b* = -.92, *SE* = .08, *p* < .001) such that working memory was more strongly associated with math gains for children who had lower math skills at the start of kindergarten.

Math Instruction and Gains

Model 1 in Table 4 show the results of the regression model examining the association between the frequency with which skills were taught and children's math gains. The model examined the relative association of each instructional skill composite with children's math gains when accounting for the other instructional composites in addition to a series of covariates. More frequently teaching Basic Math Skills was negatively associated with math gains (β = -.03, *b* = -.37, *SE* = .13, *p* = .003), but more frequently teaching Advanced Number Skills (β = .05, *b* = .50, *SE* = .10, *p* < .001) and Operations (β = .06, *b* = .56, *SE* = .09, *p* < .001) were positively associated with gains.

The role of math skills at kindergarten entry. Model 2, displayed in Table 4, was used to examine whether children's math skills at the start of kindergarten moderated the associations between the frequency with which skills were taught and children's math gains. Children's math skills at school entry did not moderate the association between the frequency of teaching Basic Math Skills or Operations and math outcomes (*p*s > .05). It did however moderate the association between more frequently teaching Advanced Number Skills and math gains (β = -.02, *b* = -.29, *SE* = .07, *p* < .001). More frequently teaching Advanced Number Skills was associated with greater gains for children who entered kindergarten with lower math skills than their peers.

The role of EF. Model 3 in Table 4 presents the results of the regression model examining whether children's fall EF skills moderated the associations between the frequency with which skills were taught and children's math gains across the year. Only one of these six interaction terms was significant: that between cognitive flexibility and more frequently teaching Advanced Number Skills. The interaction was negative (β = -.02, *b* = -.18, *SE* = .07, *p* = .011); thus, more frequently teaching Advanced Number Skills was associated with greater gains in math for children who entered kindergarten with weaker cognitive flexibility. However, cognitive flexibility did not moderate the association between the frequency of teaching Basic Math Skills or Operations and math improvements, nor did working memory moderate the association between the frequency of teaching any skill composites and math improvements.

Discussion

The purpose of this study was to explore how children's math and EF skills at kindergarten entry, and the instruction they receive in the classroom, independently and jointly predicted their math learning over the course of the school year. First, we replicated prior findings linking EF skills, specifically cognitive flexibility and working memory, to children's math learning. Then we found that working memory served as a protective factor for children who started school with lower math skills, such that children with low math skills at school entry learned more math than expected when they had strong working memory. This study also expands our understanding of the role that instructional content may play in children's math learning, as well as the ways in which the impact of instruction may depend on children's school-entry skills. First, we confirmed prior work (Engel et al., 2016) suggesting that children learn more math when advanced skills are more frequently taught, but less math when basic skills are frequently taught. Finally, we found that frequently teaching Advanced Number Skills was especially beneficial for children who entered kindergarten with low math or cognitive flexibility skills.

Executive Function and Math Improvement

Both children's cognitive flexibility and their working memory at the start of kindergarten uniquely predicted their math gains during the school year. However, the association between working memory and gains was nearly twice as large as between cognitive flexibility and gains. Specifically, entering kindergarten with cognitive flexibility skills 1 *SD* above the mean was associated .06 *SD*s greater math gains, but entering with working memory skills 1 *SD* above the mean was associated with .12 *SD*s greater math gains. Although these effect sizes are fairly small, the effect sizes were as large as (cognitive flexibility) or larger than (working memory) the effect size of SES in the model. Overall, these findings are consistent with our hypotheses and most prior work finding independent associations of each EF component with math gains, but a larger effect size for working memory (Bull & Scerif, 2001; Purpura et al., 2017). Notably, as hypothesized, both of these associations had a much smaller effect size than the association between children's math skills at kindergarten entry and their math outcomes. Furthermore, consistent with our hypotheses as well as nascent research (Blair et al., 2016; Ribner et al., 2017), children's math skills at kindergarten entry moderated the association between EF and math gains across the year; children who started kindergarten with lower math skills but strong working memory had higher than expected math outcomes.

We found that children's EF, working memory in particular, can serve as a protective or compensatory factor for children with low intital math skills, which provides an interesting potential for intervention for children struggling with math during early childhood. The optimal approach may be to combine EF and academic intervention (Bierman & Torres, 2016; Rabiner, Murray, Skinner, & Malone, 2010). A recently studied math intervention for children entering preschool with very low math knowledge and skills took this approach by combining their math intervention with an attention intervention for a subset of children in the intervention. The math intervention helped children improve significantly, but a sizeable percentage of children were still below the 10^{th} percentile in math after the intervention, and the attention intervention, while improving children's attention, did not yield academic benefits beyond the math intervention alone (Barnes et al., 2016). Findings from the present study on the compensatory role of working memory, suggest that the combination of a math intervention with an intervention focused on working memory, rather than attention, may be a key target to help those children who continue to struggle with math despite early math intervention.

Math Instruction

We next examined the association between instruction and children's math gains, hypothesizing that frequently teaching more advanced content would be associated with greater math gains while frequently teaching basic math would have a negative or null association with gains. More frequently teaching Basic Math Skills was associated with smaller math gains. In contrast, more frequent instruction on Advanced Number Skills and on Operations were associated with larger math gains. These findings differ from associations Chiatovich and Stipek (2016) found in a nationally representative sample of children attending kindergarten during the 1998-1999 school year, using the same groupings of skills. Specifically, they failed to find significant associations between how frequently these skills were taught and math gains. However, findings are consistent with our hypotheses and with more broad findings suggesting that time spent on basic math content is negatively associated or unassociated with math gains, while time spent on more advanced content is positively associated with gains (Engel et al., 2013, 2016; Guarino et al., 2006). One possibility for this discrepancy is that Chiatovich and Stipek (2016) did not include operations while the other studies, including the present study, accounted for how frequently operations are taught. Furthermore, the previous and present studies all found operations to have the strongest association with math improvements. Findings suggest that the trend, reported elsewhere (Bassok, Latham, & Rorem 2016; Engel et al., 2016), towards an increased focus on more advanced math content in kindergarten nationally may have positive effects on children's math learning in kindergarten.

Impact of instruction moderated by school entry math skills. We hypothesized that children who started kindergarten with lower math skills would benefit more than their peers from an increased focus on Basic Math Skills, while those who started school with stronger math skills would benefit more than their more novice peers from an increased focus on Advanced Number Skills and Operations. Findings diverged from our hypotheses in that the associations between Basic Math Skills and Operations and gains were not moderated by children's math skill at the start of kindergarten. Furthermore, children's math skills at the start of kindergarten did moderate the association between Advanced Number Skills and gains but in the opposite direction. That is, children who started kindergarten with lower math skills benefited more than their more advanced peers from more frequent instruction in Advanced Number Skills.

These findings are discrepant in several ways with research on children who entered kindergarten in 1998. The earlier cohort of kindergartners benefited from math instruction targeted at their skill level; those who started kindergarten with less advanced math skills benefited from instruction focused on basic skills, while those who entered with more advanced skills benefits from instruction focused on more advanced skills (Chiatovich & Stipek, 2016; Engel et al., 2013). The discrepancy in findings between the earlier and more recent cohorts may be due to a trend of increasing mathematical proficiency among children nationwide from 1998 to 2010 (Bassok and Latham, 2017). For example, we found the association between the frequency of instruction on Basic Math Skills and math gains did not vary based on children's skills at the start of kindergarten; children who started kindergarten with lower math skills did not benefit more from increased instruction on basic skills. If children entering kindergarten in 2010 were more mathematically advanced than those who entered in 1998 (Bassok and Latham, 2017), even children entering with the low math skills in the present sample (entering kindergarten in 2010) may have at least somewhat mastered the most basic skills. Therefore, in the present study, instruction on basic skills may have been unhelpful in advancing math learning for all students, regardless of incoming math skills because they had already mastered these skills. In contrast, in 1998, children entering with lower math skills may not have mastered basic skills and therefore instruction in these skills was associated with gains for those children, but not for children entering with stronger math skills (Engel et al., 2013). Similarly, among children who entered kindergarten in 1998 only those who started kindergarten with more advanced skills benefited from more frequent instruction in Operations (Engel et al., 2013). However, among children entering kindergarten in 2010, even those lower math skills upon entry may have advanced enough skills and knowledge to benefit from instruction on Operations. Therefore, in the present study increased instruction in Operations was helpful for all children.

Taken in sum, these results have important implications for classroom practice. Although results and previous research (Engel et al., 2016) suggest that focusing on advanced skills would be most helpful for students, descriptive statistics in the present study indicated that teachers were covering each group of skills we examined with similar frequency. Furthermore, other research has demonstrated that kindergarten teachers, while shifting towards more of a focus on more advanced content, continue to spend somewhat more instructional time on basic content (Engel et al., 2016). This may be because teachers of young children believe they are not ready for math education, that just teaching basic numbers and shapes is enough, or that math is only for children with mathematical aptitude (Lee & Ginsburg, 2009). However, these results are inconsistent with these notions, and specifically the notion that children entering kindergarten with lower math knowledge and skills require instruction focused on basic math before they are able to benefit from more advanced instruction. If this were the case our hypotheses that children entering with lower proficiencies would benefit from more basic instruction and children entering with greater proficiencies from more advanced content would have come to fruition. Rather, our results suggest that all children benefit from instruction focused on more advanced content and this is especially true for children entering with lower math skills and knowledge.

Impact of instruction moderated by cognitive flexibility. We hypothesized that children with stronger EF would benefit more from instruction focused on more advanced math skills (Advanced Number Skills and Operations), as compared to their peers with weaker EF. Contrary to our hypothesis, the association between a child's math gains and their exposure to instruction on Operations did not vary as a function of their EF skills. One explanation, is that children are already somewhat experienced with single-digit operations when arriving to kindergarten and, as more advanced problem solvers, use more automated problem-solving strategies that are less reliant on EF (Peng et al., 2016). Another possibility is that with the increased push for and coverage of math in kindergarten, teachers may have received more extensive training on math pedagogy either in their pre-service training and/or through professional development as practicing teachers. With improved instructional techniques, it is possible that teachers are able to provide the types of supports and scaffolding that erase any advantage children with stronger EF skills have over their peers in mastering operations. For example, providing manipulatives for children to use while performing operations may lighten the working memory load and allow children with weak working memory to better engage and thus benefit as much as their peers with stronger EF skills from the instruction.

Working memory also did not moderate the association between math outcomes and the frequency with which Advanced Number Skills was taught. However, cognitive flexibility did moderate this association, but not in the expected direction. While we hypothesized that children with stronger EF skills would benefit more from frequent instruction on Advanced Number Skills, in fact children who started kindergarten with weaker cognitive flexibility benefited more from more frequent instruction on Advanced Number Skills. The moderating role of cognitive flexibility, but not working memory, may be due to a stronger role for cognitive flexibility in performing the specific skills included in Advanced Number Skills. For example, counting by 2s, 5s, and 10s requires children to shift from one counting rule (e.g., count by 2s) to another rule (e.g., count by 5s). Similarly, all other skills in this category implicate place value, which requires children to shift their rules about what a particular digit represents from number to number (e.g., a 2 in the ones place is 2, a 2 in the tens place represents twenty, and a 2 in the hundreds represents two hundred). It is possible that children with less strong cognitive flexibility needed more frequent instruction on these skills which were more difficult for them because of poor cognitive flexibility, while children with strong cognitive flexibility were able to pick up on these skills easier and made fairly equal gains regardless of how frequently it was taught.

Limitations

Although this study adds important information to our knowledge base on how the focus of math instruction advances children's math knowledge and skills and how these associations vary as a result of children's EF and math skills at school entry, there are some limitations. First, while the ECLS-K:2011 allowed us to examine a nationally representative sample, a set of limitations arise from lack of available data.

The data available from direct child assessments was one source of limitations. First, the assessments of EF only included assessments on two of the three components of EF (working memory and cognitive flexibility). Not including an inhibitory control assessment leaves us with an incomplete picture of the interplay between children's EF skills and the math instruction they receive. It may be especially incomplete because some prior results suggest inhibitory control is more strongly related to math outcomes than cognitive flexibility or working memory (Becker et al, 2014; Blair & Razza, 2007). Secondly, the math assessment provided only a broad measure of math achievement. It did not include sub-scores for children's performance in different domains (e.g., operations vs. measurement) or provide details about their performance on skills at different levels of difficulty within a domain (e.g., basic geometry vs. advanced geometry). This likely skewed our sensitivity to math gains in particular areas. For example, we found that more frequently teaching basic skills was associated with smaller gains. However, it may be that all or some children did improve quite a bit on basic skills but not as much overall, and thus on the broad measure of achievement it appeared that instruction on basic skills was associated with smaller math gains.

Additionally, the data only included a teacher retroactive, self-report measure on math instruction rather than observations. This potentially limits our conclusions in a number of ways. First, the results may be interpreted more in accordance with the associations between a teacher's view of instruction and outcomes, rather than actual instructional time spent on certain skills and outcomes. For example, instead of concluding that more time spent on instruction covering Operations is associated with math gains, it may be that receiving instruction from a teacher who believes they frequently provide instruction on Operations is associated with math gains. Because the dataset did not have observational data on instruction, the study also did not include measures of the quality of math instruction, which plays an important role in children's math learning (Clements & Sarama, 2008). Furthermore, teachers may be providing higher quality instruction on some skills, which may be contributing to the results in addition to the quantity of instruction on certain skills. Finally, the survey on which skills were being taught did not include a range of skill difficulty within each domain (e.g., basic geometry skills through advanced geometry skills). Thus, our measure of instruction somewhat conflates domain and difficulty. Specifically, the Basic Math Skills composite included skills from a number of domains (e.g., numeracy and operations, geometry) but Advanced Number Skills and Operations were focused within the domain of numeracy and operations.

Finally, causal relations cannot be inferred for any associations examined here, because the data and design are not experimental. In the present study, we examined the association between earlier EF skills and math instruction and later math outcomes. However, it is likely that the associations between these factors are bidirectional with earlier math skills and math instruction also associated with, and possibly influencing, later EF skills (Clements et al., 2016; Schmitt, Geldhof, Purpura, Duncan, & McClelland, 2017).

Conclusion

In summary, this study found that children's math and EF skills at kindergarten entry were positively associated with main gains during kindergarten, and these skills interacted, such that working memory was more strongly related to math gains for children who entered school with low math skills. Instruction in the classroom also played a role in children's math improvements during the year; focusing on Basic Math Skills was associated with smaller math gains, while a focus on more Advanced Number Skills and Operations was associated with larger gains. Furthermore, more frequently teaching Advanced Number Skills was more strongly related to gains for children who entered kindergarten with low cognitive flexibility or low math skills and knowledge. Findings provide support for teaching more advanced math skills in kindergarten classrooms.

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Table 1
Descriptive statistics for variables of interest.

	n	Missing	Mean (*SD*)	Range	Loading (*SE*)
Fall cognitive flexbility	13,610	170 (1.2%)	14. 28 (3.27)	0-18	
Fall working memory	13,600	170 (1.3%)	433.72 (30.24)	393-581	
Fall math score	13,600	180 (1.3%)	33.87 (11.47)	8.94-128.68	
Spring math score	13,580	190 (1.4%)	47.56 (12.39)	8.94-95.03	
SES of child's family	12,510	1260 (9.2%)	-0.03 (0.81)	-2.33-2.60	
Child's age (months) at fall assessment	13,730	50 (0.3%)	67.52 (4.47)	44.81-93.90	
Teacher's years of experience	10,220	3560 (25.8%)	11.94 (9.21)	0-52	
Math Instruction					
Basic Math Skills	13,360	410 (3.0%)	4.08 (0.96)	1-6	
Ordering objects	13,540	240 (1.7%)	3.68 (1.20)	1-6	0.88 (.01)
Sort into subgroups using rule	13,510	270 (1.9%)	3.86 (1.23)	1-6	0.86 (.01)
Name geometric shapes	13,530	240 (1.8%)	3.96 (1.42)	1-6	0.63 (.01)
Identify relative quantity	13,550	220 (1.6%)	4.52 (1.23)	1-6	0.73 (.01)
Making or copying patterns	13,540	240 (1.7%)	4.38 (1.31)	1-6	0.62 (.01)
Advanced Number Skills	13,040	730 (5.3%)	4.02 (1.23)	1-6	
Reading three-digit numbers	13,510	270 (1.9%)	3.04 (2.10)	1-6	0.72 (.02)
Counting beyond 100	13,360	410 (3.0%)	3.32 (1.98)	1-6	0.62 (.02)
Place value	13,470	310 (2.2%)	3.79 (2.16)	1-6	0.66 (.02)
Reading two-digit numbers	13,540	240 (1.7%)	5.09 (1.37)	1-6	0.72 (.02)
Counting by 2s, 5s, and 10s	13,530	250 (1.8%)	4.79 (1.39)	1-6	0.64 (.02)
Operations	13,340	430 (3.1%)	4.15 (1.28)	1-6	
Add single-digit numbers	13,430	350 (2.5%)	4.42 (1.30)	1-6	0.90 (.01)
Subtract single digit numbers	13,410	360 (2.6%)	3.88 (1.48)	1-6	0.87 (.01)

Table 2
Correlations between variables included in the regression models.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Basic Math Skills	.23	.35	-.06	-.04	-.04	-.06	.00	-.11	.00	.19	.11	-.04	-.01	-.09
2. Advanced Number Skills		.28	.09	.13	.04	.06	.04	.08	.01	.12	.10	.02	.02	.00
3. Operations			.02	.08	-.01	-.01	.03	-.02	.01	.17	.14	.01	.06	.01
4. Fall Math				.82	.33	.63	.25	.43	.01	-.06	-.01	.04	.05	.12
5. Spring Math					.34	.60	.18	.41	.00	-.02	.02	.02	.04	.11
6. Cognitive Flexibility						.30	.09	.19	-.05	-.03	.00	.03	.01	.03
7. Working Memory							.13	.34	-.05	-.06	-.02	.03	.05	.09
8. Age								-.03	.07	.02	.02	-.01	-.11	-.02
9. SES									-.01	-.13	-.05	.06	.17	.19
10. Male										-.01	.01	-.02	.00	-.01
11. Hours Math/Day											.20	.02	-.01	-.10
12. Days Math/Wk.												.03	-.02	-.03
13. Years Experience													.11	.07
14. Private School														-.05
15. Religious School														

Table 3

Regression models predicting spring kindergarten math scores from executive function and entry math skills.

	Model 1			Model 2		
	β	*B*	*(SE)*	β	*B*	*(SE)*
Intercept	-0.38	-4.69	(2.26)*	-0.42	-5.23	(2.30)*
Age	-0.02	-0.04	(0.02)*	-0.02	-0.05	(0.02)*
Sex (1 = male)	0.00	0.02	(0.14)	0.00	0.07	(0.14)
SES	0.06	0.84	(0.11)**	0.05	0.78	(0.11)**
Years Experience	-0.02	-0.03	(0.01)*	-0.02	-0.03	(0.01)*
Private School	-0.01	-0.84	(0.59)	-0.01	-0.92	(0.61)
Religious School	0.01	0.54	(0.51)	0.01	0.47	(0.50)
Hours of Math/Day	0.03	0.37	(0.09)**	0.03	0.35	(0.09)**
Days of Math/Week	0.02	0.42	(0.17)*	0.02	0.42	(0.18)*
Fall Math	0.71	0.77	(0.01)**	0.72	0.79	(0.01)**
CF	0.06	0.21	(0.02)**	0.04	0.17	(0.02)**
WM	0.12	0.05	(0.00)**	0.13	0.05	(0.00)**
CF X Fall Math				-0.01	-0.11	(0.08)
WM X Fall Math				-0.07	-0.92	(0.08)**
R^2		0.69			0.70	

Note. *p < .05; **p < .001; CF = cognitive flexibility; WM = working memory.

Table 4

Regression models predicting spring kindergarten math scores from instruction composites.

	Model 1			Model 2			Model 3		
	β	*B*	*(SE)*	β	*B*	*(SE)*	β	*B*	*(SE)*
Intercept	1.35	16.78	(1.83)**	1.35	16.75	(1.84)**	-0.44	-5.45	(2.10)*
Fall Math	0.79	0.87	(0.01)**	0.80	0.87	(0.01)**	0.70	0.77	(0.01)**
CF								0.21	(0.02)**
WM								0.05	(0.00)**
BMS	-0.03	-0.37	(0.13)*	-0.03	-0.37	(0.12)*	-0.03	-0.35	(0.12)*
ANS	0.05	0.50	(0.10)**	0.05	0.48	(0.10)**	0.05	0.47	(0.10)**
Operations	0.06	0.56	(0.09)**	0.06	0.57	(0.08)**	0.06	0.60	(0.08)**
BMS X Fall Math				0.00	-0.03	(0.09)			
ANS X Fall Math				-0.02	-0.29	(0.07)**			
Operations X Fall Math				0.00	0.00	(0.09)			
BMS X CF							0.00	-0.02	(0.08)
ANS X CF							-0.02	-0.18	(0.07)*
Operations X CF							0.01	0.11	(0.08)
BMS X WM							0.00	-0.01	(0.09)
ANS X WM							0.00	0.04	(0.09)
Operations X WM							0.00	-0.05	(0.08)
R^2		0.69			0.69			0.70	

Note. *p < .05; **p < .001; BMS = basic math skills instruction; ANS = advanced number skills instruction, CF = cognitive flexibility, WM = working memory. Covariates are included in each model but not presented here for simplicity.

Appendix A
Teacher Survey Question on Math Skills

C5. For this school year as a whole, please indicate how often each of the following MATH skills is taught in your class or classes. MARK ONE ON EACH ROW.

	Not Taught		Taught				
	Taught at a higher grade level	Children should already know	Once a month or less	Two or three times a month	Once or twice a week	Three or four times a week	Daily
a. Correspondence between number and quantity	☐	☐	☐	☐	☐	☐	☐
b. Writing all numbers between 1 and 10	☐	☐	☐	☐	☐	☐	☐
c. Counting by 2s, 5s, and 10s	☐	☐	☐	☐	☐	☐	☐
d. Counting beyond 100	☐	☐	☐	☐	☐	☐	☐
e. Writing all numbers between 1 and 100	☐	☐	☐	☐	☐	☐	☐
f. Recognizing and naming geometric shapes	☐	☐	☐	☐	☐	☐	☐
g. Identifying relative quantity (e.g., equal, less, more, least, most)	☐	☐	☐	☐	☐	☐	☐
h. Sorting objects into subgroups according to a rule	☐	☐	☐	☐	☐	☐	☐
i. Ordering objects by size or other properties	☐	☐	☐	☐	☐	☐	☐
j. Making, copying, or extending patterns	☐	☐	☐	☐	☐	☐	☐
k. Recognizing the value of coins and currency	☐	☐	☐	☐	☐	☐	☐
l. Adding single-digit numbers	☐	☐	☐	☐	☐	☐	☐
m. Subtracting single-digit numbers	☐	☐	☐	☐	☐	☐	☐
n. Place value	☐	☐	☐	☐	☐	☐	☐
o. Reading two-digit numbers	☐	☐	☐	☐	☐	☐	☐
p. Reading three-digit numbers	☐	☐	☐	☐	☐	☐	☐
q. Reading simple graphs	☐	☐	☐	☐	☐	☐	☐
r. Performing simple data collection and graphing	☐	☐	☐	☐	☐	☐	☐
s. Fractions (e.g., recognizing that ¼ of a circle is colored)	☐	☐	☐	☐	☐	☐	☐
t. Ordinal numbers (e.g., first, second, third)	☐	☐	☐	☐	☐	☐	☐
u. Using measuring instruments accurately	☐	☐	☐	☐	☐	☐	☐
v. Telling time	☐	☐	☐	☐	☐	☐	☐
w. Estimating quantities	☐	☐	☐	☐	☐	☐	☐
x. Estimating probability	☐	☐	☐	☐	☐	☐	☐
y. Writing math equations to solve word problems	☐	☐	☐	☐	☐	☐	☐