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Cognition and classroom quality as predictors of math achievement in the kindergarten year

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ABSTRACT

Using a sample of 171 children, we examined classroom quality as a potential moderator of the link between three distinct but related aspects of cognition (fluid intelligence, crystallized intelligence, and executive functioning) and math achievement across the kindergarten year. Multilevel modeling analyses were conducted to account for nesting of students within classrooms. Results revealed significant aptitude by treatment interactions for fluid and crystallized intelligence, suggesting that classroom practices may affect children differently depending on their abilities. Children with higher levels of fluid intelligence and of crystallized intelligence fared better in higher quality classrooms. Results also provide some support for Cattell's investment hypothesis. Implications of the results are discussed.

1. Introduction

In an increasingly technological world, there is greater need for individuals who are skilled in math. Math skills are relevant for many career fields, and they are also important in personal health and decision making (Reyna & Brainerd, 2007). Moreover, math skills are necessary to allow the US to become more competitive in the global economy (US Department of Education, 2007), highlighting the importance of math achievement in our nation. Although US high school students won the International Mathematical Olympiad for the first time in 21 years in 2015, (Washington Post, 2015), concerns have been raised regarding math achievement in American students because American students continue to lag behind East Asian countries and several European nations in math achievement (Provasnik, Gonzales, & Miller, 2009; Provasnik et al., 2013). It has been observed that math achievement in the kindergarten year is a strong predictor of later achievement (Claessens & Engel, 2013; Duncan et al., 2007).

Although children in the United States are not required to begin school until first grade, which generally occurs around age 6 in most states (National Center for Education Statistics, 2010), the kindergarten year, occurring around age 5, is the first year of formal school entry for most children (La Paro et al., 2009). Thus, investigation of factors that predict math achievement in the kindergarten year is of national import. Cognitive abilities are the strongest predictors of early academic achievement (Watkins, Lei, & Canivez, 2007). However, we do not yet have a full understanding of the contexts under which there might or might not be relations between various aspects of cognition and academic achievement in the early years. In the present research, we examine whether classroom quality moderates the link between distinct aspects of cognition and math achievement in the kindergarten year.

1.1. Cognition and math achievement

Current research indicates that human abilities consist of many different components that are interrelated, but that would be expected to have unique effects on a given outcome (Horn & Blankson, 2012), such as math achievement. Therefore, it has been argued that increased attention should be paid to examination of specific cognitive abilities to increase our understanding of the factors that predict achievement (McGrew & Wendling, 2010). A growing number of studies focus on distinct cognitive constructs, primarily fluid intelligence, crystallized intelligence, and executive functioning, in the examination of achievement outcomes (e.g., Blair & Razza, 2007). Fluid intelligence is reasoning to arrive at

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understanding relations among stimuli, comprehending implications, and drawing inference (Horn & Blankson, 2012). Fluid intelligence is often exhibited in matrix reasoning tests. Elements of the matrix reasoning tests are figures such as circles, squares, and triangles, which are equally familiar to all. The relationships among the elements in the matrix are those of order and size that run across the rows and down the columns of the matrix. The task is to comprehend the relationships in order to fill in an element that is missing in the matrix. Relationships among elements in the matrices are not much taught in school settings. Mathematical questions often require one to figure out a problem, come up with possible ways to solve a problem, select one or more of the possible ways to solve the problem, and implement the selected strategy to arrive at a solution. The reasoning involved is inherent in the conceptualization of fluid intelligence. Children with strong fluid reasoning skills have been found to perform well on tests of math achievement (Flanagan, Ortiz, Alfonso, & Mascolo, 2006; McGrew & Wendling, 2010).

Crystallized intelligence, which is related to but independent from fluid intelligence, represents knowledge acquired through social transmission. Such knowledge can be acquired through schooling and is often measured by tests of vocabulary (Blair, 2006; Horn & Blankson, 2012). Crystallized knowledge has also been found to be related to math achievement (Floyd, Evans, & McGrew, 2003).

Executive functioning refers to a set of domain general cognitive skills that involve attentional focusing and flexibility, cognitive inhibitory control, and working memory (Diamond, Barnett, Thomas, & Munro, 2007; McClelland et al., 2007; Montgomery, Anderson, & Uhl, 2008). Research suggests that in the preschool and kindergarten years, executive functions are best represented as a unitary factor rather than distinct functions (Mungas et al., 2013; Wiebe, Espy, & Charak, 2008). Executive functioning may be especially relevant to the development of math skills. In solving mathematical problems, the individual is expected to not only come up with potential solutions, which would involve fluid reasoning skills, but also hold the potential solutions in their immediate short term awareness and manipulate this information prior to arriving at a final solution (Geary, Hoard, & Hamson, 1999).

Indeed, researchers are beginning to explore the effects of different cognitive abilities on math achievement (e.g., Parkin & Beaujean, 2011). Although the conclusion reached by Parkin and Beaujean (2011) was that a single factor model better predicted math achievement than did a model with multiple factors, in a research synthesis by McGrew and Wendling (2010), results indicated that there are differential relations between specific abilities and math achievement. For example, crystallized intelligence and fluid intelligence were related to arithmetic and computational skills, whereas short-term memory was not consistently related to arithmetic and computational skills. Fluid intelligence was also more strongly related to problem solving skills than was crystallized intelligence. Relatedly, Hale et al. (2008) examined a general cognitive ability construct as well as subcomponent scores as predictors of mathematics achievement in typically developing children and children with math disabilities. Results indicated greater predictive validity for the subcomponent scores, thus highlighting the need for assessing specific cognitive abilities in research on achievement outcomes.

Fluid intelligence, crystallized intelligence, and executive functioning have all repeatedly been found to be related to math achievement (e.g., Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Flanagan et al., 2006; Fuhs, Nesbitt, Farran, & Dong, 2014; McGrew & Wendling, 2010). However, no studies have examined these three cognitive ability variables as predictors of math achievement in the kindergarten year within the context of the classroom environment. From a contextual perspective (Bronfenbrenner, 1994), aspects of the child's environment interact with the child's own characteristics to produce adaptive or maladaptive outcomes. Next to the home environment, the classroom environment is the most proximal source of influence on a child's academic outcomes. Thus, examination of school entry cognition within the context of the classroom environment will lead to better understanding of the impact that early cognitive abilities and environmental factors play in math achievement.

1.2. The role of classroom quality

Classroom quality has garnered increased attention in recent years, with many states developing standards of excellence for kindergarten classrooms (e.g., New Jersey Department of Education, 2011). Several frameworks, such as the Classroom Assessment Scoring System (CLASS; Pianta, La Paro, & Hamre, 2006) have been developed for understanding the effects of classroom experiences on student outcomes. Elements of the classroom that have been observed to affect achievement range from the physical environment, such as the quality of learning materials in the classroom, to student–teacher relationships, such as emotional responsivity of the teachers toward their pupils (Hamre, Pianta, Mashburn, & Downer, 2007). Within these frameworks, three aspects of the classroom environment that have been identified are classroom organization, instructional support, and emotional support, each of which has been found to affect achievement (Pianta, La Paro, & Hamre, 2008). Classroom organization refers to the extent to which the teacher creates an atmosphere that is conducive to learning and provides opportunities and material for learning to take place. Instructional support refers to the extent to which teachers scaffold more complex thinking in pupils. Emotional support includes the emotional connection displayed by a teacher towards her students, the extent to which negative emotions are displayed by the teacher or students in the classroom, and the teacher's sense of awareness about student needs and perspectives (Pianta et al., 2006). When children are in classrooms that are more organized, this may maximize available opportunities for learning. If the classroom environment is organized, the teacher will spend more time on teaching the students and less time in preparing materials during the class time. Likewise, if teachers are warm and responsive, they may be better able to motivate children to learn (La Paro et al., 2009) and may have pupils who are better behaved (Raver et al., 2009). Classroom organization, instructional support, and emotional support have been found to be related to each other and are often measured using the CLASS (Pianta et al., 2006), which was used in the present study.

Theory and empirical research indicates that better classroom quality leads to greater achievement in young children. For example, Hamre and Pianta (2005) found that 5- to 6-year-old students who were at risk of failure performed as well as their low-risk counterparts when placed in classrooms with higher levels of instructional and emotional support. Perry, Donohue, and Weinstein (2007) found that students in classrooms with greater levels of instructional and emotional support made greater gains in math achievement than those in classrooms of poorer quality. These findings are consistent with other research that has highlighted the important role of classroom quality on student achievement (e.g., Cadima, Leal, & Burchinal et al., 2010; Reynolds & Ou, 2011; Weinert & Helmke, 1995). Moreover, effects of classroom quality have been observed not only in research on US samples (e.g., Pianta et al., 2008), but in European samples as well (e.g., van de Grift, 2007).

To date, no studies have considered whether classroom quality moderates the association between the cognitive abilities under investigation in the present study and math achievement in the kindergarten year, although researchers have examined the link between cognition and math achievement (e.g., Fuhs et al., 2014; Raver et al., 2011), classroom quality and cognition (e.g., Fuhs, Farran, & Nesbitt, 2013), and classroom quality and math achievement (e.g., van de Grift, 2007). Potential outcomes in the examination of cognition and classroom quality can be understood as aptitude by treatment interactions (ATI; Cronbach & Snow, 1977; Pellegrino, Baxter, & Glaser, 1999; Snow, 1992). When applied to the classroom, aptitude by treatment interactions refers to the notion that different classroom practices may differentially affect children depending on their abilities. This concept has direct relevance for education, but there has been limited support for ATIs when applied to educational research, perhaps because of the heavy focus on tests of general cognitive ability in past studies (Sternberg, Grigorenko, Ferrari, & Clinkenbeard, 2009, chap. 9). Theoretically, aptitude by treatment interactions would not be expected to occur for a general intelligence factor because general intelligence should be beneficial across all treatments (Pellegrino et al., 1999). The almost exclusive focus on the general intelligence factor in this line of work has perhaps hindered efforts to find support for ATIs in this line of study. Moreover, although the concept of ATIs was proposed over 35 years ago, few studies have tested an ATI hypothesis in samples of kindergarten children. The present study therefore makes a unique and important contribution to the extant literature by examining multiple aspects of cognition.

Furthermore, it may be the case that the effects of the classroom environment differ for the different aspects of cognition. For example, theoretically, fluid intelligence leads to achievement through a principle of investment (Cattell, 1987). That is, when fluid intelligence is invested in different opportunities and programs for acquiring the knowledge and skills that constitute the intelligence of the dominant culture of a people, it leads to development of academic achievement. Thus, there must be sufficient opportunities to learn for the effects of fluid intelligence to have the greatest impact. There is some evidence in support of a hypothesis that fluid intelligence paves the way for development of other abilities and achievement (e.g., Ferrer & McArdle, 2004; Kvist & Gustafsson, 2008; McArdle, Hamagami, Meredith, & Bradway, 2000). Moreover, the research by Ferrer and McArdle (2004) revealed that fluid intelligence was more strongly associated with changes in math achievement over time than was crystallized intelligence and these effects were strongest during childhood and adolescence (ages 5–15) than at later ages (ages 16–24). On the other hand, Floyd et al. (2003) found weaker relations between fluid intelligence and math, and the relations for fluid and crystallized intelligence with math was approximately equal and of moderate size in 6-year-olds, the youngest age group sampled. Neither study, however, examined the role of classroom quality. Based on the investment hypothesis, we would expect that significant moderation effects may occur especially for fluid abilities. However, given the paucity of research in this area, analyses of interaction effects were exploratory in nature.

1.3. The present study

The primary aim of the present research was to examine the extent to which cognition at the start of kindergarten predicts math achievement in the spring of the child's kindergarten year while controlling for fall math achievement and determine whether these effects differ across different levels of classroom quality. Examination of cognitive ability at school entry within the context of the classroom quality will lead to better understanding of the impact that early cognitive abilities and environmental factors play in math achievement.

2. Method

2.1. Participants

The sample consisted of 171 children who serve as the control group of an on-going study on the efficacy of a kindergarten curriculum designed to enhance executive functioning skills. These children are enrolled in 33 classrooms in 14 participating schools that were randomly assigned to the control condition. An average of 351 ($SD = 134$) students were enrolled in each school, with an average student-teacher ratio of 14.71 ($SD = 3.06$). Percent of students receiving free or reduced lunch ranged from 5 to 92% ($M = 34$; $SD = 30$). On average, there were five children in the sample per classroom. Children averaged 68.85 months of age ($SD = 4.19$) at the first wave of testing in the fall of the kindergarten year. Fifty-two percent of the children were female. Of the 131 children for whom information on race/ethnicity was available, 66% were White, 12% Hispanic, and 21% were of other ethnicities including multiethnic. Annual income and family size were reported by 116 mothers. The average income-to-needs ratio, which is computed by dividing the total family income by the poverty threshold for that family size and is a common indicator of income, was 2.88 ($SD = 2.52$); 47.41% of the respondents had an income-to-needs ratio below 2, 37.93% between 2 and 5, and 14.66% greater than 5.

2.2. Procedure

Participating families in the control group were recruited from 33 classrooms within 14 suburban schools in the northeast of the United States during the fall of their kindergarten year. In the fall and spring of the child's kindergarten year, children were seen in two sessions over two days. The executive functioning measures in the present study were completed on the first visit in the fall while the fluid intelligence and crystallized intelligence measures were completed on the second visit in the fall. Math achievement was assessed on the child's second visit in the fall and spring semesters. The mean test interval was 5.37 months ($SD = 1.74$).

2.3. Measures

2.3.1. Fluid intelligence

Fluid intelligence was measured with the Raven's Coloured Progressive Matrices (Raven, Court, & Raven, 1986), which is one of the most commonly used tests of fluid reasoning. During the task, a geometric image with a piece missing is presented. Children are asked to select the correct missing entry from a set of choices. Alpha = .76 (Carlson & Jensen, 1981). Validity of this test has been obtained for the use of this test in five-year-olds (Raven, Raven, & Court, 2008). The raw score was used in analyses. Test-retest reliability in the sample was .25.

2.3.2. Crystallized intelligence

Crystallized intelligence was measured with the Picture Vocabulary test from the Woodcock–Johnson III (Woodcock, McGrew, & Mather, 2001) Tests of Cognitive Abilities. This subtest is based on the extended theory of fluid and crystallized intelligence (Woodcock et al., 2001) and is designed to measure crystallized knowledge. Evidence of the reliability and validity of this measure has been obtained (Woodcock et al., 2001). In this task, the child identifies an object either by naming its image or pointing to the object's image when prompted with its name. Children received 1 point for each correct answer. The raw score was used in analyses.

Test-retest reliability in the sample was .82.

2.3.3. Executive functioning

Executive functioning was measured using a composite (average) of three tasks, consistent with the unidimensional model of executive functioning that has been observed among preschool and kindergarten samples (e.g., Brydges, Reid, Fox, & Anderson, 2012; Wiebe et al., 2008). Correlations among the tasks ranged from .29 to .52 (all $p < .01$; alpha = .61). Test-retest reliability for the composite was .65.

2.3.3.1. Dimensional change card sort (DCCS). The DCCS task is a computer adaptation of the original card-based DCCS task developed by Zelazo, Müller, Frye, and Marcovitch, (2003), which was adapted for children from Berg's Wisconsin Card Sort task for adults (Berg, 1948). The DCCS, which involves sorting pictures based on two dimensions (color and shape), measures cognitive flexibility and attention shifting (Zelazo et al., 2003). The task has been found to be reliable and valid (Zelazo, 2006). Performance on the DCCS improves with training and is correlated with performance on other executive function measures as well as measures of theory of mind (Zelazo, 2006). During administration, two pictures that vary along two dimensions (color and shape) are presented at the bottom of the screen. A target picture is presented at the top of the screen. A word (either color or shape) is both presented on the screen and spoken by a prerecorded voice to cue children to match the target picture with the correct corresponding picture on the bottom of the screen. To match the pictures, the child is asked to press one of two fuzzy buttons on opposite sides of the computer keyboard corresponding with the location of their selection. During the first round of trials, children are cued to match the target picture according to color. During the second round, children are cued to match the target picture according to shape. The final round is mixed. Children's accuracy was measured as percent correct across 50 mixed trials.

2.3.3.2. Hearts and flowers. The Hearts and Flowers task was developed by Davidson, Amso, Anderson, and Diamond (2006) and Diamond et al. (2007) as a reliable and valid measure of attention shifting and inhibitory control. In the present research, one of two target pictures (a heart or flower) appeared on the left or right side of a laptop computer screen. Children were asked to press one of two buttons on opposite sides of the laptop keyboard corresponding with the picture's location on the screen. When a heart appeared, children were instructed to press the button that corresponded to the same side of image presentation. When a flower appeared, children were asked to press the button on the opposite side of image presentation. Children's accuracy was measured as the percent correct on 33 trials of mixed hearts and flowers.

2.3.3.3. Fish flanker. The Flanker task was developed based on work by Rueda et al. (2004) and provides a measure of inhibitory control. The task requires participants to focus on a target stimulus while inhibiting attention to stimuli flanking it. For the present study, a target fish flanked by two fish on either side was presented on a laptop computer screen. Participants were instructed to press one of two "fuzzy buttons" on the keyboard corresponding to the direction in which the middle fish was pointing. On congruent trials, all of the fish were pointing in the same direction. On the incongruent trials, the flanker fish were facing the opposite direction of the target fish. Congruent and incongruent trials were mixed during test trials. Accuracy was measured as the percent correct during the text trials. This measure has been found to be reliable and valid (Zelazo et al., 2013).

2.3.4. Classroom quality

Classroom quality was measured in the spring of the child's kindergarten year using the K-3 Classroom Assessment Scoring System (CLASS; Pianta et al., 2006). Research indicates stability in classroom quality across the fall and spring semesters (Pianta et al., 2006). Therefore, spring classroom ratings can serve as a good indication of the classroom quality that the children experienced at the start of their kindergarten year. The CLASS is an observational measure designed to assess classroom organization, instructional support, and emotional support. Validity for the CLASS has been obtained (Hamre et al., 2007).

In the present study, each classroom was observed and rated starting at the beginning of the school day in four 20-min segments. Ratings were made on a 7-point Likert scale ranging from "low" to "high." To establish reliability, raters watched and scored five 20-min video segments with no feedback or discussion. Raters had to score within 1 of the master code on 80% of all codes across segments and score within 1 of the master code on each dimension on at least 2 of the 5 segments to be considered reliable. Correlations among the classroom organization, instructional support, and emotional support scores ranged from .53 to .85 (all $p < .01$), and were standardized and averaged to form a total *Classroom Quality* score (alpha = .82).

2.3.5. Math achievement

Math achievement was measured in the fall and spring with the Applied Problems subtest of the Woodcock–Johnson Tests of Achievement (Woodcock et al., 2001). In this task, the child was asked to perform mathematical calculations in response to problems presented orally or visually. Evidence of reliability and validity has been obtained (Woodcock et al., 2001). W scores were used in the present analyses. Alpha reliability was .70 and .73 for the fall and spring scores, respectively. Test-retest reliability in the sample was .37.

2.3.6. Covariate

Socioeconomic status was indicated by the percent of children who received free or reduced lunch at the school. Age was considered as a covariate, but did not meet the requirement of correlation with a predictor and the outcome for inclusion in the analyses (See Table 2).

2.4. Data analyses

Descriptive statistics and correlations between the major study variables were examined. Next, substantive analyses were conducted using 2-level multi-level modeling to account for nesting of students within classrooms, and full information maximum likelihood to account for missingness. We first tested an unconditional means model (Model 1), in which only the intercept of math

Table 1
Descriptive statistics for study variables.

Variable	Statistic				
	N	Min.	Max.	Mean	*SD*
Fluid intelligence	159	.00	11.00	7.92	2.14
Crystallized intelligence	157	4.00	16.00	11.82	1.97
Executive functioning	163	.24	.93	.68	.15
Classroom quality	171	−2.28	1.79	.00	.88
Fall math achievement	151	382.00	481.00	432.72	17.53
Spring math achievement	160	393.00	490.00	442.71	16.61
Free-reduced	171	.05	.92	.34	.30

Table 2
Correlations among study variables (*n* ranges from 140 to 171).

Variable	1	2	3	4	5	6	7
1. Fluid intelligence	1						
2. Crystallized intelligence	.09	1					
3. Executive functioning	.21**	.39**	1				
4. Classroom quality	.08	.21**	.15*	1			
5. Fall math achievement	.34**	.44**	.58**	.21**	1		
6. Spring math achievement	.29**	.44**	.56**	.37**	.72**	1	
7. Free-reduced	−.14	−.38**	−.36**	−.61**	−.48**	−.50**	1
8. Age	.12	.12	.33**	−.12	.24**	.15	.02

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

achievement at the end of the kindergarten year was modeled. The equation for the unconditional means model is $y_{ij} = \beta_0 + u_{0j} + \varepsilon_{ij}$. In this equation, β_0 represents the intercept, u_{0j} represents the classroom effect, and ε_{ij} represents error. We assume that $u_{0j} \sim N(0, \sigma^2_{u0})$ and $\varepsilon_{ij} \sim (0, \sigma^2_{\varepsilon 0})$ and are independent of one another, with *i* representing students and *j* representing classrooms.

Next, we tested a random intercept and fixed slope main effects model (Model 2) by adding the covariate, fall math achievement, and the predictors to the model. The interaction terms were added in a final model (Model 3), which included the focal interactions of classroom quality with each cognitive predictor. Level 1 variables were group mean centered because the main research question involves an interaction between a level 1 predictor (cognitive ability) and the level 2 predictor (classroom quality) (Enders & Tofighi, 2007). Because fall math achievement was included as a predictor in the analyses, we were actually predicting change in math achievement from fall to spring. We estimated R^2 using the Snijders and Bosker's (1994, 1999) approach and the values were interpreted using Cohen's (1992) guidelines. Because interaction effects were exploratory in nature and intended to generate hypotheses for future research, a .10 alpha level was used for interpretation (Durand, 2013). Significant interactions were probed by computing simple slopes at one standard deviation above and below the mean of classroom quality (Aiken & West, 1991). The effect size for the interaction was determined by computing the proportion in reduction in residual variance (Peugh, 2010).

3. Results

The means and standard deviations for the study variables are displayed in Table 1. Missingness ranged from 0% (classroom quality) to 12% (fall math scores). Scores were not related to missingness. Correlations among the variables are in Table 2. All three aspects of cognition were significantly related to spring math achievement. Additionally, the correlations for executive functioning and crystallized intelligence with math achievement were the strongest. In contrast, math achievement was less strongly related to fluid intelligence. A follow-up test of dependent correlations revealed significant differences between the correlations for fluid intelligence and executive functioning. Nevertheless, the links between cognition and math achievement may differ in different classroom contexts and when fall math achievement scores are controlled.

Results of the multilevel modeling analyses are in Table 3. In this table, R^2 values were computed using Model 1 as the baseline model. Examination of the unconditional means model revealed that the intraclass correlation (ICC) was .32, indicating that differences across classrooms accounts for 32% of differences in spring math achievement. These results suggest that modeling the nested structure is best for these data.

Examination of Table 3 shows that at the child level, the random intercept-fixed slope model reduced prediction error of math achievement by a large amount ($R^2_1 = .55$). At the classroom level, the model also reduced the prediction error of the baseline model by a large amount for each school ($R^2_2 = .66$). However, there were no main effects for the cognitive ability variables or classroom quality.

Similar to the main effects model, the effect sizes for levels 1 and 2 were large in the cross-level interaction model. Moreover, the proportion in reduction in residual variance that resulted from adding the interaction terms was 13%. There were significant interactions between classroom quality and fluid intelligence, and classroom quality and crystallized intelligence, which were probed by computing simple slopes at one standard deviation above and below the means of classroom quality (Aiken & West, 1991). Within classrooms of poorer quality, the children with higher fluid intelligence did not make significant gains (significant at the .05 alpha level at 3.24*SD* below the mean; See Fig. 1). On the other hand, within classrooms of higher quality, children with higher fluid intelligence made significantly greater gains compared to children with lower fluid intelligence (See Fig. 1). Similarly, within classrooms of higher quality, children with higher levels of crystallized intelligence made greater gains in math achievement compared to children with lower crystallized intelligence. In classrooms that were poorer in quality, there was a non-significant association between crystallized intelligence and math achievement (See Fig. 2). The interaction between executive functioning and classroom quality was not significant.

4. Discussion

Although attendance in kindergarten is not required for children in the United States, it is nevertheless the first year of formal schooling for most children (La Paro et al., 2009). Therefore, understanding the impact of the classroom environment on changes in achievement in the kindergarten year is important, as kindergarten achievement is strongly related to achievement in later years (Claessens & Engel, 2013; Duncan et al., 2007). In the present study, we examined distinct aspects of cognition as predictors of math achievement in the kindergarten year. We also explored the role of classroom quality in these associations.

More specifically, we examined fluid intelligence, crystallized intelligence, and executive functioning in the context of classroom quality as predictors of math achievement in the spring of the child's kindergarten year. Analyses revealed that fluid intelligence, crystallized intelligence, and executive functioning were each positively related to spring math achievement. The strongest zero-order relations were found for crystallized intelligence and executive functioning whereas fluid intelligence was less strongly related to math achievement in this kindergarten sample, although only the correlation between fluid intelligence and executive functioning differed significantly from each other. These findings are

Table 3
Multi-level analyses predicting math achievement.

Model	1. Unconditional			2. Main effects			3. Interaction		
Variable	B	SE	df	B	SE	df	B	SE	df
Intercept	442.48**	2.01	31.21	443.12**	1.34	21.50	443.09**	1.32	22.69
Free reduced				−24.49**	5.39	20.22	−23.93**	5.31	21.61
Fall math achievement				.41**	.08	98.93	.37**	.07	100.56
Fluid intelligence				.59	.70	131.49	.73	.67	130.85
Crystallized intelligence				.82	.55	95.65	1.22*	.53	97.03
Executive functioning				15.08	7.97	98.41	15.82*	7.63	100.29
Classroom quality				1.99	1.88	19.27	1.47	1.86	20.66
Fluid intelligence × classroom quality							1.97*	.83	135.75
Crystallized intelligence × classroom quality							1.14*	.51	98.88
Executive functioning × classroom quality							.22	7.80	97.89
	Variance component			Variance component			Variance component		
Residual	189.85	23.80		95.23	13.92		84.30	12.23	
Intercept	88.07	33.22		29.93	17.15		30.72	16.08	
		Model fit			Model fit			Model fit	
−2 Log likelihood		1330.76			1047.07			1032.95	
$R^2{}_1$		0			.55			.59	
$R^2{}_2$		0			.66			.65	

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

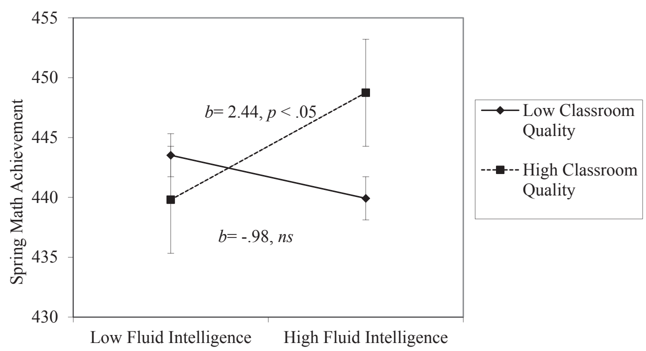

Fig. 1. Interaction between fluid intelligence and classroom quality.

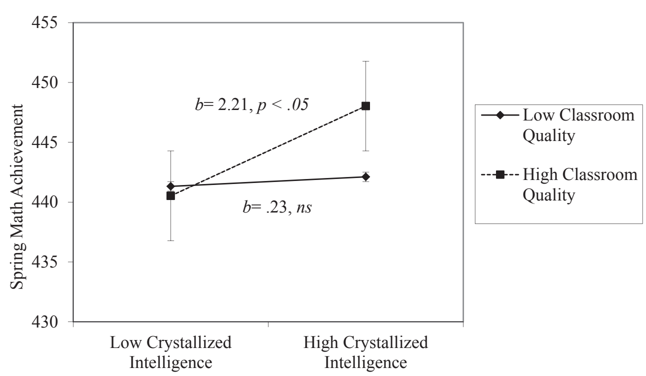

Fig. 2. Interaction between crystallized intelligence and classroom quality.

somewhat consistent with research by diSibio (1993) in which Verbal IQ was more strongly related to math achievement in kindergartners than was Performance IQ. Contrarily, Floyd et al. (2003) found moderate relations of fluid intelligence and crystallized intelligence with math achievement. In general, not much research has been conducted on these different aspects of cognition and math achievement in the same sample of participants.

Moreover, the role of contextual factors, such as classroom quality, in the relation between cognition and achievement has not been fully examined. Hence, the primary aim of the present research was to determine if the link between cognition and math achievement differed across different classroom contexts. When classroom quality was entered as a predictor along with cognition, the cognitive variables were no longer significant independent predictors of achievement. Instead, the effects of fluid intelligence and crystallized intelligence were moderated by classroom quality.

The effect of fluid intelligence on math achievement was seen among children in higher quality classroom environments. Children who enter school with higher levels of fluid intelligence may be hindered in their development if placed in classrooms that are not well organized, do not provide instructional support, or in which teachers are not emotionally supportive. Students with high fluid intelligence but in unorganized classrooms, classrooms with poorer instructional support, or in classrooms in which teachers are not emotionally responsive may grow bored with tasks, leading to subsequent apparent academic difficulties. Contrarily, children who enter school with higher levels of fluid intelligence may be supported in their development if placed in classrooms that are well organized, provide instructional support, or in which teachers are emotionally supportive. Students with high fluid intelligence but in poorer quality classrooms do not see the same benefits of their fluid intelligence.

Crystallized intelligence was also found to be most beneficial in classrooms that were of higher quality. In classroom environments that are more organized, emotionally supportive, or provide high levels of instructional support, appropriate opportunities and materials are available for pupils, learning opportunities are maximized, and teachers are sensitive to the needs of individual children (La Paro et al., 2009; Pianta et al., 2006). Results of the present research suggest that children who have strong crystallized intelligence, as indicated by vocabulary in the present study, may be better able to express their needs to their teachers in these quality classrooms. Such children may then benefit from instruction that is particularly targeted to the specific child.

Results did not reveal any interactions between executive functioning and classroom quality in predicting change in math achievement in the kindergarten year. Recently, increased research has been conducted on the link between executive functioning skills and achievement in the pre-kindergarten and kindergarten years, with findings that executive functioning plays an important role in predicting achievement. Interventions have also been designed to enhance executive functioning skills in kindergarten students. Previous literature has often examined executive functioning skills as a predictor of math achievement independently of classroom quality. When considered in isolation, executive functioning does correlate with math achievement in the present study, similar to the findings of previous research (e.g., Blair & Razza, 2007). However, that, executive functioning did not significantly predict change in math achievement independent of classroom quality highlights the importance of classroom quality in early math achievement.

There are several restrictions of the present research that should be noted, however. First, the high correlations among the classroom quality variables precluded examination of the different aspects of the classroom environment. Therefore, it is difficult to pinpoint specific aspects of quality that interacted with fluid and crystallized intelligence in the prediction of math gains. Further research should be conducted to determine whether specific aspects of classroom quality can be identified or whether global classroom quality is what matters most.

Additionally, under the theory of fluid and crystallized intelligence, which was adopted in the present research, fluid reasoning skills are often measured using matrix reasoning tasks and crystallized intelligence is often measured using tasks such as vocabulary (Horn & Blankson, 2012). Thus, the indicators that were examined in the present study are commonly used in the field. The interaction effects of classroom quality with fluid and crystallized intelligence appear to be consistent with the theory of fluid and crystallized intelligence (Horn & Blankson, 2012). According to the theory, fluid reasoning skills are the invested in learning and subsequently bring about other abilities, such as achievement (Cattell, 1987). In line with the investment hypothesis, results of the present research suggest that opportunities for investment in the learning must be present for fluid intelligence to be most beneficial to students. Within classrooms of poorer quality, children with higher fluid intelligence did not make significant gains in math when compared to children with lower fluid intelligence. Within better quality classrooms, however, those children with higher levels of fluid intelligence made greater gains than their counterparts in poorer quality classrooms due to greater availability of opportunities for their fluid abilities to bring about achievement. Nevertheless, we examined only one indicator of fluid intelligence and one indicator of crystallized intelligence. We predict that results obtained by using additional indicators of these constructs would be similar to the results obtained in the present study. However, further research should be conducted that includes more than one measure of crystallized and fluid intelligence to determine if results replicate.

Despite these restrictions, results of the present research indicate that greater attention should be placed on enhancing classroom quality within the US. Children can enter kindergarten “ready to learn”, that is, with strengths in fluid and crystallized intelligence, but when they get to school, can fail to achieve to their full potential in math due to poor classroom quality. Interventions, policies, and programs that focus solely on enhancing school readiness skills, but that do not consider classroom characteristics, may prove futile. To become more competitive globally, US must make strides to decrease the math achievement gap when compared with other industrialized nations. Because early math achievement sets a path for later math achievement, focus on the early classroom environment is paramount.

5. Conclusion

The results of the present study add to the extant literature in at least three ways. Foremost, past research has often studied cognition as a single factor. A strength of the present research is that we examined all of the cognitive variables in one model. The results provide further support to the argument that specific aspects of cognition should be examined in investigations of academic achievement (Hale et al., 2008; McGrew & Wendling, 2010).

Secondly, the results expand our understanding of the theory of fluid and crystallized intelligence, generally, and Cattell's (1987) investment hypothesis more specifically. When adequate opportunities for learning are not available, fluid intelligence alone does not result in achievement. It is when adequate opportunities are available that children are able to invest their fluid intelligence in learning to bring about achievement.

Finally, although previous research has indicated that children fare better in classrooms of better quality (e.g., Hamre & Pianta, 2005; Perry et al., 2007) and that children who enter school with stronger cognitive skills will also fare better (e.g., Fuhs et al., 2014), the results of the present study provide some support for an aptitude by treatment interaction between classroom quality and cognitive ability (Cronbach & Snow, 1977; Pellegrino et al., 1999; Snow, 1992). By examining specific aspects of cognition within different environmental contexts, we can better unpack the factors that lead to early academic success and failure, ultimately leading to development or enhancement of interventions and programs to promote optimal development in children.

Classroom quality may play a stronger role in changes in math achievement over the kindergarten year than do fluid and crystallized intelligence at kindergarten entry alone, which has implications for classroom policies and interventions. Hence, further attention should be paid to enhancing classroom quality in future policies, training programs, and interventions. Because no studies to date have examined fluid intelligence, crystallized intelligence, and executive functioning in concert with classroom quality as predictors of math gains, the present findings strengthen our understanding of role of the classroom quality and cognition in early math achievement.

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