Kindergarten Predictors of Third-Grade Reading, Math, and Science Achievement: The Influences of Self-Regulation and Early Language Development

Dominic F. Gullo[1]

[1] Drexel University, Philadelphia, USA

Correspondence: Dominic F. Gullo, Drexel University, Philadelphia, USA.

Abstract

Young children's self-regulation (executive function; approaches to learning) and early language functions have been shown to independently predict children's achievement in school, particularly reading and mathematics. Controlling for SES, gender and age at kindergarten entry, hierarchical multiple regression was used to test the hypothesis that children's executive functions, approaches to learning, and early language functions at the beginning of kindergarten would predict third-grade reading, mathematics, and science achievement. Third-grade is a benchmark year as it usually marks the beginning of standardized testing and plays a pivotal role in determining children's academic trajectories. Data from the Early Childhood Longitudinal Study Kindergarten Class of 2010-2011 (ECLS-K: 2011) were used to test the hypotheses. The hypothesized models suggest that executive function, approaches to learning, and language functions measured at the beginning of kindergarten are predictive of third-grade academic achievement. While the factors were individually predictive, the regression model was the strongest when it included the factors collectively. Implications for both policy and practice are noted.

Keywords: self-regulation, language development, kindergarten

1. Introduction

Self-regulation developed during the early childhood years is seen by some as an "early life marker for later life successes" (Montroy, et al. 2016, p. 1744). Self-regulation can be described as one's capacity to understand and manage their behavior and their reactions to things happening around them, including management of their feelings. A meta-analysis of 150 studies (Robson, et al., 2020) found that prekindergarten children's ability to self-regulate was positively associated with school engagement and academic achievement, while children's ability to self-regulate during the early school years was positively associated with literacy and mathematics achievement. Studies concluded that young children's ability to self-regulate is critical for predicting school achievement outcomes later in life.

Executive functions (EF) and approaches-to-learning (AtL) are two components of children's self-regulation. Individually, both components of self-regulation have been shown to be critically important for young children's positive development and academic growth (Diamond, 2013; Sung & Wickrama, 2018; Valcan, et al., 2020; Vitiello & Greenfield, 2017). EF are cognitive skills that facilitate an individual's planning, learning, and problem-solving (Diamond, 2013). They are involved in one's intentional control of goal-directed cognitive tasks, including attention, thinking, impulses, and behaviors (Hughes, 2011; Zelazo, 2004). EF includes three types of cognitive processes: (a) inhibitory control which is the ability to restrict or delay impulsive reactions in the process of task completion; (b) working memory, which is part of short-term memory, permits one to hold onto information for a short period of time in order to process it and manipulate it; (c) cognitive flexibility refers to the cognitive system's ability to shift both operations and focus. This involves transitioning among task rules and their associated behavioral responses, concurrently holding multiple concepts, and seamlessly shifting internal attention among them (Morgan, et al., 2019; Vulcan, et al., 2020). AtL refers to the various strategies or styles employed when acquiring new knowledge, skills, or understanding. It encompasses how individuals approach and engage in the process of learning. AtL includes such things as task persistence, attentiveness, and eagerness to learn (Gullo & Impellizeri, 2022; Li-Grining, et al., 2010; McDermott, et al., 2014).

Concomitant with self-regulation, early language development skills have been identified as predictors of children's later academic performance (Dolean, et al., 2021; Montroy, et al., 2016). Social communication skills (Ramsook, et al., 2020) and vocabulary development (Muter, et al., 2004) are the two aspects of language development skills that have been identified as early predictors of later school achievement.

While there is considerable research investigating the predictive associations of self-regulation as a single dispositional variable (Luszczynska, et al., 2004), there has been little or no research examining the predictive associations between the interface of the components of self-regulation (EF and AtL) and early language development skills with achievement. Controlling for demographic factors shown to influence children's academic trajectories (sex, SES, kindergarten entry age), the purpose of this investigation was to elucidate whether children's self-regulation (EF and AtL) and language development skills at the beginning of kindergarten were predictive of end of third-grade achievement in reading, mathematics, and science.

The end of third-grade holds considerable importance as a pivotal milestone in young children's early learning experiences. First, the end of third-grade commonly marks children's entry into the world of standardized testing. The consequential impact of these assessments on children's academic trajectories is significant (Jordan, Kaplan, Ramineni, & Locuniak, 2009). Second, the end of third-grade symbolizes children's transition from acquiring fundamental concepts and skills related to literacy and mathematics to effectively applying these foundational concepts for future learning. This shift is instrumental in fostering higher-level conceptual understanding and problem-solving abilities across domains. Knowing the role that early self-regulation and language development play in later academic development can help guide early childhood policy and practice. Previous research focused primarily on earlier or later grades when gauging the predictive association between kindergarten behavioral variables and later achievement.

2. Executive Functions and Early Academic Achievement

Recent research underscores the role that EF play in shaping academic trajectories of young learners. EF encompass a set of cognitive processes including working memory, cognitive flexibility, and inhibitory control. These processes enable individuals to plan, organize, and regulate their behavior to achieve specific goals (Diamond, 2013). Working memory has been identified as a critical factor in early academic achievement, particularly in reading comprehension and mathematical problem-solving (Gathercole & Alloway, 2008). Children who have well-developed working memory are better equipped to retain and apply information. This enables them to engage in complex cognitive tasks more effectively. Cognitive flexibility is also crucial for academic success. Anderson (2002) emphasizes the importance of cognitive flexibility in the child's ability to adapt to changing situations and seamlessly switching between tasks. Children with high cognitive flexibility navigate academic challenges more effectively. They demonstrate the ability to adapt to differing learning styles and instructional approaches. Finally, inhibitory control plays a crucial role in maintaining focus and resisting distractions in academic or other types of settings. Inhibitory control is essential for tasks requiring sustained attention, such as reading and problem-solving (Blair & Razza, 2007). A child with well-developed inhibitory control can regulate impulses, resist urges to engage in off-task behaviors, and maintain his or her concentration on relevant information for the task at hand.

The trajectory of EF is not uniform across all children. Various factors influence their development. Including personal attributes and demographic characteristics (Best & Miller, 2010; Montroy, et al., 2016). Positive and stimulating environmental experiences providing opportunities for exploration and spontaneous problem-solving contribute to the establishment of robust EF, thus laying the foundation for early academic achievement. Studies have shown that preschool aged children with strong EF performed higher on preschool assessments in pre-literacy knowledge and skills, vocabulary, mathematics, and science (Bierman, et al., 2009; Nayfeld, et al., 2013). Studies suggest that EF may be important in successful transitioning to formal schooling (Blair & Razza, 2007).

3. Approaches to Learning and Early Academic Achievement

AtL is a broad term describing a set of children's learning related behaviors and dispositions that reflect their enthusiasm for and engagement in learning activities (Hyson, 2008). They are discernable patterns and characteristics that children display when engaged in learning activities (Fantuzzo, et al., 2004; Hair, et al., 2006). They include such elements as flexibility, persistence, engagement, curiosity, frustration tolerance, and self-direction. These elements have been proven to influence academic achievement in multiple contexts by creating increased learning opportunities for children. The behaviors and dispositions associated with AtL result in children's being able to follow directions, persist in difficult tasks, engage in creative problem-solving, be independent while engaged in the tasks of learning, and work both independently as well as cooperatively with

their classmates (Razza, Martin & Brooks-Gunn, 2015). AtL, assessed in kindergarten, has been shown to be predictive of both literacy and mathematics performance through the elementary years (Li-Grining, Votruba-Drzal, Maldonado-Carreño, & Haas, 2010). Interestingly, kindergarten ATL also had the most impact on children's school performance during the elementary school years for those whose initial achievement scores were the lowest (Bodovski & Farkas, 2007; Li-Grining et al., 2010).

Children with positive AtL are more likely to have positive academic outcomes in early childhood (Bustamante, et al., 2017; Razza, et al., 2015). Having poor AtL may be considered a risk-factor as children transition from preschool or kindergarten into the elementary school grades (McClelland, et al., 2000). Positive AtL may serve as a protective-factor as children transition to the elementary grades (McClelland, et al., 2000; McWayne, et al., 2004; Yen, et al., 2004). While early AtL, and its influence on later academic achievement has not been studied to the extent that EF has been studied, there is growing evidence that positive AtL has a positive effect on children's academic performance in school. What has not been examined is how early EF and AtL together influence children's later academic performance in school.

4. Language Development Skills and Early Academic Achievement

Research studies have established correlations between early language development and subsequent academic achievement (Dolean, et al., 2021; Ramsook et al., 2020). This is particularly evident when examining early vocabulary development and social communication skills. A more expansive vocabulary helps children effectively recognize words in written form, thus, improving comprehension (Muter, et al., 2004). Vocabulary plays a pivotal role in developing code-related skills that are crucial for learning to read (Mitchell & Brady, 2013). Together, children's vocabulary and code-related skills have been shown to predict reading achievement in later grades (Storch & Whitehurst, 2002). There is also evidence suggesting that vocabulary impacts mathematics achievement. A larger vocabulary may assist in the comprehension of mathematical concepts that are presented verbally during classroom instruction as well as in story or word problems (Powell & Nelson, 2017). Acquiring new words involves creating symbolic labels for abstract concepts; a skill fundamental to early mathematics and scientific understanding where children must connect words with numerical and scientific concepts (LeFevre, et al., 2010). Studies indicate that the vocabulary of young children is associated with symbolic skills and problem-solving, even when controlling for other cognitive abilities (Purpura & Ganley, 2014). Social communication skills are described as the appropriate use of language in social settings (Ramsook, et al., 2020). Kindergarten readiness often hinges on a child's capacity to express desires, needs, and thoughts (Lin, et al., 2003). Challenges in social communication encompass difficulties seeking appropriate academic or social/emotional support, articulating points-of-view or ideas, utilizing language for collaboration and conflict resolution, as well as initiating, sustaining, or concluding conversations (Landa, 2005).

5. Demographic Factors Affecting Early Achievement

A number of demographic factors have been shown to influence children's early developmental and achievement trajectories. Among the most salient are children's age at the start of kindergarten, the child's gender, and the socioeconomic status (SES).

5.1 Kindergarten Entry Age

The effect that kindergarten entry age has on children's short- and long-range academic achievement has been the subject of considerable research and debate (e.g., Fletcher & Kim, 2016; Larsen, et al., 2021; Stipek & Byler, 2001). There are several factors that may contribute to the varying effects of entry age on academic achievement. Children who enter kindergarten at an older age may have a developmental advantage (NICHD, 2007). They may demonstrate better social, emotional, and cognitive readiness. This may lead to initial academic prowess compared to their younger peers. Older children may experience a smoother social and emotional adjustment to the initial school experience (Finders, et al., 2022; Gottfried, et al., 2019). They might possess greater self-regulation and interpersonal skills that may positively impact their ability to engage in classroom activities and social engagement. While children who are older when they enter kindergarten may demonstrate social and cognitive advantages, these may be short-term advantages. Research suggests that these advantages diminish over time and by the later grades, any initial gaps in development and/or academic achievement may narrow or completely disappear (Fletcher & Kim, 2016; Johnson & Kuhfeld, 2021; Larsen, et al., 2021).

Young children vary widely in their development and the impact of kindergarten entry age can be influenced by individual differences. Some young children may thrive academically while some older children may have difficulties. Some of these individual differences may be inherent in the child, while others may emanate from external sources. Two such influences are the child's gender and SES.

5.2 Gender

Children's early cognitive and academic skills are demonstrably important to later school success. Gender has been found to influence both adjustment to school and achievement during these early years (Cantalini-Williams, et al., 2016). Gender differences do not always exist, but when they do, it is typically found that boys perform better in numeracy (Cobb-Clark & Moschion, 2017; Williams et al., 2016), and girls perform better in literacy (Boardman, 2006; Cobb-Clark & Moschion, 2017). It was also found that boys, more than girls, were likely to exhibit more problem behaviors in the classroom and have significantly lower social skills (Bulotsky-Shearer; et al., 2012). Janus and Duku (2007) found that boys were more than two times more likely to be vulnerable to low academic readiness scores in kindergarten.

According to Cobb-Clark and Moschion (2017), there are multiple potential explanations for the gender disparities found in early school performance. They include: biological differences (e.g., spatial vs verbal learning); gender specific expectations (particularly from parents and teachers); social and cultural differences (related to expectations for boys and girls); gender differences in the acquisition of social and behavioral skills; and gender specific practices in educational settings (including teacher bias).

5.3 Socioeconomic Status

The influences of SES on children's development, behaviors, and academic performance are well documented in the literature (Engle & Black, 2008; Gullo, 2018; Isaacs, 2012). Deleterious effects of residing in low-SES home environments can be seen as early as the second year of life. These effects can extend through the elementary school years and into high school (Entwisle, et. al., 2005). When risk factors associated with poverty are present during the preschool and kindergarten years, they shape the course of school readiness and subsequent academic achievement trajectories. It has also been determined that school readiness potential sets the path for future school performance and success (Zigler, et. al., 2006), and is predictive of most education benchmarks including test scores, grade retention, special education placement, and dropout rates. Children who start kindergarten developmentally and academically behind their age-mates can almost never close the achievement gap, but rather, the gap widens as they progress through their years in school (Lee & Burkam, 2002).

6. The Present Study

The purpose of this investigation was to determine whether children's beginning of kindergarten self-regulation (EF and AtL) and language development skills were predictive of their end of third-grade reading, math, and science achievement. There are a number of ways that the present investigation adds to the existing knowledge-base in this area of study. As such, the present study not only adds to the extant literature knowledge but also in its comprehensive and integrated design, ameliorates some of the shortcomings in previous research. First, while previous studies have investigated how the independent variables in this study individually predicted achievement, they did not examine how these variables worked together in longitudinal predictive models. Second, in previous studies, student achievement was primarily limited to reading and mathematics. The present investigation also included science achievement, a little explored achievement area in these kinds of studies. Third, when previous investigations used kindergarten EF, AtL and language development as variables, they used data from the end of kindergarten. The present study used EF, AtL, and language development data from the beginning of kindergarten, therefore eliminating the effect that the kindergarten experience had on these developmental elements. There is less chance, therefore, that the influences of EF, AtL, and language development were due to kindergarten curriculum and teaching. Finally, in previous studies, control variables were limited to one or two, or were not used at all. The present study included three demographic control variables shown to young children's academic performance.

Therefore, controlling for SES, gender, and kindergarten entry age, specific research questions include:

1. Are children's beginning of kindergarten EF predictive of end of third-grade achievement in reading, mathematics, and science?
a. Are the predictive associations the same for all types of executive functions?
b. Are the predictive associations the same across all types of achievement?
2. Are children's AtL and language development at the beginning of kindergarten predictive of end of third-grade achievement in reading, mathematics, and science? Are the predictive associations the same across all types of achievement?

6.1 Methods

Data from the Early Childhood Longitudinal Survey – Kindergarten Class of 2010-2011 (ECLS-K: 2011) were analyzed for this study (Tourangeau, et al., 2018). The ECLS-K: 2010 includes a nationally representative

sample of children (N = 18,174), their families, teachers, schools, and childcare providers. Data collection began in 2010 when children entered kindergarten. Data collection concluded when children were in fifth-grade in 2015.

For the present investigation, children were included in the sample if they were first time kindergarteners, did not have an IEP on file at the end of kindergarten, and their home language was English. This resulted in a total sample of 9381 children (49% boys; 51% girls). The following racial groups were represented in the sample: 61% Caucasian; 14% African-American; 14.2% Hispanic; 3.6% Asian; 5.7% two or more races; and 1.5% American Indian/Alaska Native and Native Pacific Islander. The mean age of the children when they entered kindergarten was 66.63 months (SD = 4.16).

6.2 Measures

Multiple measures from the ECLS-K: 2011 were used for this study. The dependent variables for this study were third-grade literacy, mathematics, and science achievement scores. Control variables for this study were children's gender, kindergarten entry age, and SES. Independent variables included beginning of kindergarten: (a) teacher ratings of children's AtL, (b) children's oral language ability, and (c) three indicators of executive functioning (working memory, cognitive flexibility, inhibitory control).

6.2.1 Literacy Assessment

End of third-grade literacy achievement was assessed in three areas: basic word skills (including sight-word recognition), vocabulary knowledge, and reading comprehension. Reading comprehension questions were generated through short passages requiring students to respond to factual and inferential questions. The quality and appropriateness of the passage children read was evaluated by them. Children received a score on 19 routing items. The child's score on the routing items determined which second-stage assessment they would receive (low, middle, or high difficulty). This procedure was used to maximize assessing the child's full potential in a limited amount of time (Tourangeau et al., 2018). Internal consistency for the end of third-grade reading assessment was .87.

6.2.2 Mathematics Assessment

End of third-grade mathematical achievement was assessed in the following areas: conceptual knowledge; procedural knowledge; problem-solving knowledge. The assessment focused on number sense, properties, operations, measurement, geometry and spatial sense, data analysis, statistics and probability, patterns, algebra, and functions. Children completed a routing section consisting of 17 items that varied in difficulty, and then students were evaluated by level of ability. The text for word problems or graph labels was read orally to the students by trained assessors, and paper and pencil were offered (Tourangeau et al., 2018). Cronbach Alpha internal consistency was .92.

6.2.3 Science Assessment

End of third-grade science achievement was assessed in the following areas: scientific inquiry; life science; physical science; Earth and space science. An expert panel of educators, including curriculum specialists, examined a pool of items in the above four areas for content, framework design, accuracy, non-ambiguity of response options, and appropriate presentation formatting. Items were included in a field test and the better performing items were included in the final ECLS-K: 2011 science assessment battery. Cronbach Alpha internal consistency was .83.

Item Response Theory (IRT) scores for the reading, mathematics, and science assessments were used for analysis. IRT scores make it possible to compare the performance of children's strengths regardless of which items they were administered. By using a two-stage assessment method, all students are given the same core set of items (the routing items) and another set of items that are common within groups of students that are either ranked as low, middle, or high difficulty. IRT considers right or wrong answers to the items and the difficulty of item and can estimate a child's ability based on the same continuous scale. Further, IRT scoring allows for longitudinal measurement gains in achievement to be analyzed regardless of when a child completed the assessments (Bortolotti, et al., 2013).

6.2.4 Approaches to Learning

Teachers' ratings of children's AtL at the beginning of kindergarten were assessed using seven items in the child-level teacher questionnaire: (keeps belongings organized; shows eagerness to learn new things; works independently; easily adapts to changes in routine; persists in completing tasks; pays attention well; and follows classroom rules). Using a Likert Scale, teachers reported how often each child exhibited the learning behaviors

delineated above (never, sometimes, often, very often). Items were based on items in the Social Skills Rating System (Gresham & Elliot, 1990). The child's AtL score was the mean rating of the seven items listed above. The AtL scale for teachers has a Cronbach's alpha reliability estimate of .91.

6.2.5 Language Development Skills

In the ECLS-K study, a language screening tool was employed, consisting of three distinct subtests from the preLAS 2000 assessment (Duncan & DeAvila, 1998): "Simon Says," which gauged listening comprehension, "Art Show," designed to assess picture vocabulary, and "Let's Tell Stories," which evaluated a child's natural speech. Initially, this screening assessment was exclusively administered to children identified as language minority students. In the ECLS-K: 2011, the assessment approach evolved, and only two of the preLAS subtests, namely "Simon Says" and "Art Show," were retained for screening English language proficiency. Data from the preLAS subtests were included in the data file for all children to whom these assessments were administered, regardless of their home language. The preLAS subtest total score was used for analysis in this study. Alpha coefficients for the preLAS ranged from .69 to .97.

6.2.6 Executive Function – Working Memory

Children's working memory was assessed through the Numbers Reversed subtest from the Woodcock-Johnson III Tests of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001). This particular task is a well-established and dependable indicator of working memory (Flanagan, McGrew, & Ortiz, 2000). It has a reliability coefficient of 0.87 (Schrank, 2011). In the assessment, children were verbally presented with five two-number sequences (e.g., "2, 7"). The children were then asked to restate the number sequence in reverse order (e.g., "7, 2"). The assessment continued until either they successfully completed eight-number sequences or provided three consecutive incorrect responses. Standardized W scores (Jaffe, 2009) were used in analyses as recommended by the test publishers (Mather & Woodcock, 2001). The W scale is an equal-interval scale that facilitates the measurement of ability level and item difficulty on the same scale.

6.2.7 Executive Function – Cognitive Flexibility

Cognitive flexibility was evaluated through the use of the Dimensional Change Card Sort (DCCS) assessment, developed by Zelazo (2006). The DCCS is a well-established tool for measuring cognitive flexibility. The DCCS exhibits a strong test-retest reliability ranging from .90 to .94 (Beck, et al., 2011). Children from kindergarten to first-grade are individually asked to categorize 22 picture cards employing a specific sequence of rules: first by color, then by shape, and then by border. To advance to the border sorting task, children needed to accurately sort four out of six cards by shape. Cards with black borders were to be sorted by color, while the rest were to be sorted by shape. A cumulative score was computed by combining the scores from all three tasks. The Card Sort combined score was used for analysis.

6.2 8 Executive Function – Inhibitory Control

During the fall of children's kindergarten year, teachers were asked to rate children using the *Children's Behavior Questionnaire* (CBQ: Putnam & Rothhart, 2006). The ECLS-K: 2011 data file includes two scale scores for attentional focus from the CBQ. The mean of these two scores were used as an indicator for inhibitory control. To obtain these two scores, teachers were asked observe and rate children's behavior in response to the following two statements: decide whether it is a "true" or "untrue" description of this child's reaction to a number of situations withing the past six months: (1) when practicing an activity, has a hard time keeping her/his mind on it; (2) is easily distracted when listening to a story. Ratings ranged from 1 (extremely untrue) to 7 (extremely true), therefore a higher score indicated that teachers rated children as engaging in a specific behavior more often. The "Attentional Focus" subscale's reliability coefficient was .87 between the fall and spring of the kindergarten year's data collection.

6.2 9 Demographic Characteristics

A composite variable for SES was created during the base year of data collection. SES was computed at the individual household level and included the following components: father/male guardian's education; mother/female guardian's education; father/male guardian's occupation; mother/female guardian's occupation; and household income. Each of these indices was standardized so that the mean was "0" and the standard deviation was "1." The children's parents reported both their education and occupation during the fall of the kindergarten year. Parent's education was coded as follows: 1 = completed grade 8 or below; 2 = completed grades 9 – 12; 3 = high school diploma or equivalent; 4 = participation in a vocational or technical program; 5 = some college; 6 = bachelor's degree; 7 = graduate or professional school without completing degree; 8 = master's degree; 9 = doctorate or professional degree. Occupational prestige was coded in accordance with

guidelines provided by the General Social Survey (National Center for Educational Statistics, 2001).

Information regarding the child's sex was collected during the fall parent interviewed and confirmed during the spring parent interview. Children's age at kindergarten entry was a composite variable that was created using the child's birthdate and information from the parent interview that indicated whether fall of 2010 was the child's first or second year in kindergarten.

7. Analysis Plan

To answer the research questions, hierarchical multiple regression (HMR) was used to conduct the analyses. HMR allows the researcher to determine the order in which the predictor variables are entered into the regression equation. To control the effect of a certain variable or set of variables, a multiple regression is performed with the factor or factors as independent variables. From the regression results, the researcher has the variance accounted for by this single or group of independent variables. As the next step, another regression analysis is run with the original set of independent variables (control variables) and a new set of independent variables. This allows the researcher to examine the unique contributions accounted for by the second group of independent variables that are above and beyond the first group of independent variables. Socioeconomic status, sex, and kindergarten entry age were used as control variables in this study.

Prior to conducting an HMR, the relevant statistical assumptions were examined. Sample size was deemed adequate given the number of independent variables (Tabachnick & Fidell, 2001). Correlations among the independent variables found that none of them were highly correlated. Highly correlated independent variables may be problematic in multiple regression as they are in indication of multicollinearity. Multicollinearity is an indication that there is too much shared variance between or among variables indicating that the highly correlated variables may be accounting for the same characteristic (Meyers, et al., 2016). Predictor variables that are correlated at .70 or greater are considered highly correlated and should not be used together in the same regression equation. None of the independent variables in this study were correlated greater than .70.

The independent variables in this study met the collinearity assumptions, as indicated by Tolerance and VIF, which all fell within acceptable ranges. Tolerance quantifies the proportion of variance in an independent variable that remains unexplained by all other independent variables. A higher Tolerance value is desirable, typically above .20. VIF, or Variance Inflation Factor, serves as the reciprocal of Tolerance and reflects the extent of shared association among independent variables. A lower VIF (below 10) is generally regarded as acceptable (Coakes, 2005; Hair et al., 1998). Detailed Tolerance and VIF statistics for each independent variable can be found in Tables 1, 2, and 3 for literacy, mathematics, and science respectively. The assumptions of normality, linearity, and homoscedasticity were all confirmed through residual and scatterplots (Hair, et al., 1998; Pallant, 2020). The HMR resulted in three regression models.

In Model 1, children's gender, SES, and kindergarten entry age were entered to determine their predictive associations with third-grade reading, mathematics, and science achievement. These variables would serve as control variables in Models 2 and 3.

In Model 2, children's beginning of kindergarten AtL and language development skills were added to the predictor variables in Model 1 to determine how their addition improved upon the overall predictive power of Model 1. In addition, Model 2 would reveal the independent predictive associations between beginning of kindergarten AtL and language development skills and end of third-grade reading, mathematics, and science achievement while controlling for gender, SES, and kindergarten entry age.

In Model 3, the beginning of kindergarten EF variables (working memory, cognitive flexibility, and inhibitory control) were added to the predictor variables in Model 2. This would uncover how the addition of these variables would improve the overall predictive power of Model 2. In addition, Model 3 would show the predictive associations between each of the three EF variables at the beginning of kindergarten and end of third-grade reading, mathematics, and science achievement.

8. Results

The means and standard deviations for third-grade reading, mathematics, and science IRT achievement scores were as follows: reading - 124.06 (SD = 14.03); mathematics - 147.89 (SD = 16.46); science - 62.38 (SD = 11.00).

8.1 Reading Achievement Predictions

For third-grade reading performance, the HMR revealed that in Model 1, Gender, SES, and kindergarten entry age significantly contributed to the regression model, $F(3, 6665) = 476.27$, $p < .001$). Together, gender, SES, and

kindergarten entry age accounted for 17.6% of the variance in third-grade reading performance. Model 2 was an improvement over the first model in which teacher ratings of beginning of kindergarten AtL and oral language proficiency was added to the variables in Model 1. Model 2 accounted for 25.8% of the variance in third-grade reading performance, explaining an additional 8.2% of the variance. The change in R^2 was significant, F $(2,6663)$ = 370.35, $p < .001$. Model 3 was an improvement over Model 2 in which the three beginning of kindergarten executive function variables were added (working memory, cognitive flexibility, attentional focus). Model 3 accounted for 35.8% of the variance in third-grade reading performance, explaining an additional 10.0% of the variance. This change in R^2 was also significant, F $(3,6660)$ = 344.71, $p < .001$. The β coefficients for the constant and 8 predictors can be found in Table 4. All the β coefficients were significant at the $p < .001$ level meaning that each predictor significantly contributed to the variance of the outcome variable, third-grade literacy performance. Based on these data, the most important predictor of reading performance in third-grade was "working memory" followed by SES. Kindergarten entry age accounted for the least amount of variance in third-grade reading performance. Hierarchical multiple regression analyses and model summary statistics for third-grade reading are reported in Tables 1 and 4.

Table 1. Summary of Hierarchical Multiple Regression analysis for variables predicting third-grade reading performance

Third Grade Reading Performance						
Model 1	B	Beta	t	Sig.	Tolerance	VIF
(Constant)	90.427		34.91	.001		
Gender	2.852	.102	9.12	.001	.995	1.006
SES	7.138	.389	35.01	.001	1.000	1.000
KAge	0.430	.127	11.42	.001	.994	1.006
Model 2						
(Constant)	59.615		19.46	.001		
Gender	1.129	.040	3.69	.001	.939	1.065
SES	5.899	.322	29.68	.001	.947	1.055
KAge	0.244	.072	6.70	.001	.959	1.043
AtL	5.178	.241	21.40	.001	.880	1.136
preLAS	1.567	.156	14.43	.001	.957	1.045
Model 3						
(Constant)	90.134		29.37	.001		
Gender	1.235	.044	4.33	.001	.933	1.071
SES	4.446	.242	23.35	.001	.894	1.118
KAge	0.120	.036	3.55	.001	.946	1.057
AtL	2.039	.095	6.06	.001	.394	2.535
preLAS	0.902	.090	8.71	.001	.911	1.098
Working Memory	4.300	.306	27.92	.001	.800	1.251
Cognitive Flex	1.346	.096	9.25	.001	.897	1.115
Inhibitory Control	-1.344	-.089	-5.792	.001	.408	2.449

Table 4. Model Summary of Hierarchical Multiple Regression for Third-Grade Reading, Math, and Science Performance

			Third Grade Reading Performance					
Model	R	R^2	Adjusted R^2	ΔR^2	ΔF	df_1	df_2	Sig. ΔF
1	.420[a]	.177	.176	.177	476.27	3	6665	.001
2	.509[b]	.259	.258	.082	370.35	2	6663	.001
3	.599[c]	.359	.358	.100	344.71	3	6660	.001

			Third-Grade Math Performance					
Model	R	R^2	Adjusted R^2	ΔR^2	ΔF	df_1	df_2	Sig. ΔF
1	.421[a]	.178	.177	.178	479.40	3	6664	.001
2	.506[b]	.256	.256	.079	353.58	2	6662	.001
3	.615[c]	.379	.378	.122	437.10	3	6659	.001

			Third-Grade Science Performance					
Model	R	R^2	Adjusted R^2	ΔR^2	ΔF	df_1	df_2	Sig. ΔF
1	.427[a]	.182	.182	.182	495.16	3	6661	.001
2	.499[b]	.249	.248	.066	294.52	2	6659	.001
3	.586[c]	.344	.343	.095	320.10	3	6656	.001

Notes:

[a]Predictors: (Constant), SES, Gender, Kindergarten Entry Age

[b]Predictors: (Constant), SES, Gender, Kindergarten Entry Age, preLAS, Teacher Rated ATL

[c]Predictors: (Constant), SES, Gender, Kindergarten Entry Age, preLAS, Teacher rated ATL, Working Memory, Cognitive Flexibility, Inhibitory Control

8.2 Math Achievement Predictions

For third-grade math performance, the HMR revealed that in Model 1, Gender, SES, and kindergarten entry age significantly contributed to the regression model, F (3, 6664) = 479.40, p < .001). Together, gender, SES, and kindergarten entry age accounted for 17.7% of the variance in third-grade math performance. Model 2 was an improvement over the first model in which teacher ratings of beginning of kindergarten AtL and oral language proficiency was added to the variables in Model 1. Model 2 accounted for 25.6% of the variance in third-grade math performance, explaining an additional 7.9% of the variance. The change in R^2 was significant, F (2,6662) = 370.35, p < .001. Model 3 was an improvement over Model 2 in which three beginning of kindergarten executive function variables were added (working memory, cognitive flexibility, attentional focus). Model 3 accounted for 37.8% of the variance in third-grade math performance, explaining an additional 12.2% of the variance. This change in R^2 was also significant, *F* (3,6659) = 344.71, p < .001. The β coefficients for the constant and 8 predictors can be found in Table 4. All the β coefficients were significant at the p < .001 level meaning that each predictor significantly contributed to the variance of the outcome variable, third-grade math performance. Based on these data, the most important predictor of math performance in third-grade was also "working memory" followed by SES. As with reading, kindergarten entry age accounted for the least amount of variance in third-grade reading performance. Hierarchical multiple regression analyses and model summary statistics for math are reported in Tables 2 and 4.

Table 2. Summary of Hierarchical Multiple Regression analysis for variables predicting third-grade math performance

Third Grade Math Performance						
Model 1	B	Beta	t	Sig.	Tolerance	VIF
(Constant)	78.028		25.70	.001		
Gender	-4.068	-.124	-11.09	.001	.995	1.006
SES	8.155	.377	33.95	.001	1.000	1.000
KAge	0.516	.130	11.70	.001	.994	1.006
Model 2						
(Constant)	44.535		12.38	.001		
Gender	-6.090	-.185	-16.96	.001	.939	1.065
SES	6.695	.311	28.67	.001	.947	1.055
KAge	0..301	.076	7.05	.001	.959	1.043
AtL	6.132	.243	21.57	.001	.880	1.136
preLAS	1.678	.142	13.16	.001	.957	1.045
Model 3						
(Constant)	84.173		23.76	.001		
Gender	-5.955	-.181	-18.09	.001	.933	1.071
SES	4.807	.233	21.88	.001	.894	1.118
KAge	0.140	.035	3.57	.001	.946	1.057
AtL	2.132	.084	5.49	.001	.394	2.535
preLAS	0.806	.068	6.75	.001	.911	1.098
Working Memory	5.540	.337	31.17	.001	.800	1.251
Cognitive Flex	1.872	.114	11.15	.001	.897	1.115
Inhibitory Control	-1.666	-.094	-6.22	.001	.408	2.449

8.3 Science Achievement Predictions

For third-grade science performance, the HMR revealed that in Model 1, Gender, SES, and kindergarten entry age significantly contributed to the regression model, F (3, 6661) = 495.52, $p < .001$). Together, gender, SES, and kindergarten entry age accounted for 18.2% of the variance in third-grade science performance. Model 2 was an improvement over the first model in which teacher ratings of beginning of kindergarten AtL and oral language proficiency was added to the variables in Model 1. Model 2 accounted for 24.8% of the variance in third-grade science performance, explaining an additional 6.6% of the variance. The change in R^2 was significant, F (2,6659) = 370.35, $p < .001$. Model 3 was an improvement over Model 2 in which the three beginning of kindergarten executive function variables were added (working memory, cognitive flexibility, attentional focus). Model 3 accounted for 34.3% of the variance in third-grade reading performance, explaining an additional 9.5% of the variance. This change in R^2 was also significant, F (3,6656) = 320.10, $p < .001$. The β coefficients for the constant and 8 predictors can be found in Table 4. All the β coefficients were significant at the $p < .001$ level meaning that each predictor significantly contributed to the variance of the outcome variable, third-grade literacy performance. Based on these data, the most important predictor of reading performance in third-grade was "working memory" followed by SES. Kindergarten entry age accounted for the least amount of variance in third-grade reading performance. Hierarchical multiple regression analyses and model summary statistics for science are reported in Tables 3 and 4.

Table 3. Summary of Hierarchical Multiple Regression analysis for variables predicting third-grade science performance

Third Grade Science Performance						
Model 1	B	Beta	t	Sig.	Tolerance	VIF
(Constant)	40.760		2.014	.001		
Gender	-1.448	-.066	-5.92	.001	.995	1.006
SES	5.733	.399	35.98	.001	1.000	1.000
KAge	0.349	.132	11.86	.001	.994	1.006
Model 2						
(Constant)	15.706		6.494	.001		
Gender	-2.546	-.116	-10.63	.001	.939	1.065
SES	4.867	.157	31.01	.001	.947	1.055
KAge	0.221	.083	7.68	.001	.959	1.043
AtL	3.248	.192	17.00	.001	.880	1.136
preLAS	1.321	.167	15.40	.001	.957	1.045
Model 3						
(Constant)	38.619		15.86	.001		
Gender	-2.487	-.113	-10.99	.001	.933	1.071
SES	3.765	.262	24.92	.001	.894	1.118
KAge	0.124	.047	4.60	.001	.946	1.057
AtL	1.191	.071	4.47	.001	.394	2.535
preLAS	0.788	.100	9.59	.001	.911	1.098
Working Memory	3.114	.283	25.49	.001	.800	1.251
Cognitive Flex	1.427	.130	12.37	.001	.897	1.115
Inhibitory Control	-0.692	-.058	-3.76	.001	.408	2.449

9. Discussion

This study used HMR to elucidate whether children's self-regulation (EF and AtL) and language development skills at the beginning of kindergarten were predictive of third-grade achievement in reading, mathematics, and science. Gender, SES, and kindergarten entry age were used as control variables in all analyses. The study's focus was on third-grade achievement because third-grade is both a benchmark and pivotal for establishing children's academic trajectories. Three multiple regression models were generated in response to the research questions.

9.1 Model 1: Gender, SES, and Kindergarten Entry Age

In the HMR Model 1, children's gender, SES, and kindergarten entry age were entered into the analysis to control for the effects of those variables in the analyses that followed. As was discussed previously, gender, SES, and kindergarten entry age have been shown to be compelling predictors of children's development and academic trajectories in previous research. While the principal emphasis in this investigation was not to assess the predictive potential of these variables, it is nonetheless interesting to examine their ability to do so.

SES was the most robust predictor of children's third-grade academic achievement in reading, mathematics, and science. This finding was supported by earlier research findings (i.e., Engle & Black, 2008; Gullo, 2018; Isaacs, 2012). The primary focus of previous research was examining reading and mathematics outcomes within the context of SES. The present study showed that SES also had a significant predictive association with science

achievement. Examination of the standardized beta weights indicated that SES was equally as predictive of third-grade achievement in science as it is for achievement in reading and mathematics. Further examination of the standardized beta weights indicated that gender, while a significant predictor, had the weakest predictive association with all three third-grade achievement outcomes. What's important to note is that all three of the control variables were significant in predicting third-grade achievement outcomes in reading, mathematics, and science. This finding confirms the need for controlling for their effects in further analyses and in subsequent studies.

9.2 Model 2: Approaches to Learning and Early Language Development

In the HMR Model 2, beginning of kindergarten AtL and language development skills were added to the regression analysis. Controlling for gender, SES, and kindergarten entry age, both AtL and language development skills assessed at the beginning of kindergarten were significant predictors of reading, mathematics, and science achievement in third-grade. In addition, the addition of AtL and language development skills significantly improved the predictive model for all three achievement areas.

Examination of the standardized beta weights revealed that while significant, AtL had a weaker predictive association for science achievement than it did for either reading or mathematics. AtL was equally predictive of both reading and mathematics. The finding for reading and mathematics is consistent with previous research indicating that AtL has predictive associations with these two achievement areas (Li-Grinning, et al., 2010), but inconsistent with other findings (Gullo & Impellizeri, 2022; Razza et al., 2015) that indicated that AtL stronger predictive associations with mathematics. It is speculated that this difference in findings may be due to the nature of the control variables used in the present investigation. In previous studies, if control variables were used at all, they were limited to one or two, usually SES.

The finding that AtL was a weaker predictor for science achievement than it was for either reading or mathematics achievement is difficult to explain since the preponderance of studies do not include science achievement as a dependent variable in investigations such as this one. In one study on science achievement in kindergarten and third-grade (Sackes, et al., 2011), it was found that AtL was a significant predictor of end of kindergarten and end of third-grade science achievement score, but a weaker predictor than gender and SES. The researchers attributed this finding to early childhood teachers being less well equipped to teach science and that science was an often overlooked subject area in early childhood education. In the present study's findings, SES and gender were also stronger predictors of third-grade science achievement that was AtL, as was kindergarten entry age. More research on early childhood science achievement is warranted as well as on those factors that predict and support children's successful performance in early science.

Findings from this study regarding AtL provide evidence that AtL represents a skill domain set that is worthy of consideration when designing instructional practices. In doing this, teachers and administrators are providing the scaffolding and support young children require as they develop the skills needed as young learners (goal directed behavior, persistence, organization) to undertake the increasingly difficult demands placed on them in complex learning tasks.

Overall, language development skills was a significant predictor of third-grade reading, mathematics, and science achievement. Extant research findings regarding the predictive associations between early language development and later achievement in reading and mathematics (e.g., Dolean, et al., 2021; Ramsook, et al., 2020) also show these associations. Having larger vocabularies in the early years has been associated with later comprehension of mathematical concepts and the development of symbolic concepts and problem-solving skills.

Examination of the standardized beta coefficients, however, indicate that early language development was a stronger predictor of science achievement than it was for either reading or mathematics achievement in third-grade; and early language development was a weaker predictor for third-grade mathematics than it was for either reading or science. The finding that early language development had the strongest predictive association with science achievement is difficult to explain since most other studies did not include science achievement as a dependent variable in studies such as this one. When science was included, previous studies were more focused later elementary, middle-school, or high-school performance (e.g., Blums, et al., 2017). In one investigation (Foster, et al., 2022), it was found that language proficiency in kindergarten predicted science achievement in kindergarten, first- and second-grade among English monolinguals and multilinguals. The Foster, et al. (2022) study also indicated that early language development was predictive of later science achievement for both groups of children. They did not, however, examine differential magnitudes of the predictive associations as compared to those for reading and mathematics. Because there are so few studies investigating this topic, more research is needed that will elucidate if and why predictive associations for science achievement may be comparably different from those for reading and mathematics achievement.

9.3 Model 3: EF (Working Memory; Cognitive Flexibility; Inhibitory Control)

In the HMR Model 3, the three elements of beginning of kindergarten EF (working memory; cognitive flexibility; inhibitory control) were added to the regression analysis. The addition of these three components of EF significantly improved the predictive model for all three achievement areas. In addition, all three EF factors were significant predictors of reading, mathematics, and science achievement in third-grade. Examination of the standardized beta weights indicated that working memory was the strongest predictor of the three achievement areas while inhibitory control was the weakest predictor.

The finding in this study that EF factors had differential predictive associations with varied achievement domains is substantiated in the extant research. Understanding the critical, albeit differential roles that components of EF play in early academic achievement has important implications for educational planning. Working memory has most consistently predicted achievement in mathematics (De Smedt et al., 2009) and reading (Christopher, et al., 2012). Cognitive flexibility and inhibitory control, however, did not consistently predict academic achievement in young children (Lee, et al., 2012). Contrary to these findings, some study results show that inhibitory control is related to reading and mathematics achievement (Blair & Razza, 2007; Vandenbroucke, et al., 2017), and that there is a relationship between cognitive flexibility and academic achievement (Morgan, et al., 2017; Vandenbroucke, et al., 2017). It should be noted that again, previous research did not include science achievement in their investigations. Further research is needed that includes science achievement if we are to fully understand the roles that early AtL, language development and EF factors play in supporting and predicting later science achievement.

As shown in previous research, EF encompasses skills that enable effective planning and goal-oriented behavior. These, in turn, may play a role in influencing children's attitudes, behaviors, and strategies towards learning when confronted with new challenges, resulting in discernible actions that teachers may distinguish as approaches to learning.

10. Limitations, Implications, and Future Directions

There are a number of limitations that must be taken into account when interpreting the finding of this study. Using data from the ECLS-K 2011 was both a strength and a limitation. The ECLS-K 2011 data are both longitudinal and nationally representative. These elements of the data perhaps make the findings from this study more generalizable and therefore valid implications may be drawn. The ECLS-K 2011 data are also very comprehensive and there were a number of variables that could have been utilized in this study that were not. Aspects of the classroom environment, other characteristics of the child, home environment variables, and parent characteristics all have been shown to influence children's school performance. Exclusion of these other variables may have affected the findings. Further research should be conducted with these variables.

The constructs used this this study (EF, AtL, language development skills, achievement) are multifaceted, complicated, and challenging to assess. The evaluation of children's EF was limited to two direct assessments for cognitive flexibility and working memory. Inhibitory control was assessed by teachers' observation ratings of children's behaviors. AtL was also determined by teacher ratings of children's behaviors. Additional research is needed to replicate this study's findings using other measures, other children, and in different contexts. While the findings from this investigation may be generalizable, it may be that they are only generalizable to children in the United States.

Despite the limitations, this study's findings expand our understanding in a number of different ways. First, science has not been an achievement domain used in most previous studies. This study expanded our understanding of the predictive associations between the dependent variables in this study (EF, AtL, language development skills) and science achievement. Second, the control variables in this study were more comprehensive than they were in most previous studies. The analysis strategy in this study determined the collective predictive association between the control variables and the dependent variables. This analytic process effectively increased the internal validity of the study by limiting the influence of potential confounding variables that might bias the results. Third, previous studies primarily examined the predictive associations between EF, AtL or language development skills independent from one another. This study found that when these variables are used together to predict achievement, the strongest associations were found. Finally, this study's findings found that children's beginning of kindergarten EF, AtL, and language development skills were strong predictors of third-grade achievement in reading, mathematics, and science; this has strong implications for both prekindergarten and kindergarten curriculum development. Also, the findings from this study can and should be used for developing parent and caregiver education, the purpose of which is to assist them in understanding how early EF, AtL and language development skills may impact their child's academic trajectories. In addition, both professional development and parent/caregiver education should focus on how to facilitate EF, AtL and language development skills in young children.

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