


Kindergarten predictors of third-grade reading and math achievement: The influences of executive function and approaches to learning

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ABSTRACT

This study examines how executive function and approaches to learning at kindergarten entry jointly predict longer-term academic outcomes. While each factor has independently been linked to early achievement, less is known about their combined contribution to academic performance by the end of third grade, a critical milestone characterized by increased academic demands and high-stakes testing. Using nationally representative data from the Early Childhood Longitudinal Study–Kindergarten Class of 2010–2011, the study employed hierarchical multiple regression analyses. Executive function skills and approaches to learning were measured at the beginning of kindergarten and reading and mathematics achievement were assessed at the end of third grade. Analyses controlled for socioeconomic status, gender, and age at school entry. Results indicate that both executive function and approaches to learning at kindergarten entry significantly predict third grade reading and mathematics achievement. Models including both predictors demonstrated the greatest explanatory power, revealing that cognitive regulatory skills and learning-related behaviors contribute unique and additive effects to later academic success. Findings underscore the importance of addressing both cognitive self-regulation and learning behaviors in early education. Early screening and intervention efforts that integrate executive function and approaches-to-learning assessments may help identify children at risk for later academic difficulties. Strengthening these competencies in the early years may support more positive and sustained academic trajectories through elementary school.

Keywords: *Achievement, Approaches to learning, Executive function, Kindergarten, Multiple regression Third grade.*

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Highlights of this paper:

- Executive function and approaches to learning at kindergarten entry independently and jointly predicted reading and math achievement at the end of third grade.
- Models including both cognitive regulatory skills and learning-related behaviors provide the strongest prediction of later achievement outcomes.
- Early identification and targeted support of self-regulation and learning behaviors may yield lasting benefits for children's academic trajectories.

1. INTRODUCTION

Executive functions (EF) and approaches to learning (AtL) are widely recognized as essential contributors to young children's developmental and academic success (Diamond, 2013; Sung & Wickrama, 2018; Valcan, Davis, Pino-Pasternak, & Malpique, 2020; Vitiello & Greenfield, 2017). EF encompasses a set of mental processes that support goal-oriented behavior, including planning, learning, and problem-solving (Diamond, 2013). These processes enable individuals to regulate attention, manage impulses, and control behavior in pursuit of cognitive tasks (Hughes, 2011; Philip David Zelazo, 2004). EF is typically categorized into three domains: (a) inhibitory control—which involves resisting impulsive actions to maintain task focus; (b) working memory—which allows temporary storage and manipulation of information; and (c) cognitive flexibility—which refers to the ability to adapt thinking and behavior in response to changing demands or perspectives (Morgan et al., 2019; Valcan et al., 2020).

AtL refers to the behavioral and motivational tendencies children exhibit when engaging in learning activities. It includes traits such as persistence, attentiveness, and curiosity, which influence how children approach new tasks and challenges (Gullo & Impellizeri, 2022; Li-Grining, Votruba-Drzal, Maldonado-Carreño, & Haas, 2010; McDermott et al., 2009).

Both EF and AtL are foundational elements of self-regulation—a developmental construct that reflects a child's ability to manage emotions, behaviors, and attention in response to environmental stimuli. Early self-regulation is considered a key predictor of later success, with some scholars describing it as an “early life marker for later life successes” (Montroy, Bowles, Skibbe, McClelland, & Morrison, 2016). Robson, Allen, and Howard (2020) in a meta-analysis of 150 studies, found that self-regulation in preschool-aged children was positively linked to school engagement and academic performance. Furthermore, self-regulation in the early elementary years was associated with gains in literacy and mathematics achievement, reinforcing its role in long-term educational outcomes.

Although self-regulation has been extensively studied as a unified trait (Luszczynska, Diehl, Gutiérrez-Doña, Kuusinen, & Schwarzer, 2004) there is a lack of research exploring how its individual components—EF and AtL—both separately and together influence academic achievement. This study seeks to address that gap by investigating whether EF and AtL measured at the start of kindergarten can predict reading and math achievement at the end of third grade. The conducted analyses account for demographic variables known to affect academic development. They include gender, socioeconomic status, and the child's age at the beginning of kindergarten.

The conclusion of third grade represents a critical juncture in children's academic progression. It often coincides with the introduction of standardized assessments, which can significantly shape future educational pathways (Jordan, Kaplan, Ramineni, & Locuniak, 2009). Additionally, this period marks a transition from learning basic literacy and numeracy skills to applying these foundational abilities in more complex and abstract contexts. Understanding how early self-regulatory behaviors and learning dispositions contribute to later academic success can inform educational policy and early childhood practices. Prior studies have tended to focus on either earlier or

later grade levels, leaving a gap in understanding the predictive value of kindergarten entry behaviors on third-grade achievement.

2. THEORETICAL FRAMEWORK

2.1. Executive Functions and Early Academic Achievement

Executive functions are widely acknowledged as essential cognitive processes that underpin early academic performance. These functions include working memory, cognitive flexibility, and inhibitory control, each contributing to a child's ability to manage goal-directed behaviors (Diamond, 2013). Working memory has been linked to performance in reading comprehension and mathematical reasoning, as it supports the retention and manipulation of information necessary for complex cognitive tasks (Gathercole & Alloway, 2008).

Cognitive flexibility plays a vital role in academic achievement. Defined as the ability to shift attention and adapt to changing demands, it enables children to transition between tasks and respond effectively to diverse instructional strategies (Anderson, 2002). Students who exhibit strong cognitive flexibility are better equipped to navigate varied learning environments and problem-solving contexts.

Inhibitory control, the ability to suppress impulsive responses and maintain attention, is critical for sustaining focus during academic tasks. This component of EF supports self-regulation and task persistence, particularly in activities that require prolonged concentration such as reading and mathematics (Blair & Razza, 2007). Children who exhibit strong inhibitory control are more likely to resist distractions and remain engaged with task-relevant information.

The development of EF varies among individuals and is shaped by a range of personal and contextual factors. Research suggests that both demographic factors and individual traits contribute to differences in how executive functions develop among children (Best & Miller, 2010; Montroy et al., 2016). Environments that encourage exploration and problem-solving have been shown to foster EF growth, thereby supporting early academic competencies.

Empirical studies have demonstrated that preschool children with stronger EF skills tend to perform better on assessments of early literacy, vocabulary, mathematics, and science (Bierman, Torres, Domitrovich, Welsh, & Gest, 2009; Nayfeld, Fuccillo, & Greenfield, 2013). Collectively, these findings underscore the importance of fostering executive function skills during early childhood, as they serve as critical predictors of academic readiness and long-term educational outcomes (Blair & Razza, 2007).

2.2. Approaches to Learning and Early Academic Achievement

Approaches to Learning refers to a range of behaviors and dispositions that signify young children's motivation and engagement in educational contexts. Traits such as persistence, curiosity, adaptability, emotional regulation, and autonomy are commonly observed during learning and have been consistently associated with academic success across diverse settings (Fantuzzo, Perry, & McDermott, 2004; Hair, Anderson, Tatham, & Black, 2006; Hyson, 2008). Children who exhibit these characteristics tend to approach tasks with greater focus, follow instructions reliably, apply creative problem-solving strategies, and collaborate effectively with peers (Razza, Martin, & Brooks-Gunn, 2015).

Empirical studies have demonstrated that AtL, particularly when assessed during kindergarten, serves as a strong predictor of subsequent achievement in literacy and mathematics throughout the elementary years (Li-Grining et al., 2010). Notably, AtL appears to have a pronounced impact on students who enter school with lower

initial academic performance, suggesting its potential to reduce early educational disparities (Bodovski & Farkas, 2007; Li-Grining et al., 2010).

Children with well-developed AtL skills are more likely to experience positive academic trajectories during early childhood (Bustamante, White, & Greenfield, 2017; Razza et al., 2015). In contrast, insufficient development of these skills may hinder successful transitions from preschool to later schooling, functioning as a potential risk factor (McClelland, Morrison, & Holmes, 2000). Conversely, strong AtL competencies may serve as protective factors, facilitating children's adjustment and academic success in elementary education (McClelland et al., 2000; McWayne, Fantuzzo, & McDermott, 2004; Yen, Konold, & McDermott, 2004).

Although research on AtL is not as extensive as that on EF, emerging evidence highlights its critical role in shaping academic outcomes. The interaction between early EF and AtL, and their combined influence on long-term educational performance, remains an underexplored area. Future investigations should examine how these processes jointly contribute to children's learning and development across time.

2.3. Demographic Factors Affecting Early Achievement (Control Variables)

Children's early developmental and academic outcomes are shaped by a complex interplay of demographic factors. Research consistently highlights several key variables that significantly influence these trajectories. Among the most prominent are *age at kindergarten entry*, which can affect readiness and long-term academic performance; *gender*, which may be associated with differences in social-emotional development and learning styles; and *socioeconomic status (SES)*, a multifaceted construct encompassing income, education, and access to resources, which plays a critical role in shaping educational opportunities and developmental support. Understanding how these factors interact provides valuable insight into the diverse pathways children follow in their early years, and informs strategies for promoting equitable educational outcomes.

2.3.1. Kindergarten Entry Age

The impact of kindergarten entry age on children's short- and long-term academic achievement has been extensively researched and debated (Fletcher & Kim, 2016; Larsen, Little, & Coventry, 2021; Stipek & Byler, 2001). Several mechanisms may account for the differential effects of entry age on academic performance. Children who begin kindergarten at an older age may possess developmental advantages (NICHD Early Child Care Research Network, 2007) including enhanced social, emotional, and cognitive readiness. These attributes may contribute to initial academic success relative to younger peers. Additionally, older children may experience smoother social and emotional transitions into later, more structured schooling (Finders, Geldhof, Dahlgren, Olsen, & McClelland, 2022; Gottfried & Sublett, 2019) potentially due to more well-developed self-regulation and interpersonal competencies that facilitate classroom engagement and peer interactions.

Despite these initial advantages, empirical evidence suggests that the benefits associated with older kindergarten entry age may be transient. Developmental and academic disparities tend to diminish over time, with gaps narrowing or disappearing by later grades (Fletcher & Kim, 2016; Larsen et al., 2021). Furthermore, individual differences among children significantly influence outcomes; some younger children may excel academically, while some older children may encounter challenges. These differences may be attributable to intrinsic child characteristics or external factors, including gender and SES.

2.3.2. Gender

Early cognitive and academic competencies are critical predictors of subsequent educational success, and gender has been identified as a factor influencing school adjustment and achievement during early childhood (Cantalini-Williams, Perron, & Biemiller, 2016). Although gender differences are not universally observed, existing literature indicates that boys tend to outperform girls in numeracy (Cobb-Clark & Moschion, 2017; Williams, White, & MacDonald, 2016) whereas girls typically excel in literacy (Boardman, 2006; Cobb-Clark & Moschion, 2017). Boys are also more likely to exhibit behavioral challenges and reduced social skills in classroom contexts (Bulotsky-Shearer, Bell, and Domínguez (2012). Janus and Duku (2007) reported that boys were more than twice as likely as girls to demonstrate vulnerability in academic readiness upon kindergarten entry. Cobb-Clark and Moschion (2017) propose several explanatory mechanisms for these gender-based disparities, including biological differences (e.g., spatial versus verbal learning), gender-specific expectations from parents and educators, sociocultural norms, differential acquisition of social and behavioral skills, and gendered educational practices, such as teacher bias.

2.3.3. Socioeconomic Status

The influence of SES on children's developmental, behavioral, and academic outcomes is well-established in the literature (Engle & Black, 2008; Gullo, 2018; Isaacs, 2012). Adverse effects associated with low-SES environments can manifest as early as the second year of life and persist throughout the entire educational trajectories of children (Entwisle, Alexander, & Olson, 2005). Risk factors linked to poverty during the preschool and kindergarten years significantly shape school readiness and subsequent academic achievement. School readiness has been identified as a robust predictor of future educational benchmarks, including standardized test performance, grade retention, special education placement, and dropout rates (Zigler, Gilliam, & Jones, 2006). Children who enter kindergarten developmentally and academically behind their peers often struggle to close the achievement gap. Rather than narrowing, this gap frequently widens as children progress through their educational experiences (Lee & Burkam, 2002). These factors are associated with low-SES environs.

3. PURPOSE OF THE STUDY

This study aimed to investigate whether children's EF and AtL at the beginning of kindergarten predict reading and mathematics achievement at the end of third grade. The present research contributes to the literature in several important ways. Beyond extending prior findings, it addresses notable methodological limitations through a comprehensive and integrated design. First, while previous studies have examined the independent predictive effects of EF and AtL on academic achievement, few have explored how these constructs jointly operate, particularly within longitudinal models. Second, prior research typically assessed EF and AtL at the end of kindergarten, introducing potential confounds related to kindergarten experiences. By utilizing data collected at the beginning of kindergarten, this study ameliorates the influence of the kindergarten's curriculum and instructional practices on these developmental constructs. Finally, earlier investigations often employed limited or no control variables. In contrast, this study incorporates three demographic controls—gender, socioeconomic status (SES), and kindergarten entry age, each of which is empirically linked to early academic performance influences.

3.1. Research Questions

Controlling for SES, gender, and kindergarten entry age, this study addressed the following questions: 1. To what extent do EF skills at the beginning of kindergarten predict third-grade achievement in reading and mathematics? a. Do predictive associations vary across different EF dimensions? b. Do these associations differ by

achievement domain? 2. To what extent does AtL at the beginning of kindergarten predict third-grade achievement in reading and mathematics? Do these associations vary across achievement domains?

4. METHODS

Data were drawn from the Early Childhood Longitudinal Study – Kindergarten Class of 2010–2011 (Tourangeau et al., 2015) a nationally representative sample of children (N = 18,174), their families, teachers, schools, and childcare providers. Data collection began in 2010 at kindergarten entry and concluded in 2015 when participants reached fifth grade.

4.1. Subjects

For this analysis, children were included if they were first-time kindergarteners, had no individualized education program (IEP) at the end of kindergarten, and spoke English at home. The final analytic sample comprised 9,381 children (49% boys; 51% girls). The racial composition was as follows: 61% White, 14% African American, 14.2% Hispanic, 3.6% Asian, 5.7% two or more races, and 1.5% American Indian/Alaska Native or Native Pacific Islander. The mean age at kindergarten entry was 66.63 months (SD = 4.16).

4.2. Measures

This study employed multiple measures from the Early Childhood Longitudinal Study, Kindergarten Class of 2011 (Tourangeau et al., 2015). The dependent variables were end of third-grade reading and mathematics achievement scores. Control variables included child gender, age at kindergarten entry, and socioeconomic status (SES). Independent variables consisted of teacher ratings of children's AtL at the beginning of kindergarten and three indicators of EF: Working memory, cognitive flexibility, and inhibitory control.

4.2.1. Reading Assessment

The Tourangeau et al. (2015) assessed third grade reading achievement across three domains: basic word skills (e.g., sight-word recognition), vocabulary knowledge, and reading comprehension. Comprehension items were based on short passages requiring responses to factual and inferential questions. Children initially completed 19 routing items, which determined assignment to a second-stage assessment of low, medium, or high difficulty, optimizing measurement within limited time (Tourangeau et al., 2015). Internal consistency for the reading assessment was $\alpha = 0.87$.

4.2.2. Mathematics Assessment

In the Tourangeau et al. (2015) mathematics achievement was evaluated in conceptual knowledge, procedural knowledge, and problem-solving. Content areas included number sense, operations, measurement, geometry, data analysis, and algebraic reasoning. Children completed 17 routing items before progressing to ability-based second-stage items. Word problems and graph labels were read aloud by trained assessors, and paper-and-pencil responses were permitted (Tourangeau et al., 2015). Internal consistency was $\alpha = 0.92$.

Mathematics and reading achievement IRT-scaled scores were used for all analyses. This approach enables comparison across students regardless of item sets administered and supports longitudinal analysis of achievement growth. IRT incorporates item difficulty and response accuracy to estimate ability on a continuous scale (Bortolotti, Tezza, de Andrade, Bornia, & de Sousa Júnior, 2013).

4.2.3. Approaches to Learning (AtL)

Teachers rated children's AtL at the beginning of kindergarten using seven items (e.g., organization, eagerness to learn, independence, adaptability, persistence, attention, rule-following) on a four-point Likert scale ranging from never to very often observed. Items were adapted from the Social Skills Rating System (Gresham & Elliot, 1990). The composite AtL score was the mean of these items, with reliability $\alpha = 0.91$.

4.2.4. Executive Function - Working Memory

Working memory was assessed using the Numbers Reversed subtest of the Woodcock-Johnson III Tests of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001) a validated measure with reliability of 0.87 (Schrank, 2011). Children repeated number sequences in reverse order until reaching an eight-number sequence or three consecutive errors. Standardized W scores were used for analysis (Mather & Woodcock, 2001).

4.2.5. Executive Function - Cognitive Flexibility

Cognitive flexibility was measured using the Philip David Zelazo (2006) which requires sorting cards by color, shape, and border. Reliability ranges from 0.90 to 0.94 (Beck, Schaefer, Pang, & Carlson, 2011). A combined score across tasks was analyzed.

4.2.6. Executive Function - Inhibitory Control

Teachers completed the Putnam and Rothbart (2006) rating attentional focus on two items (e.g., difficulty maintaining attention, distractibility) on a seven-point scale. Higher scores indicated greater attentional focus. Reliability was $\alpha = 0.87$ across kindergarten data collection.

4.2.7. Demographic Characteristics

A composite variable for socioeconomic status (SES) was created during the base year of data collection. SES was computed at the individual household level and included the following components: father or male guardian's education, mother or female guardian's education, father or male guardian's occupation, mother or female guardian's occupation, and household income. Each index was standardized to a mean of 0 and a standard deviation of 1. Parents reported their education and occupation during the fall of the kindergarten year. Education was coded as follows: 1 = Completed grade 8 or below; 2 = Completed grades 9–12; 3 = high school diploma or equivalent; 4 = 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 according to guidelines provided by the General Social Survey (NICHD Early Child Care Research Network, 2007).

Information regarding the child's gender was collected during the fall parent interview and confirmed during the spring interview. Children's age at the beginning of kindergarten was derived from birthdate and parent interview data indicating whether fall 2010 was the child's first or second year in kindergarten.

4.3. Analysis Plan

Hierarchical multiple regression (HMR) was employed to address the research questions. HMR enables researchers to specify the order in which predictor variables enter the regression equation, thereby allowing examination of incremental contributions of variable sets (Tabachnick & Fidell, 2019). To control for specific variables, an initial regression was conducted with SES, gender, and kindergarten entry age as predictors. This

model provided the variance explained by these control variables. Subsequently, additional models were estimated by introducing new predictors, enabling assessment of their unique contributions beyond the control variables.

4.3.1. Assumption Testing

Prior to conducting the analyses, HMR assumptions were evaluated.

- Sample Size: Adequate for the number of predictors (Tabachnick & Fidell, 2019).
- Multicollinearity: Correlation analyses indicated that none of the independent variables were highly correlated. Correlations of .70 or higher are considered problematic; none exceeded this threshold (Meyers, Gamst, & Guarino, 2016).
- Collinearity Diagnostics: Tolerance values exceeded .20, and Variance Inflation Factor (VIF) values were below 10, both within acceptable ranges (Coakes, 2005; Hair et al., 2006). Tolerance reflects the proportion of variance in a predictor not explained by other predictors, whereas VIF is its reciprocal.
- Normality, Linearity, and Homoscedasticity: Verified through residual and scatterplot analyses (Hair et al., 2006; Pallant, 2020).

Detailed Tolerance and VIF statistics for literacy and mathematics models are presented in Tables 1–2.

4.3.2. Hierarchical Models

- Model 1: Gender, SES, and kindergarten entry age were entered to predict third-grade reading and mathematics achievement. These served as control variables in subsequent models.
- Model 2: Beginning-of-kindergarten AtL was added to assess its incremental predictive power and unique association with third-grade reading and mathematics achievement, controlling for Model 1 variables.
- Model 3: Beginning of kindergarten EF components (Working memory, cognitive flexibility, and inhibitory control) were added in Model 3, examining their contributions beyond AtL and control variables to predict third-grade reading and mathematics achievement.

5. RESULTS

Descriptive statistics for third-grade achievement indicated mean IRT scores of 124.16 (SD = 14.00) for reading and 107.20 (SD = 16.43) for mathematics.

5.1. Predictors of Reading Achievement

Hierarchical multiple regression (HMR) analyses were conducted to examine predictors of end of third-grade reading performance.

- Model 1 included gender, SES, and kindergarten entry age. These variables were used as control variables. This model was statistically significant, $F(3, 6665) = 476.27$, $p < 0.001$, and accounted for 17.6% of the variance in reading achievement.
- Model 2 added teacher ratings of AtL at the beginning of kindergarten. The inclusion of AtL significantly improved the model, explaining an additional 8.2% of variance ($\Delta R^2 = 0.082$), $F(2, 6663) = 370.35$, $p < 0.001$, for a total of 25.8% variance explained.
- Model 3 incorporated three EF measures assessed at the beginning of kindergarten: working memory, cognitive flexibility, and attentional focus. This model accounted for 35.8% of the variance, representing an additional 10.0% improvement over Model 2 ($\Delta R^2 = 0.100$), $F(3, 6660) = 344.71$, $p < 0.001$.

All predictors in the final model were statistically significant ($p < 0.001$). Standardized regression coefficients (β) for the constant and seven predictors are presented in Table 1. Among these, working memory emerged as the strongest predictor of third grade reading performance, followed by SES. Inhibitory control contributed the least variance. Summary statistics and full regression results for third grade reading achievement are reported in Tables 1 and 2.

5.2. Predictors of Mathematics Achievement

Hierarchical multiple regression (HMR) analyses were conducted to examine predictors of end of third-grade mathematics performance.

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)	90.308		34.16	0.001		
Gender	2.951	0.105	9.34	0.001	0.995	1.005
SES	7.065	0.207	34.17	0.001	1.000	1.000
KAge	0.425	0.125	11.17	0.001	0.995	1.006
Model 2						
(Constant)	85.018		33.29	0.001		
Gender	1.301	0.047	4.16	0.001	0.942	1.062
SES	6.225	0.339	30.78	0.001	0.967	1.034
KAge	0.283	0.083	7.55	0.001	0.967	1.034
AtL	5.723	0.262	22.89	0.001	0.898	1.114
Model 3						
(Constant)	26.405		8.89	0.001		
Gender	1.462	0.052	5.04	0.001	0.933	1.071
SES	4.537	0.247	23.42	0.001	0.901	1.11
KAge	0.131	0.039	3.76	0.001	0.950	1.052
AtL	3.282	0.15	9.25	0.001	0.381	2.625
Working Memory	0.151	0.323	29.22	0.001	0.822	1.216
Cognitive Flex	0.528	0.106	10.19	0.001	0.913	1.095
Inhibitory Control	0.363	0.184	1.97	0.048	0.399	2.509

Table 2. Model summary of hierarchical multiple regression for third-grade reading and math performance.

Third grade reading performance								
Model	R	R ²	Adjusted R ²	ΔR^2	ΔF	df ₁	df ₂	Sig. ΔF
1	0.420 ^a	0.177	0.176	0.177	476.27	3	6665	0.001
2	0.509 ^b	0.259	0.258	0.082	370.35	2	6663	0.001
3	0.599 ^c	0.359	0.358	0.100	344.71	3	6660	0.001
Third-Grade Math Performance								
Model	R	R ²	Adjusted R ²	ΔR^2	ΔF	df ₁	df ₂	Sig. ΔF
1	0.421 ^a	0.178	0.177	0.178	479.40	3	6664	0.001
2	0.506 ^b	0.256	0.256	0.079	353.58	2	6662	0.001
3	0.615 ^c	0.379	0.378	0.122	437.10	3	6659	0.001

Note: ^aPredictors: (Constant), SES, Gender, Kindergarten Entry Age.
^bPredictors: (Constant), SES, Gender, Kindergarten Entry Age, Teacher Rated ATL.
^cPredictors: (Constant), SES, Gender, Kindergarten Entry Age, Teacher rated ATL, Working Memory, Cognitive Flexibility, Inhibitory Control.

- Model 1 included gender, SES, and age at kindergarten entry. These variables were used as control variables. This model was statistically significant, $F(3, 6664) = 479.40, p < 0.001$, and accounted for 17.7% of the variance in math achievement.

- Model 2 added teacher ratings of AtL at the beginning of kindergarten. The inclusion of AtL significantly improved the model, explaining an additional 8.2% of variance ($\Delta R^2 = 0.082$), $F(2, 6663) = 370.35$, $p < 0.001$, for a total of 25.8% variance explained.
- Model 3 incorporated three EF measures assessed at the beginning of kindergarten: working memory, cognitive flexibility, and attentional focus. This model accounted for 37.8% of the variance, representing an additional 12.2% improvement over Model 2 ($\Delta R^2 = 0.122$), $F(3, 6659) = 344.71$, $p < 0.001$.

All predictors in the final model were statistically significant ($p < 0.001$). Standardized regression coefficients (β) for the constant and eight predictors are presented in Table 3. Among these, working memory emerged as the strongest predictor of third-grade math performance, followed by SES. Kindergarten entry age contributed the least variance. Summary statistics and full regression results for third grade math achievement are reported in Tables 2 and 3.

Table 3. 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		25.7	0.001		
Gender	-4.068	-0.124	-11.09	0.001	0.995	1.006
SES	8.155	0.377	33.95	0.001	1.000	1.000
KAge	0.516	0.13	11.70	0.001	0.994	1.006
Model 2						
(Constant)	44.535		12.38	0.001		
Gender	-6.09	-0.185	-16.96	0.001	0.939	1.065
SES	6.695	0.311	28.67	0.001	0.947	1.055
KAge	0.301	0.076	7.05	0.001	0.959	1.043
AtL	6.132	0.243	21.57	0.001	0.880	1.136
preLAS	1.678	0.142	13.16	0.001	0.957	1.045
Model 3						
(Constant)	84.173		23.76	0.001		
Gender	-5.955	-0.181	-18.09	0.001	0.933	1.071
SES	4.807	0.233	21.88	0.001	0.894	1.118
KAge	0.140	0.035	3.57	0.001	0.946	1.057
AtL	2.132	0.084	5.49	0.001	0.394	2.535
preLAS	0.806	0.068	6.75	0.001	0.911	1.098
Working Memory	5.54	0.337	31.17	0.001	0.800	1.251
Cognitive Flex	1.872	0.114	11.15	0.001	0.897	1.115
Inhibitory Control	-1.666	-0.094	-6.22	0.001	0.408	2.449

6. DISCUSSION

The present study examined whether and to what extent EF and AtL at the beginning of kindergarten predict third-grade achievement in reading and mathematics, while controlling for SES, gender, and kindergarten entry age. Using hierarchical multiple regression (HMR), it was found that both EF and AtL contributed significantly to later academic outcomes, with EF skills—particularly working memory—emerging as the strongest predictors across domains.

Consistent with prior research, EF skills accounted for substantial variance in academic achievement beyond demographic controls and AtL ratings (Diamond, 2013; Zelazo, Blair, & Willoughby, 2016). Working memory was the most robust predictor for both reading and mathematics, aligning with evidence that working memory supports complex cognitive tasks such as reading comprehension and mathematical problem-solving (Ahmed, Tang, Waters, & Davis-Kean, 2019; Cragg & Gilmore, 2014). Cognitive flexibility and attentional focus also contributed

significantly, though to a lesser extent, suggesting that multiple EF components collectively support academic development (Miyake et al., 2000).

Although EF and AtL predicted achievement in both domains, the magnitude of EF contributions was slightly greater for mathematics than for reading. This pattern is consistent with research suggesting that mathematics places heavier demands on working memory and cognitive flexibility compared to reading (Raghubar, Barnes, & Hecht, 2010; Philip David Zelazo & Carlson, 2020). AtL effects were relatively similar across domains, indicating that positive learning behaviors benefit both literacy and numeracy development.

This study's findings make a substantive contribution by advancing the field beyond limitations identified in prior research. Although earlier studies have demonstrated associations between EF and academic achievement, many have depended on small, relatively homogeneous samples or on composite EF indices, constraining generalizability and masking component-specific effects (Blair & Raver, 2015; Diamond, 2013). By examining distinct EF dimensions within a large, diverse sample, the present study isolates the components most predictive of long-term academic achievement, identifying working memory as the most influential factor.

Second, research on AtL has often focused on short-term outcomes or early grades (Li-Grining et al., 2010) leaving its predictive power for later achievement less understood. Our results demonstrate that AtL at kindergarten entry predicts third-grade performance even after controlling for EF and demographic factors, highlighting its enduring influence.

Third, few studies have examined EF and AtL simultaneously while controlling for SES and entry age. This omission has made it difficult to disentangle cognitive and behavioral contributions from socioeconomic influences. Our findings show that both EF and AtL remain significant predictors beyond these controls, suggesting that interventions targeting these skills could mitigate achievement gaps associated with SES (Hu, 2025).

Finally, prior literature has called for research that integrates multiple predictors within a single analytic framework to understand their relative contributions (Philip David Zelazo & Carlson, 2020). This study responds to that call by using hierarchical regression to quantify incremental variance explained by AtL and EF, providing a clearer picture of how these constructs jointly shape academic trajectories (Tabachnick & Fidell, 2019).

This investigation produces critical insights that meaningfully advance the field beyond what earlier studies have achieved. First, the simultaneous inclusion of multiple EF dimensions—working memory, cognitive flexibility, and attentional focus—allowed us to compare their relative contributions within the same model. While previous studies often examine EF as a composite score, our results highlight that working memory is the most influential predictor of later achievement, whereas attentional focus contributes minimally. This nuanced understanding advances theory by demonstrating that EF is not uniformly predictive across components.

Second, this study controlled for SES, gender, and kindergarten entry age, providing a more rigorous test of EF and AtL effects. The persistence of EF and AtL as significant predictors after accounting for these demographic factors suggests that these skills exert unique and robust influences on academic trajectories, independent of socioeconomic and developmental variables.

Third, the incremental variance explained by AtL before adding EF skills ($\Delta R^2 = 0.062$ for reading; $\Delta R^2 = 0.079$ for math) underscores the importance of behavioral engagement in early learning contexts. This finding suggests that AtL may serve as an accessible intervention target for educators, particularly in settings where direct EF training is less feasible.

Finally, the large sample size and use of teacher ratings for AtL combined with direct EF assessments strengthen the ecological validity of our findings. Few studies have examined these predictors in tandem using

nationally representative data, making this study a valuable contribution to understanding early predictors of academic success.

7. IMPLICATIONS, LIMITATIONS, FUTURE DIRECTIONS

7.1. Implications

The present findings carry several important implications for early childhood education, developmental science, and policy. First, the strong predictive role of EF—particularly working memory—reinforces the view that early cognitive control processes form a foundational architecture for later academic learning. Because EF skills are malleable and responsive to structured practice (Blair, 2017; Diamond, 2013) early interventions that embed working memory and cognitive flexibility training into classroom routines may yield sustained academic benefits. Evidence from randomized trials suggests that EF-focused curricula can improve both cognitive skills and downstream academic outcomes, especially when integrated into everyday instructional activities rather than delivered as isolated training modules (Pandey et al., 2018; Schmitt, McClelland, Tominey, & Acock, 2015).

Second, the enduring predictive power of AtL underscores the importance of behavioral engagement, persistence, and self-regulation as mechanisms through which children access and benefit from instruction. AtL may serve as a particularly feasible intervention target because it can be shaped through teacher–child interactions, classroom climate, and instructional design (McClelland, Geldhof, Cameron, & Wanless, 2018). Strategies such as promoting autonomy-supportive teaching, scaffolding sustained attention, and reinforcing task persistence may be especially beneficial for children from socioeconomically disadvantaged backgrounds, who often face structural barriers to developing these skills (Megan M McClelland & Cameron, 2011).

Third, the finding that EF and AtL each contribute uniquely to later achievement—even after controlling for SES, gender, and kindergarten entry age—suggests that cognitive and behavioral readiness represent distinct but complementary pathways to academic success. This supports multidimensional models of school readiness that emphasize the interplay between cognitive control, motivation, and learning behaviors (Vitiello & Greenfield, 2017). Policymakers and practitioners may therefore benefit from adopting assessment frameworks that capture both EF and AtL rather than relying solely on academic or behavioral indicators.

Finally, the use of a large, diverse, and nationally representative sample strengthens the generalizability of these implications. The results suggest that early EF and AtL are robust predictors across demographic groups, supporting the potential scalability of interventions targeting these skills. Given increasing policy interest in early childhood education as a lever for reducing achievement disparities, these findings highlight EF and AtL as promising, evidence-based targets for early investment (Yoshikawa, Weiland, & Brooks-Gunn, 2016).

7.2. Limitations

Despite its contributions, the study has several limitations that should be acknowledged. First, EF and AtL were assessed at a single time point, which restricts the ability to model developmental change or examine reciprocal relations between cognitive and behavioral skills. Longitudinal studies indicate that EF and learning behaviors may mutually reinforce one another over time (Fuhs, Nesbitt, Farran, & Dong, 2014) suggesting that cross-lagged or growth-curve models could yield deeper insights.

Second, although the models accounted for key demographic covariates, other contextual factors—such as instructional quality, teacher–child relationships, home learning environments, and exposure to stress—likely influence both EF development and academic achievement. Prior work shows that classroom quality and/or home environments moderate the association between EF and academic outcomes (Cadima, Verschueren, Leal, & Guedes,

2016; Pietropoli & Gracia, 2025) and future research should incorporate such variables to better understand environmental moderators.

Third, AtL was measured using teacher ratings, which may introduce subjectivity or bias. Teachers' perceptions can be influenced by classroom behavior norms, implicit expectations, or cultural differences (Ready & Wright, 2011). Incorporating multi-informant assessments, direct observations, or performance-based measures would strengthen construct validity.

Fourth, although EF was assessed using direct measures, the study focused on three EF components. Emerging research suggests that additional processes—such as inhibitory control subtypes, processing speed, and attentional shifting—may also contribute to academic trajectories (Friedman & Miyake, 2017). Expanding the EF battery could provide a more comprehensive understanding of cognitive predictors.

Finally, while hierarchical regression offers clear insights into incremental variance explained, more advanced analytic approaches—such as structural equation modeling or machine learning prediction models—could capture nonlinearities, interactions, and latent structures that traditional regression may overlook.

7.3. Future Directions

Building on these findings, several avenues for future research are warranted. First, longitudinal studies that track EF and AtL across multiple developmental periods would help clarify how these skills co-develop and jointly influence academic trajectories. Growth-mixture modeling could identify subgroups of children with distinct developmental profiles.

Second, future work should examine potential mediators and moderators of the EF–achievement and AtL–achievement relationships. For example, instructional quality, peer interactions, and home learning environments may amplify or attenuate these associations (Hamre, Hatfield, Pianta, & Jamil, 2014). Understanding these mechanisms could inform more targeted interventions.

Third, intervention research should explore whether combined EF and AtL programs yield additive or synergistic effects. Preliminary evidence suggests that interventions integrating cognitive and behavioral components may be more effective than those targeting either domain alone (Raver et al., 2011; Schmitt et al., 2015).

Fourth, future studies should investigate whether the predictive strength of EF and AtL varies across academic domains beyond reading and mathematics, such as science, writing, or problem-solving. Domain-specific analyses may reveal unique pathways linking early cognitive and behavioral skills to later competencies.

Finally, given the increasing diversity of early childhood populations, research should examine whether EF and AtL predict achievement similarly across cultural, linguistic, and socioeconomic groups. Culturally responsive measurement and intervention approaches will be essential for ensuring equitable support for all learners (Rogoff, 2016).

8. CONCLUSIONS

Taken together, the findings demonstrate that both executive function and approaches to learning at kindergarten entry serve as powerful and enduring predictors of children's academic trajectories through third grade. Working memory, in particular, emerged as a central cognitive mechanism supporting later reading and mathematics achievement, while AtL contributed uniquely by capturing behavioral engagement that facilitates learning across contexts. By integrating multiple EF components, behavioral dispositions, and key demographic controls within a single analytic framework, this study provides a clearer and more nuanced understanding of the

early skills that shape long-term academic success. These results underscore the importance of early educational environments that intentionally cultivate both cognitive regulation and positive learning behaviors, highlighting promising avenues for interventions aimed at reducing achievement disparities and promoting equitable academic outcomes.

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