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THE IMPACT OF A PLAY-BASED EXECUTIVE FUNCTION-FOCUSED PROGRAM ON EARLY LITERACY AND MATHEMATICS

Michelle L. Peters, University of Houston-Clear Lake, College of Education, Professor, Research & Applied Statistics

Amber Brown, University of Houston-Clear Lake, College of Education, Professor, Early Childhood Education

INTRODUCTION

The importance of high-quality early education on children's later cognitive and behavioral outcomes is clear (McCoy et al., 2017; Yoshikawa et al., 2013). While all children benefit from high-quality early education, children from low-income households and English Language Learners benefit the most (Blau et al. 1998; Brilli et al., 2013; Burger, 2010; Currie, 2006; Yoshikawa et al., 2013). In addition to academic benefits for children, economists have also shown the cost benefits of investing in high-quality early education, which generates approximately $7 for every dollar invested (Bartik, 2014). However, the evidence is also clear that quality is crucial when it comes to early education programs. Children in lower-quality care often develop significant cognitive delays, as well as social and behavioral issues (Belsky et al., 2007; Brilli et al., 2013; Cleveland et al., 2006; Tran & Weinraub, 2006).

Many early childhood programs contribute to the quality of early education for young children. However, the critical component is a comprehensive curriculum based on early learning standards that addresses the whole child, is developmentally appropriate, and is effectively implemented (National Association for the Education of Young Children [NAEYC], 2019; Wechsler et al., 2016; Yoshikawa et al., 2013). In addition to domain-specific content areas (e.g., emergent literacy and numeracy skills), an early childhood curriculum that focuses on child-initiated learning (Serpell & Esposito, 2016) and domain-general skills (e.g., executive functioning, critical thinking, and problem-solving) provide the best environment for long-term development and academic learning (Center on the Developing Child at Harvard University, 2011; McClelland et al., 2007). Therefore, promoting executive function skills within early education may be the key to reducing the substantial gaps in school readiness and later achievement that separate disadvantaged children from their more advantaged peers (Shonkoff & Phillips, 2000).

STATEMENT OF THE PROBLEM

Although there has been an increase in access to early childhood education, children from economically disadvantaged backgrounds often enter school with underdeveloped executive function skills that are essential for academic readiness and long-term success. Academically focused pre-kindergarten programs may not adequately support the development of these executive function skills, which can lead to persistent achievement gaps in literacy and mathematics. As a results, it is essential to investigate whether play-based, executive function-centered interventions can improve academic outcomes and promote equity for underserved populations in their early years of schooling.

BACKGROUND TO THE STUDY

What are Executive Functions?

Executive function skills are essential cognitive processes for goal-oriented problem-solving and include working memory, cognitive flexibility, and inhibitory control (Diamond, 2013; Garon et al., 2010). Working memory enables children to retain and connect information, which is essential for informed decision-making (Alloway & Alloway, 2013). Cognitive flexibility enables the ability to switch between tasks and focus on relevant information (Blair & Raver, 2015). Inhibitory control enables individuals to suppress distractions and maintain focus on goals (Garon et al., 2010).

Importance of Executive Functions

Executive functions are widely recognized as essential building blocks for academic learning and social-emotional development (Blair & Raver, 2015; Diamond, 2013). Zelazo et al. (2003) argue that these skills support self-regulation and are central to cognitive development during early childhood. These skills help children stay focused longer, make better choices, and prepare for school and future challenges (Diamond, 2013; Zelazo & Carlson, 2020). Early development of executive function skills is linked to higher academic achievement and improved social behavior (Ahmed et al., 2015; Diamond, 2013). They are crucial for planning, decision-making, and emotional regulation (Yeager & Yeager, 2013). Executive function skills are especially critical in early childhood because this is a period of rapid neurological development in the prefrontal cortex—the brain region most associated with higher-order thinking and self-control (Center on the Developing Child at Harvard

University, 2011). During this time, children are highly sensitive to environmental inputs that shape cognitive development, making early intervention both impactful and necessary (Shonkoff & Phillips, 2000).

Research shows that executive function development in early years not only predicts later academic outcomes but also contributes to mental health and adaptive behavior throughout life (Best et al., 2011). Research shows that children who develop these skills early in life are more likely to succeed academically and exhibit prosocial behavior (Blair & Raver, 2015; McClelland et al., 2015). Delays in executive function skills can hinder academic and social success, resulting in difficulties with task completion and attention (Zelazo & Carlson, 2020). A long-term study by Moffitt et al. (2011) found that children with weaker executive function skills were more likely to experience poorer health and lower life satisfaction as adults. The findings also suggested that minor improvements in these skills during childhood were linked to meaningful benefits later in life.

SOCIOECONOMIC DISPARITIES AND EXECUTIVE FUNCTION

Children from low socioeconomic backgrounds often enter school with underdeveloped executive function skills compared to their more privileged peers (Raver et al., 2013). Executive functions are essential for regulating attention, managing emotions, and organizing goal-directed behavior (Best & Miller, 2010; Diamond, 2013). These skills are foundational for academic tasks, such as following instructions, solving problems, and maintaining focus in the classroom (Blair & Raver, 2015). When children struggle with executive functioning, they are more likely to face challenges in learning environments that require sustained attention, behavioral regulation, and effective time management (McClelland et al., 2007). Early deficits in executive function can hinder academic progress from the outset, putting children at a disadvantage compared to their peers. Over time, these difficulties contribute to the ongoing academic achievement gap observed between students from different socioeconomic backgrounds (Blair & Raver, 2012; Ursache et al., 2012). Without targeted interventions, this gap tends to widen, reinforcing long-term educational disparities. Exposure to chronic stress, reduced access to enriched learning environments, and limited caregiver scaffolding can all impede the development of executive function (Evans & Schamberg, 2009; Ursache et al., 2012). As such, interventions that specifically target executive function development are particularly promising for addressing educational inequities (Blair & Raver, 2016).

THE ROLE OF PLAY IN EXECUTIVE FUNCTION DEVELOPMENT

Play has been increasingly highlighted in both psychological theory and educational practice as a powerful mechanism for supporting executive function (Bodrova & Leong, 2007; Whitebread et al., 2017). Play, particularly guided and open-ended play, helps children develop executive function skills during early childhood. Play offers the perfect setting for children to practice key executive function skills, such as working memory, cognitive flexibility, and inhibitory control (Diamond & Lee, 2011; Hirsh-Pasek et al., 2009). During play, children engage in complex and imaginative scenarios that help them develop essential cognitive skills. They practice working memory by remembering sequences and rules, demonstrate cognitive flexibility by adapting to changing roles and contexts, and exercise inhibitory control by managing impulses and delaying gratification to follow group norms or game rules.

Guided play combines the freedom to explore with intentional support from adults, allowing children to stretch their cognitive abilities in a nurturing environment. These experiences are neurologically enriching and support the development of the prefrontal cortex, an area of the brain closely linked to executive function (Pellegrini & Smith, 2007). These cognitive challenges in play stimulate the brain, strengthening the neural pathways linked to executive function. As a result, play is not just fun; it is also a powerful tool for cognitive and academic growth. By incorporating purposeful play into early education, we not only align with what is developmentally appropriate but also enhance learning.

THEORETICAL FRAMEWORK

Executive functions are best viewed through the lens of constructivism. Constructivists hold the view that as children experience their world, knowledge is created, and this knowledge is not acquired passively. According to Roopnarine and Johnson (2005), constructivist theory identifies learning at early ages as an active, contextualized phenomenon of constructing knowledge rather than merely acquiring it. The basic premise of constructivist theory is supported by Dewey (1963), Vygotsky (1978), and Piaget (1968), who found that specific environmental factors such as family and teachers facilitate the development of a student's executive function when they show engagement in the students' lives. The constructivist theory relies on the predisposition of how children naturally learn to explain the development of executive function (Bolton & Hattie, 2017; Verenikina, 2003). According to Vygotsky (1997), children learn through social interactions with older and more knowledgeable people within their environment.

FUELING BRAINS SYSTEM

Fueling Brains is an early childhood education system that focuses on measuring and developing executive function skills. The Fueling Brains system is grounded in the science of neuroplasticity and epigenetics. It takes a holistic approach focused on optimizing ecologically authentic learning opportunities. It incorporates current research and best practices in education, neuroscience, and technology to provide a systematic approach to enhancing the executive capacities of children, considering contextual and situational variables that influence development. The system utilizes brain data and the resulting iterations of adaptations to inform the development of students' executive function skills. The program draws on ecologically authentic learning opportunities to foster the generalization of skills developed, combining a hands-on, interactive instructional approach with a creative, community-focused approach. This immersive approach aims to engage the whole child in a contextualized learning experience. This focus on the whole child and executive function skills develops lifelong skills and abilities, enabling children to be successful both academically and socially (Brock et al., 2009).

RESEARCH Purpose and Question

This quasi-experimental (QED) study aimed to investigate the impact of the Fueling Brains executive function-focused program on the reading and mathematics achievement of early childhood students. The overall research question guiding the investigation was: *Is there a statistically significant mean difference in reading and mathematics achievement between students who participated in an executive function-focused program and those who participated in a traditional academic-focused early childhood program?*

METHOD

Participants

Participants were selected from pre-kindergarten (Pre-K) classrooms located in a large, economically disadvantaged, high-minority school district in the Southwest United States. In this state, children are eligible for public Pre-K if they meet specific eligibility criteria, including being economically disadvantaged, homeless, or having a parent in the military. The participating school district served approximately 24,000 students, with 2,370 enrolled in Pre-K and Kindergarten (Pre-K = 769; Kindergarten = 1,601). School district enrollment was 80.1% minority (16.2% Black, 63.9% Hispanic), higher than the state at 66.3% (12.8% Black, 53.5% Hispanic), and 71.7% of the students are eligible for free and reduced lunch.

During Year 1 of the study, 358 pre-kindergarten students from 13 schools (treatment = 6; control = 7) were selected to participate. A sample of 179 pre-kindergarten students participating in the Fueling Brains EF program (treatment group) were individually matched by gender, race, ethnicity, economically disadvantaged, and at-risk status to 179 pre-kindergarten students participating in a traditional academic-focused program (control group). By the end of 1st grade, 37 students were removed from the final analysis due to missing assessment data. Once those students, along with their matched counterparts, had been removed from the database, a total of 284 students (treatment = 142; control = 142) remained for the final analysis. Table 1 displays the demographics of the students included in this research.

Table 1

Student Demographics (n = 284)

	Treatment (%) (n = 142)	Control (%) (n = 142)
Male	52.8	52.8
Female	43.7	43.7
African American/Black	23.9	23.9
Asian	2.1	2.1
Caucasian/White	12.0	12.0
Hispanic/Latino	58.5	58.5
2 or more races	3.5	3.5
At-risk[1]	47.2	47.2
Economically disadvantaged[2]	88.7	88.7

Note: [1]A student was identified as at risk of dropping out of school using state-defined criteria, including inadequate academic progress, limited English proficiency, custody or care of the Department of Protective Services and Regulatory Services, and/or homelessness (TEA, 2020a). [2] An economically disadvantaged student is identified as one who is eligible for free or reduced-price meals under the U.S. federally mandated National School Lunch and Child Nutrition Program (TEA, 2020b).

INSTRUMENTATION

The CIRCLE Progress Monitoring System – PreK (CIRCLE) is a standardized, criterion-referenced measure developed through a collaborative effort among the U.S. Department of Education, the Texas Education Agency (TEA), and the Children's Learning Institute (CLI) at UT Health to create a pre-kindergarten assessment (CLI Engage, 2024). CIRCLE relates well to established standardized tests and is sensitive to growth in children's skills over time (Children's Learning Institute at UT Health, 2021). The data used to support the reliability and validity of the CIRCLE Progress Monitoring System were derived from numerous research studies conducted by the CLI over a five-year period. The CIRCLE assessment consists of nine directly measurable subtests and six observable subtests administered at the Beginning-of-Year (BOY, Wave 1), Middle-of-Year (MOY, Wave 2), and End-of-Year (EOY, Wave 3). Data was collected on the subtests measuring: (a) rapid letter naming, (b) rapid vocabulary, (c) phonological awareness, and (d) mathematics. Table 2 describes each of the CIRCLE subtests.

Table 2

CIRCLE Pre-K Subtests

	CIRCLE Subtest	Description
1.	Rapid Letter Naming	Student's ability to identify letters of the alphabet.
2.	Rapid Vocabulary	Student's expressive vocabulary skills.
3.	Phonological Awareness	Student's understanding of sound: (a) ability to separate a word into parts, (b) ability to blend two parts of a word together when segmented between the beginning consonant(s) and the rest of the word, (c) ability to give two or more words that have the same sound(s) at the beginning of the words, and (d) ability to distinguish if two words rhyme when spoken.
4.	Mathematics	Student's mathematical skills across multiple domains are considered to be important by the National Council of Teachers of Mathematics (NCTM), including (a) rote counting, (b) shape naming, (c) number discrimination, (d) number naming, € shape discrimination, (f) counting sets, and (g) operations.

Texas Kindergarten Entry Assessment (TX-KEA) is a standardized, criterion-referenced measure resulting from a collaborative effort between the U.S. Department of Education, the Texas Education Agency, and the Children's Learning Institute (CLI) at UTHealth to develop an assessment to be used to screen children's school readiness upon their entry into kindergarten (CLI Engage, 2025). The TX-KEA consists of six domains and 18 subtests, with most being administered at BOY, MOY, and EOY. Some of the subtests are teacher-reported, while others are student-selected. Data were collected on the subtests measuring: (a) vocabulary, (b) spelling, (c) letter names, (d) letter sounds, € decoding, (f) blending, and (g) mathematics. Table 3 describes each of the TX-KEA subtests.

Table 3

TX-KEA Kindergarten Subtests

TX-KEA Subtest	Description
1. Vocabulary	Student's vocabulary abilities.
2. Spelling	Students' early spelling abilities include the ability to use sound-symbol relationships to write words.
3. Letter Names	Students' knowledge of the names associated with various letters of the alphabet.
4. Letter Sounds	Students' knowledge of letter sounds.
5. Decoding	Student's ability to read non-high frequency words by sounding them out (decoding) rather than knowing the whole word from memory (rote visual memory).
6. Blending	Student phonological awareness, or sensitivity to the sound structure of oral language.
7. Mathematics	Student's ability to problem-solve and use mathematics in academic and everyday settings. This subtest focuses on math skills related to numbers and counting, operations, patterning, and mathematics in the real world.

Northwest Evaluation Association Measure of Academic Progress (NWEA MAP) test is a nationally validated computer-adaptive assessment that measures K-12 achievement and growth in mathematics, reading, language usage, and science (NWEA, 2025). The NWEA MAP test has been administered to over 13 million students across 146 countries, representing over 4,500 school districts and 35,900 schools. The RIT, Rasch UnIT, scores range from 100-350 and do not change based on a student's age or grade, and student growth can be tracked from year to year. Students respond to multiple-choice and fill-in-the-blank items administered at BOY, MOY, and EOY in English or Spanish. This untimed test typically takes 45-60 minutes to complete and is adaptive to whether a student gets the item right or wrong. Data were collected on the subtests measuring: (a) reading and (b) mathematics.

Data Collection & Analysis

Following IRB permission, archived student data were collected from the participating school district for BOY and EOY test scores. Classroom teachers administered BOY assessments to the students prior to any program implementation and the EOY assessments at the end of the academic school year. Given that students were nested within classrooms, the potential need for multilevel modeling was examined.

To account for the nested structure of students within classrooms, a one-way ANOVA with random effects model (also known as the null or unconditional model) was used to determine the existence and degree of unexplained variance in achievement between classrooms. The between-classroom variance was found to be nonsignificant ($p < .05$), and the intraclass correlation coefficients (ICC) were found to be less than 10% indicating that less than 10% of the variance in achievement was attributable to classroom-level differences. Given the lack of significant clustering, subsequent analyses were conducted at the student level using single-level regression models (Hox et al., 2017).

Data were analyzed using hierarchical regression analysis. Hierarchical regression analysis allowed for statistical adjustments to be made by controlling for baseline (BOY) data to correct for any initial group differences. The significance value was set at .05, and R^2 and ΔR^2 were calculated to assess the proportion of variance explained by the program.

RESULTS

Year 1: Pre-Kindergarten

Rapid letter naming. The results of the hierarchical regression analysis indicated that there was not a statistically significant mean difference in rapid letter naming scores for students in the treatment group versus those in the control group, controlling for BOY scores, $F(1, 281) = .278$, $p = .599$, $R^2 = .294$, $\Delta R^2 = .001$. The model explained 29.4% of the variance, with the addition of program type accounting for an additional 0.1% of the variance. Although a statistically significant mean difference was not found, students in the treatment group (M = 21.3, SD = 12.0), on average, scored higher in rapid letter naming than those in the control group (M = 19.7, SD = 11.4).

Rapid vocabulary. The results of the hierarchical regression analysis indicated that there was a statistically significant mean difference in rapid vocabulary subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, $F(1, 281) = 6.583$, $p = .011$, $R^2 = .255$, $\Delta R^2 = .017$. The model explained 25.5% of the variance, with the addition of program type accounting for an additional 1.7% of the variance. Students in the treatment group (M = 21.3, SD = 6.4), on average, scored higher in rapid vocabulary than those in the control group (M = 19.1, SD = 5.7).

Phonological awareness. The results of the hierarchical regression analysis indicated there was a statistically significant mean difference in phonological awareness subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, $F(1, 281) = 12.51$, $p < .001$, $R^2 = .123$, $\Delta R^2 = .039$. The model explained 12.3% of the variance, with the addition of program type accounting for an additional 3.9% of the variance. Students in the treatment group (M = 19.3, SD = 6.0), on average, scored higher in rapid vocabulary than those in the control group (M = 17.6, SD = 5.2).

Mathematics. The results of the hierarchical regression analysis indicated that there was not a statistically significant mean difference in mathematics subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, $F(1, 281) = 2.873$, $p = .091$, $R^2 = .310$, $\Delta R^2 = .007$. The model explained 31.0% of the variance, with the addition of program type accounting for an additional 0.7% of the variance. Although a statistically significant mean difference was not found to exist between the two groups of students, those in the treatment group (M = 23.1, SD = 4.4), on average, scored higher in mathematics than those in the control group (M = 22.3, SD = 6.0).

Table 4

Group Comparisons for Pre-Kindergarten

	Subtest	R^2	ΔR^2	*p*-value
1.	Rapid letter naming	.294	.001	.599
2.	Rapid vocabulary	.255	.017	.011*
3.	Phonological awareness	.123	.039	< .001*
4.	Mathematics	.310	.007	.091

*Statistically Significant (p < .05)

Year 2: Kindergarten

Vocabulary. The results of the hierarchical regression analysis indicated that there was a statistically significant mean difference in vocabulary subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, $F(1, 281) = 4.523$, $p = .034$, $R^2 = .413$, $\Delta R^2 = .009$. The model explained 41.3% of the variance, with the addition of program type accounting for an additional 0.9% of the variance. Students in the treatment group (M = 5.3, SD = 3.1), on average, scored higher in vocabulary than those in the control group (M = 5.5, SD = 3.5).

Spelling. The results of the hierarchical regression analysis indicated that there was not a statistically significant mean difference in spelling subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, $F(1, 281) = 3.775$, $p = .053$, $R^2 = .178$, $\Delta R^2 = .011$. The model explained 17.8% of the variance, with the addition of program type accounting for an additional 1.1% of the variance. Although a statistically significant mean difference was not found to exist between the two groups of students, those in the treatment group (M = 19.2, SD = 7.8), on average, scored higher in spelling than those in the control group (M = 16.9, SD = 9.4).

Letter names. The results of the hierarchical regression analysis indicated there was a statistically significant mean difference in letter names subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, F(1, 281) = 12.19, p = .001, R^2 = .187, ΔR^2 change = .035. The model explained 18.7% of the variance, with the addition of program type accounting for an additional 3.5% of the variance. Students in the treatment group (M = 10.4, SD = 1.7), on average, scored higher on letter names than those in the control group (M = 9.7, SD = 2.9).

Letter sounds. The results of the hierarchical regression analysis indicated there was a statistically significant mean difference in letter sounds subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, F(1, 281) = 6.15, p = .014, R^2 = .099, ΔR^2 change = .020. The model explained 9.9% of the variance, with the addition of program type accounting for an additional 2.0% of the variance. Students in the treatment group (M = 6.1, SD = 2.0), on average, scored higher on letter sounds than those in the control group (M = 5.7, SD = 2.3).

Decoding. The results of the hierarchical regression analysis indicated that there was a statistically significant mean difference in decoding subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, F(1, 281) = 6.812, p = .010, R^2 = .229, ΔR^2 = .019. The model explained 22.9% of the variance, with the addition of program type accounting for an additional 1.9% of the variance. Students in the treatment group (M = 3.2, SD = 2.4), on average, scored higher in decoding than those in the control group (M = 2.6, SD = 2.3).

Blending. The results of the hierarchical regression analysis indicated that there was a statistically significant mean difference in blending subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, F(1, 281) = 11.688, p = .001, R^2 = .135, ΔR^2 = .036. The model explained 13.5% of the variance, with the addition of program type accounting for an additional 3.6% of the variance. Students in the treatment group (M = 6.0, SD = 3.9), on average, scored higher in blending than those in the control group (M = 4.6, SD = 3.5).

Mathematics. The results of the hierarchical regression analysis indicated that there was a statistically significant mean difference in mathematics subtest scores for students in the treatment group versus those in the control group, controlling for BOY scores, F(1, 281) = 16.212, $p < .001$, R^2

= .283, ΔR^2 = .041. The model explained 28.3% of the variance, with the addition of program type accounting for an additional 4.1% of the variance. Students in the treatment group (M = 9.2, SD = 3.6), on average, scored higher in mathematics than those in the control group (M = 7.9, SD = 3.9).

Table 5

Group Comparisons for Kindergarten

	Subtest	R^2	ΔR^2	*p*-value
1.	Vocabulary	.413	.009	.034*
2.	Spelling	.178	.011	.053
3.	Letter names	.187	.035	.001*
4.	Letter sounds	.099	.020	.014*
5.	Decoding	.229	.019	.010*
6.	Blending	.135	.036	.001*
7.	Mathematics	.283	.041	< .001*

*Statistically Significant (p < .05)

Year 3: First Grade

Reading. The results of the hierarchical regression analysis indicated there was a statistically significant mean difference in reading scores for students in the treatment group versus those in the control group, controlling for BOY scores, F(1, 281) = 29.03, $p < .001$, $R^2 = .691$, ΔR^2 change = .032. The model explained 69.1% of the variance, with the addition of program type accounting for an additional 3.2% of the variance. Students in the treatment group (M = 166.0, SD = 12.2), on average, scored higher in reading than those in the control group (M = 159.1, SD = 11.7).

Mathematics. The results of the hierarchical regression analysis indicated there was a statistically significant mean difference in mathematics scores for students in the treatment group versus those in the control group, controlling for BOY scores, $F(1, 281) = 83.14$, $p < .001$, $R^2 = .711$, ΔR^2 change = .086. The model explained 71.1% of the variance, with the addition of program type accounting for an additional 8.6% of the variance. Students in the treatment group (M = 171.1, SD = 12.5), on average, scored higher in mathematics than those in the control group (M = 168.7, SD = 13.5).

Table 6

Group Comparisons for 1st Grade

	Subtest	R^2	ΔR^2	*p*-value
1.	Reading	.691	.032	< .001*
2.	Mathematics	.711	.086	< .001*

*Statistically Significant ($p < .05$)

DISCUSSION

The findings from this longitudinal study indicate that participation in an executive function-focused program in pre-kindergarten has significant and lasting academic benefits. Students who participated in the Fueling Brains program consistently outperformed their peers in a traditional, academic-focused setting across multiple measures of literacy and mathematics from pre-kindergarten through first grade. Specifically, significant gains were found in rapid vocabulary and phonological awareness in pre-kindergarten, vocabulary, letter names, letter sounds, decoding, blending, and mathematics in kindergarten, and sustained higher achievement in reading and mathematics at the end of first grade.

These results build on earlier research showing just how important executive function is for young children's success in school (Blair & Raver, 2015; Diamond, 2013; McClelland et al., 2015). They add to the growing evidence that skills like working memory and self-control play a key role in helping kids stay engaged and learn more effectively in the classroom (Best et al., 2011; Blair & Razza, 2007; Morgan et al., 2019; Willoughby et al., 2019). It's important to point out that the gains weren't short-lived. The academic advantages seen in first grade, based on NWEA MAP scores, suggest that strengthening executive function skills early on can help set the stage for long-term success in school. These results also support the hypothesis that early executive function-focused interventions may help close achievement gaps for children from economically disadvantaged backgrounds, who are often at heightened risk for early academic struggles (Moffitt et al., 2011; Zelazo & Carlson, 2020).

While the overall findings are promising, it is worth noting that not all assessed domains showed significant differences between groups at every time point. For example, no statistically significant differences were found in rapid letter naming in pre-kindergarten or spelling scores in kindergarten. This suggests that some skills may be less immediately responsive to executive function-focused interventions or that certain content-specific skills require direct instruction in addition to executive function development (Hayashi et al., 2013).

IMPLICATIONS

The results of this study have significant implications for early childhood education, particularly in promoting both executive function and academic growth, as well as addressing achievement gaps among students from economically disadvantaged backgrounds. The findings suggest that play-based early childhood education programs like Fueling Brains, which focus on nurturing all aspects of a child's growth, including executive function, are essential for a child's overall well-being and academic success. The increases in literacy and mathematics achievement observed among pre-kindergarten students who participated in the Fueling Brains program indicate the importance of incorporating executive function skill development into early learning environments. These achievement gains were sustained throughout pre-kindergarten and into first grade, emphasizing the influence of executive function skills on early learning and as a predictor of long-term academic success.

A key element of the Fueling Brains program is its integration of guided and open-ended play, which research increasingly supports as an effective medium for developing executive function skills. During play, children engage in complex, imaginative scenarios that require them to remember sequences and rules (working memory), adjust to changing roles and contexts (cognitive flexibility), and control impulses or delay gratification to adhere to group norms or game rules (inhibitory control). Guided play, in particular, combines the freedom of exploration with intentional adult scaffolding, helping children stretch their cognitive abilities within a supportive environment. Such experiences are neurologically enriching and promote the development of the prefrontal cortex; an area of the brain closely linked to executive function. By embedding cognitive skill-building into meaningful and engaging contexts, play serves not only as a developmentally appropriate practice but as a powerful catalyst for academic readiness.

These findings also emphasize the potential of programs that focus on developing executive function skills to help reduce disparities in academic performance related to socioeconomic status. Children from low-income families often start school with underdeveloped executive function skills, which puts them at a disadvantage in classroom settings that require sustained attention, emotional regulation, and goal-directed behavior. The data from this study demonstrate that when executive function skills are intentionally developed in early learning contexts, particularly through guided, play-based instruction, students not only show improvement in their current literacy and mathematics performance but continue to exhibit advantages in later grades. These sustained literacy and math scores suggest that executive function development may serve as a way to close the achievement gap already evident at pre-kindergarten.

At the policy level, these findings support the allocation of resources toward early intervention programs that emphasize executive function development as a means to foster school readiness and long-term success, particularly for children in low-income communities. Investing in such programs may yield long-term educational and societal benefits by reducing the need for remediation, decreasing behavioral referrals, and improving high school graduation rates. Future research should continue to explore the mechanisms by which executive function-focused instruction contributes to academic resilience and examine how these effects persist or evolve into later stages of schooling.

Unlike traditional, academically focused programs, the Fueling Brains approach supports the development of working memory, cognitive flexibility, and inhibitory control through both guided and open-ended play. The implications extend to curriculum design and instructional practice, where early childhood programs should prioritize the integration of executive function development into daily routines and learning activities. The play-based, cognitively enriching strategies employed in the

Fueling Brains program offer a developmentally appropriate and empirically supported model for fostering both cognitive and academic growth.

Additionally, these findings stress the importance of equipping early childhood educators with the knowledge and skills necessary to support executive function development through play-based learning. Teacher preparation programs and ongoing professional development initiatives should focus on the role of executive functions in learning, providing educators with practical strategies for incorporating executive function-building opportunities and creating play-based, contextualized learning environments within daily instruction. Teachers are crucial in facilitating the enriched, socially interactive experiences that foster executive function development.

The findings of this study highlight the importance of developing executive function skills and their impact on academic success in school, as these skills are crucial to the learning process. Investing in early education that focuses on executive function development is a promising approach to enhancing individual academic growth and promoting equity in early childhood education. Additional research needs to conducted to continue adding to the body of literature addressing the impact of Ef skills on children.

FUTURE RESEARCH

Longitudinal studies are needed to assess the long-term impact of early executive function development on academic, behavioral, and social-emotional outcomes beyond the primary grades. Further longitudinal research on executive function-focused early childhood programs and traditional academic instruction could reveal strategies for maximizing student learning. Future studies are also needed to explore which specific components of executive function-focused interventions are most effective and how these approaches can be adapted to different educational contexts utilizing both quantitative and qualitative data.

CONCLUSION

Executive functions are essential cognitive processes that play a crucial role in childhood development, academic achievement, and overall life outcomes. Executive function skills, like working memory, flexibility, and self-control, are key to how well kids can learn and succeed in school. The results of this study indicate that early childhood programs like Fueling Brains, which focus on developing executive functions through guided and open-ended play, can significantly improve young children's literacy and math skills. This research highlights how focusing on executive function skills can help close the achievement gap, especially for children from low-socio economic backgrounds. The findings suggest that early interventions to strengthen these skills could make a real difference in narrowing disparities in academic achievement.

Based on this study's results, policymakers and educators should consider including executive function training in early childhood programs. Play-based activities that promote problem-solving, goal-setting, and self-regulation can help kids develop essential skills for success in school and beyond. In conclusion, enhancing executive functions through these activities shows promise in improving educational outcomes and fostering lifelong success, particularly for children from historically marginalized communities. In conclusion, strengthening executive functions through play-based activities holds promise for improving educational outcomes and fostering lifelong success, especially for children from historically marginalized communities.

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