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Article

Bridging the science achievement gap: Using survival analysis to assess the impact of center-based early childhood programs on children with disabilities

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Abstract: Understanding the factors that influence early science achievement is crucial for developing effective educational policies and ensuring equity within the education system. Despite its importance, research on the patterns of young children achieving science learning milestones and the factors that can reduce disparities between students with and without disabilities remains limited. This study analyzes data from the Early Childhood Longitudinal Study of Kindergarten Cohort 2011 (ECLS-K: 2011), which includes 18,174 children from 1328 schools across the United States, selected through a complex sampling process and spanning kindergarten to 5th grade. Utilizing survival analysis, the study finds that children with disabilities achieve science milestones later than their peers without disabilities, with these disparities persisting from early grades. The research highlights the effectiveness of center-based programs in enhancing science learning, particularly in narrowing the achievement gap between children with and without disabilities. These findings contribute to the broader discourse on equity in the education system and policy by introducing novel methodologies for assessing the frequency and duration of science learning milestones, and by providing insights into effective strategies that support equitable science education.

Keywords: education system; science achievement; disparities; students with disabilities; societal equity; center-based programs; education policy; survival analysis

1. Introduction

For decades, policymakers and researchers have focused on enhancing science achievement among U.S. students (Betancur et al., 2018; Quinn and Cooc, 2015). This focus has increased as science-related jobs are projected to grow faster than other fields (Pew Research Center, 2021). Currently, 15% of the U.S. workforce is employed in computer, engineering, and science fields, which, along with other STEM (Science, Technology, Engineering and Mathematics)-related areas, are anticipated to make up the top 30 fastest-growing occupations by 2026 (U.S. Bureau of Labor Statistics, 2018).

Despite their potential to fill positions, 85% of students with disabilities (SWD) graduates are underemployed or unemployed (Griffiths et al., 2021). Here, disabilities are defined as those that qualify children for special education services under the Individuals with Disabilities Education Act (IDEA) (P.L. 101–476), including intellectual disabilities, hearing and visual impairments, speech or language impairments, emotional disturbances, orthopedic impairments, autism, traumatic brain injuries, other health impairments, and specific learning disabilities. Children must require special education and related services to access their education.

Employment enhances self-concept, adaptability, social interaction, well-being, and productivity, while unemployment results in lower life quality, financial outcomes, and day time activities for SWD (Almalky, 2020; Beyer et al., 2010; Taylor and Seltzer, 2011; Zikic and Hall, 2011). Building on the growing demand for STEM-related careers, equitable STEM learning opportunities are essential for improving future employment outcomes for SWD.

Educators increasingly recognize the importance of addressing the diverse learning needs and strengths of all students in STEM fields. The Next Generation Science Standards (NGSS Lead States, 2013) and the Framework for K-12 Science Education (National Research Council, 2012), which underpin the NGSS, aim to provide equitable and high-quality science education for all students. In this context, many interventions and instructional methods have been designed and implemented to improve STEM outcomes for SWD. For instance, Universal Design for Learning (UDL) has been used as a framework for STEM education for SWD, considering their abilities, age, culture, disabilities, gender, preferences, and sexual orientation (Basham et al., 2020; Schreffler et al., 2019).

However, STEM learning for SWD has mainly been studied in middle school, high school, and postsecondary education, with limited research on early STEM experiences in kindergarten and primary grades. Early childhood is crucial for introducing STEM (Clements and Sarama, 2014). Young children can observe, explore, and understand their world, developing conceptual knowledge (National Research Council, 2012). Engaging in early science practices fosters curiosity and scientific thinking, offering chances to grasp basic natural phenomena and foundational science skills (Eshach and Fried, 2005). However, this potential often remains unrealized, especially for SWD.

Morgan et al. (2016) found that low general knowledge at kindergarten entry predicts struggles in science through eighth grade, with science achievement gaps beginning early and persisting. These gaps are largely explained by modifiable factors, emphasizing that kindergarten general knowledge is the strongest predictor of future science achievement. This study highlights the significance of missed opportunities in STEM learning, showing that early educational interventions are crucial for long-term success in science. Addressing these gaps early is essential to ensure all students have the foundation to succeed in STEM fields.

While there is increasing recognition of the need for equity in STEM education, the focus remains primarily on low-resource and underserved racial and ethnic groups. Underserved children, especially those in poverty and cultural and linguistic minority groups, face a significant STEM opportunity gap, showing lower achievement levels (Betancur et al., 2018; Jang et al., 2024; Pew Research Center, 2021; Riegle-Crumb and King, 2010). These achievement gaps are widening (Darling-Hammond, 2007) and start early. Low-income children enter kindergarten with less STEM knowledge than their middle-income peers due to limited opportunities at home and school, with science being particularly concerning as Head Start children have the lowest readiness scores compared to other learning domains (Clements et al., 2016; Greenfield et al., 2009).

What about SWD? The U.S. Department of Education’s Civil Rights Data Collection showed that disparities in STEM opportunities for school-age children are evident, with SWD constituting 8% of biology students, 4% of Algebra II, chemistry, and physics students, and less than 1% of calculus students (Clements et al., 2020). While research has highlighted these disparities among older students with disabilities, it has largely overlooked the specific needs of young children with disabilities, especially when compared to other underserved groups. Families of children with disabilities and special needs report limited child care options (Sullivan et al., 2018; Weglarz-Ward and Santos, 2018), which may restrict their opportunities for STEM experiences within center-based settings. They rely heavily on informal care, have fewer weekly care hours, and experience more instability than children without special needs (Booth-LaForce and Kelly, 2004; Knoche et al., 2006). With less than 45% of children with disabilities ages 3–5 receiving most special education services in regular early childhood classrooms (U.S. Department of Education, 2017), there is a need for more access to inclusive STEM environments and resources for quality STEM education for all children, including those with disabilities.

Given the lack of compelling evidence on the early emergence of science achievement gaps between students with and without disabilities, as well as the specific factors that reduce these disparities, this study aims to investigate the developmental characteristics that impact science achievement and the role of center-based programs in addressing these gaps. This study is grounded in the Ecological Systems Theory (Bronfenbrenner and Morris, 1998), which posits that individual development is shaped by context, highlighting the uneven distribution of opportunities for early learning and development among children. The hypothesis suggests that systematic disparities originating from these contextual differences may contribute significantly to the observed science achievement gaps between children with and without disabilities.

The implementation of national science standards and policies requires robust methods to accurately assess children's science achievement, particularly in determining whether students reach critical milestones for timely diagnosis and intervention. However, many studies fall short in addressing the timing of these milestones, relying on cross-sectional data or static models like logistic regression that overlook the dynamic nature of longitudinal processes (Lougheed et al., 2019; Scarborough et al., 2011). This methodological gap hampers the understanding of science achievement needed to align with national standards, which aim to inform evidence-based policies and address the specific challenges faced by students with disabilities (SWD). This study used survival analysis to identify children at specific ages who exhibit superior science achievement and to find factors that reduce disparities. This method measures the time taken to reach milestones, providing insights into individual science achievement as a developmental process.

This study addressed two primary research questions: (1) How did patterns and variations in the attainment of the science learning threshold for children with and without disabilities evolve over time? (2) Do center-based programs reduce the observed science achievement gaps between children with and without disabilities? The hypotheses were that children with disabilities would reach the science learning threshold later than those without disabilities, with these achievement gaps appearing early and persisting through early and middle childhood. It was anticipated that center-based programs would enhance science learning, particularly by narrowing the learning disparity between children with and without disabilities.

2. Materials and methods

2.1. Dataset

The current study analyzed data from the Early Childhood Longitudinal Survey-Kindergarten Class of 2010–2011 (ECLS-K: 2011), conducted by the National Center for Educational Statistics (NCES). The dataset includes 18,174 children from 1328 schools, selected through multistage probability sampling, with data collected from kindergarten in 2010 through 5th grade in 2015. Parental consent was obtained. The sample was diverse, with 49% girls and 51% boys. Racial/ethnic distribution was: 1% Native American/Pacific Islander, 8.5% Asian, 13% Black, 53% Caucasian, 25.3% Hispanic, and 4% multiracial. Home languages were 80.6% English, 18.3% non-English, and 1.1% multilingual. Socioeconomic status distribution was: 21.3% below poverty level, 23.7% between 100%–199% of the poverty level, and 54.9% at or above 200% of the poverty level. The NCES employed strategies to maximize the participation of children with disabilities in the ECLS-K without oversampling them. Children were identified as having a disability if they met federal special education eligibility and had an individualized education program (IEP) or 504 plan on record. Field supervisors then assessed the need for accommodations to conduct the direct child assessment.

2.2. Measures

2.2.1. Science

The science assessment evaluated students' knowledge and skills in earth and space science, physical science, life science, and scientific inquiry. Based on their responses to 15 initial questions, students were directed to one of three follow-up test forms. To ensure reading ability did not affect science scores, questions, response choices, and visible text (e.g., graph labels) were read aloud (Tourangeau et al., 2015). The science cut-off score provides a benchmark for assessing science proficiency (Halle et al., 2012).

2.2.2. Center-based ECE participation

Respondents provided retrospective reports on their children's nonparental care in the year before kindergarten. Children who attended a daycare center, nursery school, preschool, or prekindergarten program regularly in the year prior to starting kindergarten were coded as participating in center-based care.

2.3. Analytic strategy

Research Question 1 focused on examining the changing patterns and differences in reaching the science learning threshold over time for children with and without disabilities. This analysis utilized the Kaplan-Meier survival analysis method (Guo, 2010; Kaplan and Meier, 1958). Research Question 2 aimed to identify the characteristics of children who exceed the established science learning threshold and to determine if center-based early childhood programs help narrow the science achievement gaps. A multilevel Cox regression analysis (Cox, 1972; Therneau, 2024) was used to address this question. Further details on these analyses are outlined below.

Numerous studies on developmental thresholds examine the relationship between variables measured at a particular point in time and the later achievement of developmental milestones. However, this approach does not shed light on when the threshold is surpassed or the distinctions between early and late achievers. This study seeks to enhance the understanding of children's attainment of learning thresholds by including the timing of milestone achievement in the analysis.

This study uses survival analysis to examine the dynamic relationship between children's developmental characteristics, experiences, and their achievement of the science learning threshold. Survival analysis (Clark et al., 2003; Guo, 2010) estimates the conditional probability of reaching the specified threshold, treating it as a time-dependent variable that captures both whether the threshold is achieved and when it is achieved. The analysis focuses on the time children take to reach the threshold, with some not achieving it by Spring 2016, resulting in censored data. For example, Child A, observed for 6 semesters, reaches the threshold, while Child B, tracked for 11 semesters, does not, leading to right-censored data. This underscores the importance of survival analysis in accurately interpreting longitudinal data (Clark et al., 2003; Guo, 2010).

The Kaplan-Meier (KM) method was employed to estimate survival probabilities based on observed survival times, where $S(t)$ represents the probability of survival beyond the t-th semester. Unlike traditional approaches, KM accounts for censored data, retaining partial information. This method was used to identify trends in children's progress toward reaching the science learning threshold over time (Guo, 2010; Kaplan and Meier, 1958).

To explore factors associated with children's attainment of the science learning threshold, multilevel Cox regression was applied (Cox, 1972; Therneau, 2024). This approach analyzed the timing of children surpassing the threshold while accounting for the nested structure of children within schools. A random effect was incorporated to capture differences in hazard functions across schools. Child-level characteristics were categorized as time-invariant (e.g., gender) or time-varying (e.g., age) and were examined for their relationship with achieving the science learning threshold.

Gender, race/ethnicity, and dual language learner status were included as covariates due to their well-documented association with children's science achievement in prior research (e.g., Morgan et al., 2016). Although some variables are highly correlated (as shown in **Table 1**), it is essential to control for fundamental demographic and developmental factors due to their established relevance to science achievement.

Parameter estimates were expressed as hazard ratios (HR) for easier interpretation, calculated as $HR = exp\,[\beta]$. In equation 1.1, $h_{ij}(t)$ represents the hazard of child j in school i achieving the science threshold during semester t. This hazard is modeled as $h_0(t)$, the baseline hazard function, multiplied by $exp(v_i)$, an exponentiated school-specific random effect, and the exponentiated linear function of the time-varying predictors $X_{ij}(t)$ and the time-invariant predictors X_j.

$$h_{ij}(t) = h_0(t) \times exp\,(v_i) \times exp\Big(\beta_1 Age_{ij}(t) + \beta_2 Gender_j(t) + \beta_3 White_j(t) + \beta_4 Black_j(t) + \beta_5 Hispanic_j(t) + \beta_6 DLL_j(t) + \beta_7 Disability_{ij}(t) + \beta_8 Early\ Childhood\ Center\ Based\ Program_j(t)\Big) \tag{1}$$

Table 1. Repeated measures correlation table.

	Age	**Male**	**White**	**Black**	**Hispanic**	**DLL**	**Disability**	**Center-Based Program**
Age	1.00	0.00	−0.01	0.01	0.00	0.00	−0.06	0.01
Male	-	1.00	0.05	0.00	−0.01	−0.02	0.11	0.00
White	-	-	1.00	−0.52	0.19	−0.17	0.03	0.01
Black	-	-	-	1.00	−0.12	−0.03	0.02	−0.02
Hispanic	-	-	-	-	1.00	−0.06	−0.05	−0.13
DLL	-	-	-	-	-	1.00	−0.04	−0.02
Disability	-	-	-	-	-	-	1.00	0.03
Center-Based Program	-	-	-	-	-	-	-	1.00

3. Results and discussion

This discussion demonstrates the use of survival analysis to examine patterns and variations in the time it takes for children with and without disabilities to reach the science learning milestone. Additionally, it explores potential relationships between various child characteristics and experiences and the duration required to achieve this outcome.

3.1. Patterns and variations in science milestone attainment between children who have faced disabilities and those who have not

Figure 1 depicts the estimate of $S(t)$, representing the probability that children remain below the science learning threshold beyond the t-th semester. The graph shows a steady decline, reflecting cumulative probabilities. This pattern indicates that the likelihood of remaining below the threshold for t semesters depends on having stayed below it for $t-1$ semesters. The Kaplan-Meier curve is characterized by stepwise estimates, rather than smooth functions, which is typical of non-continuous data presentation (Guo, 2010; Kaplan and Meier, 1958). The vertical gaps between horizontal segments highlight changes in the cumulative probability of staying below the threshold at different points on the curve. Censoring impacts survival rates, with censored observations typically marked immediately following the event.

Kaplan-Meier models were used to assess whether certain groups of children were more likely to remain below the science learning threshold. Survival rates for two groups were compared, with visual representations of the survival functions providing deeper insights. The chart displays distinct survival curves for children with and without disabilities, with time (semesters) on the *x*-axis and the probability of remaining below the threshold on the *y*-axis. At specific points, the curves diverge, indicating differing survival patterns. This suggests statistically significant differences in the likelihood of remaining below the threshold between children with and without disabilities. The log-rank test, covering the entire follow-up period, revealed that children without disabilities were more likely to exceed the science learning threshold earlier than children with disabilities ($\chi^2 = 17.3, df = 1, p < 0.001$).

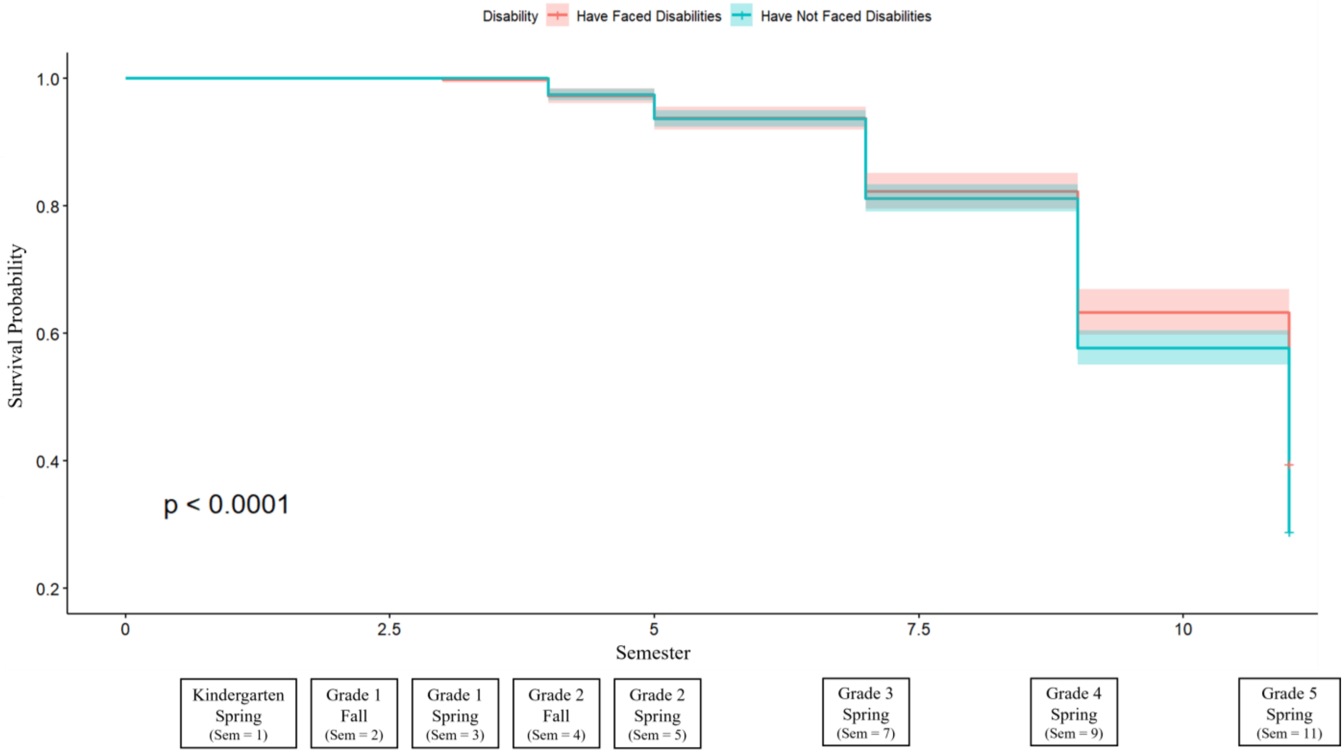

Figure 1. Log-rank test: Children with disabilities vs. without disabilities.

The findings reveal that children with disabilities have an 82.2% probability of remaining below the threshold beyond the 3rd grade, compared to an 81.1% likelihood for children without disabilities. This gap widens in later grades. By the 4th grade, the probability for children with disabilities to stay below the threshold is 63.2%, while it is 57.7% for children without disabilities. By the 5th grade, these probabilities drop to 39.4% for children with disabilities and 28.8% for children without disabilities, highlighting the enduring nature of these disparities (**Table 2**).

Table 2. Survival probability: Children with disabilities vs. without disabilities.

Disability	Semester	Survival probability	Standard error	Lower 95% confidence interval	Upper 95% confidence interval
Have faced disabilities	K spring	1.000	-	-	-
	G1 fall	1.000	-	-	-
	G1 spring	0.997	0.001	0.993	1.000
	G2 fall	0.972	0.006	0.960	0.984
	G2 spring	0.937	0.009	0.919	0.955
	G3 spring	0.822	0.014	0.795	0.851
	G4 spring	0.632	0.018	0.598	0.669
	G5 spring	0.394	0.018	0.360	0.432

Table 2. (*Continued*).

Disability	Semester	Survival probability	Standard error	Lower 95% confidence interval	Upper 95% confidence interval
Have not faced disabilities	K spring	1.000	-	-	-
	G1 fall	1.000	-	-	-
	G1 spring	0.999	0.000	0.998	1.000
	G2 fall	0.974	0.004	0.965	0.983
	G2 spring	0.936	0.006	0.923	0.950
	G3 spring	0.811	0.010	0.790	0.833
	G4 spring	0.577	0.013	0.550	0.604
	G5 spring	0.288	0.012	0.265	0.314

3.2. Factors mitigating the disparities in science achievement

Multilevel Cox regression was utilized to investigate factors related to children's success in reaching the science learning threshold, with an emphasis on disparities in science achievement. The findings from this multilevel survival analysis are presented in **Table 3**. A Hazard Ratio (HR) of 1 or a coefficient (β) of 0 suggests no relationship between the predictor and the outcome. An HR greater than 1 or a positive coefficient indicates that higher predictor values are associated with an increased likelihood of surpassing the threshold, whereas an HR less than 1 or a negative coefficient implies a reduced likelihood of surpassing the threshold as predictor values increase (Cox, 1972).

Table 3. Multi-level cox regression.

	Model 1			Model 2		
	Estimate	**Standard error**	**Hazard ratio (HR)**	**Estimate**	**Standard error**	**Hazard ratio (HR)**
Main effects						
Age	0.01*	0.00	1.01	0.01**	0.00	1.01
Male	0.10*	0.04	1.11	0.10*	0.04	1.11
White	−0.01	0.08	0.98	−0.01	0.08	0.98
Black	−0.66***	0.11	0.51	−0.66***	0.11	0.51
Hispanic	−0.67***	0.07	0.50	−0.67***	0.07	0.50
Dual language learner	−0.19	0.17	0.82	−0.20	0.17	0.81
Disability	−0.19**	0.07	0.81	−0.54**	0.18	0.58
Center-based Program	0.18**	0.06	1.20	0.14*	0.06	1.16
Moderation						
Disability × center-based program	-	-	-	0.41*	0.20	1.50

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The likelihood of exceeding the science learning threshold significantly increased for older children ($\beta = 0.01, HR = 1.01, SE = 0.00$), boys ($\beta = 0.10, HR = 1.11, SE = 0.04$), non-Black children ($\beta = -0.66, HR = 0.51, SE = 0.11$), non-Hispanic children ($\beta = -0.67, HR = 0.50, SE = 0.07$), children who have not faced disabilities ($\beta = -0.19, HR = 0.81, SE = 0.07$), and those who received nonparental care in the year before kindergarten ($\beta = 0.18, HR = 1.20, SE = 0.06$). These findings underscore disparities within child demographic and developmental characteristics.

Additionally, the negative impact of disabilities on the likelihood of surpassing the science learning threshold was mitigated when children received nonparental care prior to kindergarten ($\beta = 0.41, HR = 1.50, SE = 0.20$). Children with disabilities who regularly attended a daycare center, nursery school, preschool, or prekindergarten program in the year before they started kindergarten were more likely to meet or exceed the science learning threshold. This attendance reduced the difference in science outcomes between them and children without disabilities, giving them a better chance to perform on par with their peers.

4. Discussion

This research utilized data from the Early Childhood Longitudinal Study of the Kindergarten Cohort 2011 (ECLS-K: 2011) to examine the development of disparities in science achievement between children who have faced disabilities and those who have not, from kindergarten through 5th grade. The study also explored how nonparental care prior to kindergarten might mitigate these disparities. The primary goals were twofold: first, to analyze the patterns and variations in the achievement of the science learning threshold for children with and without disabilities over time; and second, to investigate the lasting impact of center-based early childhood programs on their performance exceeding the science learning threshold.

The inferential analyses revealed the following insights: (1) Children who have not faced disabilities are more likely to surpass the science learning threshold earlier than those who have faced disabilities. After accounting for censoring, the likelihood of children with disabilities remaining below the threshold beyond 3rd grade is 82.2%, compared to 81.1% for children without disabilities. This disparity becomes more pronounced in later grades, with the probabilities decreasing to 39.4% for children with disabilities and 28.8% for children without disabilities by 5th grade. (2) Children with disabilities who attended daycare, nursery school, preschool, or prekindergarten regularly in the year before kindergarten were more likely to meet or exceed the science learning threshold during elementary school. This early attendance helped narrow the gap in science outcomes between them and children without disabilities.

This research underscores the importance of fostering science interest from early childhood through elementary school for all children. The U.S. science education reforms like the K-12 Science Framework (National Research Council, 2012) and NGSS (2013) emphasize starting science education from kindergarten to 3rd grade. However, most research focuses on middle and high school, with less attention on early development. In addition, national science standards stress the importance of providing equitable, high-quality science education to all students from an early age, aiming to address disparities among underrepresented groups (Betancur et al., 2018; Griffiths et al., 2021; Guss et al., 2024; Lee et al., 2019; Quinn and Cooc, 2015), including children with disabilities. Despite this emphasis, research on these disparities is limited compared to studies on gaps in reading and math skills (Scammacca et al., 2020). This study examines the disparity in science outcomes between children with and without disabilities from early years, linking its results to prior research and contributing to the existing body of knowledge.

Research shows that high-quality center-based early childhood programs can help close the achievement gap, particularly benefiting children from low-income families and those who do not speak English at home (Li et al., 2013). Landmark studies from the 1960s (Perry Preschool) and 1970s (Abecedarian) indicate that high-quality early education can mitigate or eliminate the achievement gap in children (Yazejian et al., 2015). Recent randomized clinical trials, quasi-experimental studies, and observational studies (Welsh et al., 2010) confirm that high-quality center-based early childhood programs have long-term positive effects through elementary school (Belsky et al., 2007) and high school (Vandell et al., 2010).

However, few studies have explored how children’s experiences in center-based early childhood programs, such as daycare, nursery school, preschool, or prekindergarten, impact the science achievement gap between children with and without disabilities during the elementary years. The current study uncovered that children with disabilities who attended center-based programs before kindergarten were more likely to meet or exceed science learning thresholds in elementary school, narrowing the gap in science outcomes with children without disabilities. These findings align with prior research on the role of center-based early childhood programs in mitigating science achievement gaps. Skilled teachers nurture children’s understanding of science by harnessing their natural curiosity and fostering developmentally appropriate, STEM-infused play. They encourage questioning, exploration, collaboration, and reflection (Clements and Sarama, 2014) and support hands-on learning, such as digging for worms and raising plants, to deepen children’s understanding of the world (Clements et al., 2016). While previous research focused on the role of center-based programs for children from low-income families and those who are dual language learners, this study makes a unique contribution by demonstrating the long-term effect of center-based programs on the science achievements of children with disabilities.

The study’s implications extend to practical, policy, and research domains. Disparities in science achievement between children with and without disabilities begin early and persist, underscoring the need for targeted efforts during the formative years, including early elementary and preschool stages. Children with disabilities are an underserved group that requires high-quality center-based programs to narrow the developmental gap with their peers without disabilities (Sullivan et al., 2018; Weglarz-Ward and Santos, 2018). However, the range of conditions recognized as disabilities varies, necessitating diverse and tailored supports for science achievement. While high-quality care significantly benefits these children, they need services and supports aligned with their specific needs to fully benefit from such environments (Henly and Adams, 2018). Targeted professional development and specialized equipment present practical solutions to bridge this gap, facilitating the creation of inclusive science classrooms in early childhood.

Additionally, this study improves our understanding of science learning by analyzing both the occurrence and duration of milestone attainment. National science standards require categorizing performance levels such as “exceeding” or “falling short” of the learning threshold. Many studies neglect the timing of attainment, which is essential for understanding when children are likely to succeed and the factors that influence early achievement. Methodologically, survival analysis offers strong tools for assessing the probabilities of science achievement and for facilitating early diagnosis and intervention. This method enables more precise identification of children at risk of falling behind, allowing for targeted interventions that can be implemented early in their educational trajectory. This is especially critical for children with disabilities, who may require tailored support to achieve developmental milestones.

The study has several limitations. First, it lacks intersectional analysis of demographic factors such as gender, race/ethnicity, socio-economic status, and disabilities. Second, the findings are limited by focusing solely on the United States, reducing their generalizability to other countries. Third, data from 2010–2016 may not reflect current conditions due to demographic changes and societal shifts, including COVID-19. Fourth, despite its comprehensive longitudinal design, the study’s reliance on ECLS-K data may overlook earlier manifestations of academic gaps. Fifth, transforming continuous achievement data into categorical variables may result in information loss. While this approach helps to address performance levels inadequately captured by traditional methods, it may obscure finer details of student progress and variations in achievement. Sixth, a specific limitation of the ECLS-K dataset is that students with disabilities were not oversampled, which may affect the generalizability of the findings to the broader population of students with disabilities. To create a better estimate of sampling error, the multi-level extension of survival analysis was used to account for the nested structure of the ECLS-K data. To further enhance generalizability, particularly for students with disabilities, future studies should consider oversampling this population. Additionally, future research should adopt experimental designs, incorporate intersectional analyses, utilize recent international datasets, and examine disparities from birth to inform more effective early intervention strategies. Finally, the study lacks innovative approaches for measuring children’s science learning through standardized assessments; future research could utilize AI-driven methods, such as analyzing log data (Jang et al., 2020) and textual data (Jang and Leech, 2023), to more effectively evaluate the depth of science concept understanding.

Conflict of interest: The author declares no conflict of interest.

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