Article:
Di Lonardo Burr, S., Xu, C. and Susperreguy, M.I. (2026) The role of school socioeconomic status in early mathematical development in Chile. Journal of Experimental Child Psychology, 272. 106583. ISSN: 0022-0965

https://doi.org/10.1016/j.jecp.2026.106583

The Role of School Socioeconomic Status in Early Mathematical Development in Chile

Sabrina Di Lonardo Burr[1*], Chang Xu[2] , & María Inés Susperreguy[3]

[1] School of Psychology, University of Sheffield

[2] School of Psychology, Queen's University Belfast

[3] Faculty of Education, Pontificia Universidad Católica de Chile

This manuscript was accepted for publication in the *Journal of Experimental Child Psychology* on July 1, 2026. This preprint is the peer-reviewed accepted version but has not yet been copyedited and may differ from the final version published in the journal.

Abstract

This preregistered study examined how school socioeconomic status (SES) relates to the development of mathematical skills. At the study's start, Chilean children were enrolled in kindergarten (n = 101; M_{age} = 5.9 years; 51 low SES; 48 boys), Grade 1 (n = 95; M_{age} = 6.8 years; 46 low SES; 52 boys), Grade 2 (n = 87; M_{age} = 7.9 years; 52 low SES; 47 boys), or Grade 3 (n = 84; M_{age} = 8.8 years; 52 low SES; 38 boys). Children completed cognitive (receptive vocabulary, number comparison, number ordering), mathematics (calculation, math fluency, applied problems), and literacy (letter-word identification, passage comprehension) tasks. Across domains, children from high-SES schools outperformed children from low-SES schools**.** Patterns consistent with widening SES differences were observed for mathematics outcomes that rely more heavily on formal instruction, including calculation, math fluency, and applied problems, though the timing and magnitude of these effects varied by outcome and grade. For cognitive precursors, SES differences were generally stable across grades, with the exception of receptive vocabulary, for which SES differences widened by Grade 3. Longitudinally, school SES predicted one-year gains in calculation and math fluency, but not literacy outcomes, after accounting for maternal education and cognitive precursors**.** These findings highlight the compounding role of school SES in children's mathematical development within a segregated education system, pointing to a need for policies and practices that promote equitable learning opportunities.

Keywords: Socioeconomic status, mathematical development, cognitive precursors

The Role of School Socioeconomic Status in Early Mathematical Development in Chile

The foundational numeracy and mathematical skills acquired during the early years of formal education are predictive not only of later mathematics performance but also general academic success and long-term economic outcomes (Dougherty, 2003; Duncan et al., 2007; Watts et al., 2014). Consistently, socioeconomic status (SES) has been identified as a key determinant of early mathematical skills, with children from low-SES backgrounds entering school with lower levels of numerical and cognitive preparedness than their higher-SES peers (Duncan & Magnuson, 2011; Sirin, 2005). However, what remains unclear is how school socioeconomic context contributes to changes in mathematical development once children enter formal schooling, above and beyond family background.

A central unresolved issue is whether the mathematics achievement gap between low- and high-SES students widens, narrows, or remains stable during formal schooling and whether the size of the gap differs based on the mathematical skills assessed (Ayala et al., 2024; Baumert et al., 2012; Denton & West, 2002; Nennstiel, 2023; Short & McLean, 2023; Skopek & Passaretta, 2021; Von Hippel et al., 2018). These patterns have been interpreted in terms of three competing developmental frameworks that differ in how educational processes are expected to shape SES-related differences over time. A divergence account (often described as a Matthew effect; Stanovich, 1986) proposes that early SES-related differences are amplified over time due to cumulative advantages in instruction and skill acquisition. A compensatory account proposes that formal schooling reduces initial SES differences by providing more standardized instruction and structured learning opportunities that support lower-SES students in catching up to their peers (Cremin, 1951). A stability account proposes that SES-related differences are largely established prior to schooling and remain relatively constant during early education, with limited systematic convergence or divergence (Von Stumm et al., 2022). In the present study, we investigate these trajectories in Chilean students during the early years of formal education to determine how school SES is related to improvements in mathematics in areas that align with classroom instruction.

Socioeconomic Disparities in Mathematics Achievement

Children from low-SES families tend to enter formal schooling with weaker numerical skills than children from higher-SES families (Duncan & Magnuson, 2011; Sirin, 2005). For example, data from the Early Childhood Longitudinal Study (ECLS-K) in the United States indicate that children in the bottom SES quintile perform approximately 1.3 standard deviations lower on early numeracy tasks than their peers in the highest SES quintile upon kindergarten entry (Duncan & Magnuson, 2011, 2012). These tasks include number identification, shape recognition, counting, and basic arithmetic understanding, highlighting the breadth of SES disparities at school entry. Importantly, similar SES-related gaps have been documented across diverse national contexts, including China, Germany, Turkey, and the United Kingdom, indicating that the phenomenon is global, though the magnitude varies depending on educational systems and the specific mathematical skills being assessed (Altindağ Kumaş, 2022; Blakey et al., 2020; Liu et al., 2020; Sirin, 2005; Skopek & Passaretta, 2021; Von Hippel & Hamrock, 2019).

Developmentally, the trajectories of these gaps remain less clear, in part because they appear to differ based on age and mathematics assessment. Several studies provide evidence consistent with the divergence account, documenting widening gaps (i.e., Matthew effects) as children progress through school. For example, using data from the Chilean Early Childhood Longitudinal Survey, Ayala et al. (2024) found that for primary school children in Chile (7 to 12), the SES gap widened exponentially for written calculations and math fluency. This finding aligns with other research suggesting that mathematical tasks with higher linguistic and cognitive demands, such as arithmetic fluency, calculation, and problem solving, tend to show larger SES disparities than tasks that are less dependent on language, such as number comparisons (Jordan et al., 1992; Laski et al., 2016; Short & McLean, 2023). Similarly, in the US Johnson et al. (2022) observed a growing income gap in mathematical achievement from kindergarten to Grade 6, and Jordan et al. (2009) noted that low-income students showed slower progress in a general mathematics assessment from Grade 1 to Grade 3.

In contrast, other research provides evidence consistent with the compensatory account, documenting narrowing gaps as children progress through school. For example, using large datasets collected with children in the US, Reardon (2011) found that the gap declined between ages 7 and 9 (Prospects Grade 1) and at age 13 (Prospects Grade 3) for math concepts and applications. Similarly, using the ECLS-K (1999, 2011) data of US children, Von Hippel et al. (2018) found that the SES gap in mathematical achievement decreased during the kindergarten and Grade 1 school year. Thus, in the earliest stages of education, schooling might act as an equalizer.

Finally, some research provides evidence consistent with the stability account or suggests more complex and context-dependent trajectories. For example, Ayala et al. (2024) found that the gap in applied problem solving increased initially but then remained constant for Chilean primary school children. Similarly, using data from the National Educational Panel Study in Germany, Skopek and Passaretta (2021) found that the gap increased during primary school then stabilized in secondary school. Research by Von Hippel et al. (2018) adds another layer of complexity. Using data from two cohorts (1999, 2011) from the ECLS-K, they found that for the 1999 cohort the SES gap decreased during kindergarten, grew during the summer, and then decreased during Grade 1, suggesting that schools are equalizers. In the 2011 cohort, they also observed a decrease in kindergarten followed by a growth during the summer, but then the math gaps remained constant during Grade 1 and Grade 2, suggesting that inequality originates prior to formal schooling. However, in a study using data from Canada’s National Longitudinal Study of Children and Youth (NLSCY), Caro et al. (2009) found that the academic achievement gap remained fairly stable in childhood (ages 7 to 11), but then widened at an increasing rate during early adolescence (ages 11 to 15). Collectively, these findings suggest that SES-related differences in mathematics may vary across developmental periods, mathematical domains, and the educational contexts in which children learn.

School Socioeconomic Status and Mathematical Development

Perhaps the mathematics achievement gap evolves during formal education not only because of familial SES, but also school SES. Once children enter formal schooling, schools can either exacerbate, maintain, or reduce SES-related differences in mathematics achievement. High-SES schools often have more access to financial resources, experienced teachers, and academically prepared peer groups, all of which contribute to enhanced learning opportunities for students (Betts et al., 2000; Hanselman, 2018; Van Ewijk & Sleegers, 2010). In contrast, low-SES schools may face structural limitations, such as fewer instructional resources and less experienced staff, which can constrain the opportunities available to children and contribute to the persistence or widening of achievement gaps (Chmielewski, 2019; Otto & Kistner, 2017; Sontag & Stoeger, 2015).

Importantly, school SES is closely associated with family-level socioeconomic characteristics, including parental education. However, different SES indicators (e.g., parental education, income, occupation) may reflect partially distinct developmental pathways and therefore should not necessarily be treated as interchangeable measures of socioeconomic advantage (Duncan & Magnuson, 2003). Given the present study's focus on children's academic and cognitive outcomes, maternal education was considered particularly relevant because parental education has been consistently linked to children's learning environments, executive functioning, and academic achievement (Davis-Kean et al., 2021; Harding et al., 2015; Waters et al., 2021). Accordingly, school SES is interpreted here as reflecting broader differences in educational contexts and opportunities experienced by children once they enter formal schooling, while acknowledging its association with family socioeconomic background.

School effects can also be understood in terms of their potential to either reproduce or compensate for initial familial SES disparities. Some research suggests that schools have a compensatory effect, narrowing gaps by providing additional resources or instructional support for lower-SES students (Downey & Condron, 2016; Klein et al., 2019). Examples include differentiated instruction, targeted interventions, and exposure to enriched curricular materials, which can help children who begin school with lower foundational skills to catch up with their peers (Slavin, 1987). In other contexts, schools may maintain existing SES gaps, providing similar learning opportunities for all students regardless of background, resulting in stable inequalities over time (Raudenbush & Eschmann, 2015). In high-segregation contexts, such as Chile, evidence suggests that schools may contribute to widening SES disparities, particularly for mathematical skills that rely heavily on formal instruction and cognitive engagement (Ayala et al., 2024; Valenzuela et al., 2014). If indeed differences in formal instruction might contribute to widening SES disparities, then it is possible that gaps in mathematical outcomes widen with each additional year of schooling (i.e., Matthew effect).

Socioeconomic Disparities Beyond the Domain of Mathematics

Socioeconomic disparities in academic achievement are not restricted to mathematics but extend consistently across cognitive and literacy domains. Large-scale international assessments indicate that children from lower-SES backgrounds also demonstrate lower reading achievement at school entry and throughout primary schooling, with SES gradients evident across multiple countries and educational systems (OECD, 2010; Sirin, 2005). However, the developmental course of these disparities in literacy is not uniform and varies depending on age, instructional context, and the specific literacy skills assessed.

In the ECLS-K, family factors such as home literacy environment and parental involvement were the strongest predictors of initial reading differences at school entry (Aikens & Barbarin, 2008). Moreover, although children from lower-SES backgrounds started school with lower reading scores, they made relatively faster progress during the primary school years (Kieffer, 2012). Over time, school and neighbourhood factors explained more of the variation in reading growth than family characteristics. Similarly, analyses of data from the Australian Programme for International Student Assessment (PISA) show that students in higher-SES schools have higher literacy achievement on average, with effects that apply broadly across students regardless of their familial SES (Perry & McConney, 2010).

Meta-analytic findings report a medium effect for familial SES and a large effect for school SES on literacy achievement (Sirin, 2005). Consistent with this, studies from the UK and USA show that school-level SES is strongly associated with reading attainment and reading growth, with effects that are comparable to, and in some cases larger than, those linked to familial SES (Cassen & Kingdon, 2004; Rumberger & Palardy, 2005). Longitudinal evidence also suggests that school SES becomes more influential across schooling, while the association with familial SES may weaken over time (Holmes-Smith, 2006).

Other evidence points to variation depending on literacy skill and context. In Spain, students in Grades 2 and 4 from socioeconomically disadvantaged schools performed worse across literacy measures, with the largest differences observed for higher-order literacy skills (i.e., reading comprehension and text production); even after accounting for familial SES, differences in higher-order literacy skills of children attending low- versus mid-high-SES schools remained (Salas & Pascual, 2023). In Chile, using data from national standardized tests (Grades 4, 8, and 10), school SES explained a substantial share of variation in reading comprehension outcomes (Cáceres-Serrano & Alvarado-Izquierdo, 2017). In a Canadian longitudinal study conducted in a district with intensive literacy instruction, familial SES was significantly associated with reading, spelling, and phonological skills at kindergarten entry, but these associations declined systematically across the early school years and were no longer significant by Grade 3, alongside a general reduction in the prevalence of reading failure over time (D'Angiulli et al., 2004). Across studies, SES-related differences in literacy do not follow a single pattern. The direction and magnitude of effects vary across educational systems, school contexts, and literacy subskills, suggesting that, like mathematics, reading development can show widening, narrowing, or stable inequalities depending on the conditions under which learning takes place.

Importantly, the developmental processes underlying SES differences in academic achievement may differ for foundational cognitive skills (including executive functions, working memory, language, and early quantitative skills) compared to later curriculum-based mathematics and literacy outcomes. These foundational cognitive skills consistently predict later academic achievement and partially account for SES-related differences in both mathematics and literacy outcomes (Bull & Scerif, 2001; Duncan et al., 2007; Geary, 2011; Hackman et al., 2015; Passolunghi et al., 2008). In mathematics, early number competencies such as symbolic magnitude understanding, number ordering, and counting principles are particularly important because they support the later acquisition of calculation and problem-solving skills (Geary, 1995; Griffin et al., 1994; Jordan et al., 2009; Levine et al., 1992; Zhu et al., 2025). These foundational skills are themselves associated with SES-related differences in children's early learning environments and language exposure (Gardner-Neblett et al., 2014; Hooper et al., 2010; Purpura et al., 2011).

However, unlike curriculum-based mathematics and literacy outcomes, many cognitive abilities appear to become relatively stable across childhood following school entry. Meta-analytic evidence indicates that cognitive abilities show increasing rank-order stability during the primary school years, with substantial stabilization evident by approximately age 7

(Breit et al., 2024). This pattern suggests that foundational cognitive and quantitative skills may contribute to early SES-related differences in learning while being less susceptible to cumulative divergence during schooling than curriculum-based academic outcomes that depend more heavily on sustained instructional exposure. Consistent with this interpretation, in their review Korous et al. (2022) argue that SES-related disparities likely operate through distinct developmental pathways depending on the domain and mechanism involved. Distinguishing between cognitive precursors and curriculum-based achievement outcomes may therefore help clarify why SES-related disparities show different developmental patterns across domains and educational contexts.

The Present Study

The present preregistered study aimed to address three research questions concerning the association between school SES and early academic development within the context of Chile's highly segregated educational system: i) Are there differences in mathematics outcomes and cognitive skills for children attending high- versus low-SES schools? ii) Do differences in mathematics performance and cognitive skills for children attending high- versus low-SES schools change with each additional year of formal schooling? iii) Does school SES predict gains in mathematics and literacy outcomes after accounting for maternal education and cognitive and quantitative precursors? These questions reflect three complementary aspects of how school socioeconomic context may shape early development: baseline differences in performance, change in those differences across the early years of formal schooling, and the extent to which school SES explains progress beyond family background and children's own cognitive starting points.

The Chilean educational system provides a particularly informative context for examining our research questions. Chile has a highly socioeconomically segregated school system, consisting of municipal public schools, private-voucher schools, and private feepaying schools. Admission policies, financial resources, and student composition vary systematically across these school types (Ceron et al., 2022; OECD, 2019; Valenzuela et al., 2014). Specifically, there is an association between the students' socioeconomic status and the type of school they attend, with private schools generally serving higher-SES students, and public and voucher schools serving higher proportions of low-SES and middle-SES students, respectively (Valenzuela & Allende, 2023). To estimate the degree of school segregation, researchers have used the Duncan Dissimilarity Index, which corresponds to the proportion of vulnerable students that would need to change schools to achieve a homogeneous distribution of students across schools (Molina, 2021). The Duncan index ranges from 0 (perfect integration) to 1 (complete segregation), with values below 0.3 indicating low segregation, values between 0.3 and 0.45 indicating moderate segregation, values between 0.45 and 0.6 indicating high segregation, and values above 0.6 indicating hypersegregation (Treviño et al., 2019). The Chilean educational system has been characterized as highly or hyper-segregated, with similar patterns of school social segregation observed across all educational levels (Gutiérrez & Carrasco, 2021; Valenzuela & Allende, 2023). This pattern is often interpreted in light of Chile's market-oriented educational system (Valenzuela et al., 2014), which may contribute to substantial differences in educational opportunities and instructional experiences across school contexts.

Consistent with extensive evidence showing that socioeconomic differences are already evident at school entry and persist across multiple domains of cognitive and academic functioning (Duncan & Magnuson, 2011; Sirin, 2005), we hypothesized that in kindergarten, Grade 1, Grade 2, and Grade 3, children attending high-SES schools would show overall advantages in both foundational cognitive skills and mathematics outcomes compared to children attending low-SES schools (Hypothesis 1). Given evidence that foundational numerical and cognitive skills tend to stabilize once acquired and show less dependence on cumulative instructional exposure (Breit et al., 2024), we expected SES-related differences in cognitive precursors to remain stable across grades, with no grade-by-SES interaction (Hypothesis 2a). In contrast, given evidence that SES-related differences in mathematics tend to vary over the early school years, particularly for skills shaped by formal instruction (Ayala et al., 2024), and in light of the high level of socioeconomic segregation in Chilean schooling, which may reinforce cumulative learning processes (Cáceres-Serrano & Alvarado-Izquierdo, 2017), we hypothesized a grade-by-SES interaction for mathematics outcomes. Specifically, we hypothesized that SES-related gaps between children attending high- and low-SES schools would widen from kindergarten to Grade 3 (Hypothesis 2b). Finally, building on evidence that school socioeconomic composition predicts academic development beyond family background and children's initial skills (Chmielewski, 2019; Sirin, 2005), we hypothesized that children from high-SES schools would make greater gains over the course of one school year for mathematical and literacy outcomes than children from low-SES schools (Hypothesis 3a), with school SES continuing to reliably predict mathematical gains above and beyond maternal education (Hypothesis 3b) and cognitive skills (Hypothesis 3c).

Method

Participants and Procedure

Children (N = 367) were recruited from and tested in low- or high-SES schools in the urban metropolitan area of Santiago, Chile. At Time 1, children were enrolled in either kindergarten (n = 101; M_{age} = 5.9 years; 51 low SES; 48 boys), Grade 1 (n = 95; M_{age} = 6.8 years; 46 low SES; 52 boys), Grade 2 (n = 87; M_{age} = 7.9 years; 52 low SES; 47 boys), or Grade 3 (n = 84; M_{age} = 8.8 years; 52 low SES; 38 boys). Except for the children in Grade 3, children were tested a second time one year later (Time 2) in Grade 1 (n = 94), Grade 2 (n = 82), and Grade 3 (n = 77). At each time point, children participated in two 20- to 30-minute testing sessions, conducted in a private space at their schools by trained research assistants, and received a sticker as a token of appreciation for their participation. Assessments were presented in the same order for all children.

Measures

Demographic Measures

School Socioeconomic Status. Two private schools and three publicly funded schools participated. The two private schools were considered high-SES schools, per the classification by the Quality of Education Evaluation System (SIMCE in Spanish). Three publicly funded schools were considered low-SES schools. These schools received government subsidies due to student vulnerability, determined by the Chilean National Council for School Assistance and Scholarships using the annual School Vulnerability Index (Índice de Vulnerabilidad Escolar, IVE; Agencia de Calidad de la Educación, 2015). Students are classified into three categories, or "priorities", based on poverty level and likelihood of school failure or dropout. Students experiencing severe poverty are classified as first priority whereas students with a likelihood of school failure are classified as second and third priorities. The IVE is a percentage ranging from 0 to 100% calculated as the total number of students in each of the three priority levels divided by the total number of students enrolled in the school, multiplied by 100. Higher percentages represent a higher degree of vulnerability in the school. At the time of testing, the participating low-SES schools had IVEs between 74% and 85%. This classification reflects school-level socioeconomic context rather than individual family SES.

Maternal Education. Maternal education was assessed at Time 1 on a 12-point scale, ranging from 'some primary school' (1) to 'doctorate degree' (12). This measure was used as an individual-level proxy for socioeconomic background. For the whole sample, the median education level was 'graduated community college/professional institute' (8). By school SES, the median education levels were 'high school diploma' (4) and 'undergraduate degree' (10) for mothers of children who attended low- and high-SES schools, respectively.

Cognitive and Quantitative Precursors

Children completed linguistic (i.e., receptive vocabulary) and quantitative (i.e., number comparison, number ordering) tasks at both Time 1 and Time 2. Because we were interested in investigating cognitive precursors, in the present study we only include data for these tasks collected during Time 1. Receptive vocabulary and number comparison were completed by children in all grades at Time 1 whereas number ordering was completed in Grades 1, 2, and 3.

Receptive Vocabulary. The Hispanic-American adaptation of the Peabody Picture Vocabulary Test-Revised: Test de Vocabulario en Imágenes Peabody (Dunn et al., 1986) was used as a measure of receptive vocabulary. In this task, children are presented with four pictures, and the experimenter orally presents a word. Children must point to the picture that best represents the spoken word. The starting point is determined by the child's age. Testing is discontinued when a child makes six errors in a set of eight items. Scoring was the total number of correct responses. Reported split-half reliability is excellent, ranging from .80 to .94 for children ages 4 to 9 (Dunn et al., 1986).

Number Comparison. In this task, children are asked to touch the larger of two single-digit numbers presented on an iPad ("Bigger Number" app), as quickly and accurately as possible. If children do not provide a response within 3 s, the task automatically advances to the next trial. Across the 26 trials, scoring was calculated using a linear integrated speed-accuracy score (LISAS; $RT_{adj} = RT_{correct} + PE \times [SD_{RT}/SD_{PE}]$), where $RT_{correct}$ is the mean response time on the correct trials and percentage error (PE) is weighted by the ratio of the standard deviations of the correct response time and the percentage of error (Vandierendonck, 2017). The internal reliability based on RT for correct trials was .94.

Number Ordering. In this task children are presented with three single-digit numbers on an iPad ("Number Ordering" app) and asked to tap the numbers in ascending order as quickly and accurately as possible. If children do not provide a response within 7 s, the task automatically advances to the next trial. Children complete three practice trials with feedback to ensure they understand the task prior to the 12 experimental trials. Scoring was calculated based on adjusted RT using the LISAS method described above. Internal reliability based on RT for correct trials was .86.

Mathematical and Literacy Outcomes

Children were administered three mathematics and two literacy subtests of the Batería III Woodcock-Muñoz Pruebas de Aprovechamiento (WJ III Test of Achievement; Muñoz-Sandoval et al., 2005): calculation, math fluency, applied problems, letter-word identification, and passage comprehension. The median reliability coefficient alphas for all age groups for all subtests are excellent, ranging from .88 to .96 (Grenwelge, 2009). Administration of these subtests, described below, followed the specific administration protocols outlined in the testing manual. Mathematics subtests were completed by children in all grades at Time 1 and Time 2. Letter-word identification was completed in kindergarten at Time 1 and Grade 1 at Time 2. Passage comprehension was completed in Grade 2 at Time 1 and Grade 3 at Time 2.

Calculation. The *Cálculo* (Calculation) subtest is a paper-and-pencil calculation assessment. Children are presented with mathematical calculations that increase in difficulty (i.e., basic arithmetic to rational numbers and algebraic operations). The subtest includes 45 written mathematical calculations presented across two pages. The start point is dependent on the child's grade level. Testing is discontinued once a child makes six consecutive errors or omissions. Scoring was the total number of correct responses.

Math Fluency. The *Fluidez en Matemáticas* (Math Fluency) subtest is a paper-and-pencil math fluency assessment. Children have 3 min to solve as many operations as they can. There are 160 items in total, presented in rows of 10 across two pages. Children are instructed to answer as quickly and accurately as possible, moving from one row to the next, and then to the second page. If they do not know how to solve one of the operations, they are instructed to move to the next one in the row. Scoring was the total number of correct responses within the 3 min time limit.

Applied Problems. The *Problemas Aplicados* (Applied Problems) subtest assesses mathematical skills and concepts, including arithmetic operations, money, time, measurement, geometry, fractions and percentages, probability, and algebra. A math problem is read aloud to the children, accompanied by either a visual stimulus or a written version of the problem. Children are then asked to provide a verbal response to the problem. The subtest includes 62 items. The start point is dependent on the child's grade level. Testing is discontinued once a child makes six consecutive errors or omissions. Scoring was the total number of correct responses.

Letter-Word Identification. The *Identificación de Letras y Palabras* (Letter-Word Identification) subtest assesses children's early reading skills. The subtest includes 76 items. For the first 10 items, children are asked to name or point to individual letters. For the remaining items, children are asked to read words aloud from an increasingly difficult vocabulary list, and their pronunciation is assessed. The start point is dependent on the child's grade level. Testing is discontinued once a child makes six consecutive errors or omissions. Scoring was the total number of correct responses.

Passage Comprehension. The *Comprensión de Textos* (Passage Comprehension) subtest assesses children's reading comprehension. The subtest includes 47 items of increasing vocabulary level. Early items involve matching pictures to words or simple text comprehension. As the assessment progresses, children need to read longer, more complex sentences and passages. Children are asked to read the sentence(s) or passage silently and then decide on a specific word needed in the blank to make a sentence complete. The start point is dependent on the child's grade level. Testing is discontinued once a child makes six consecutive errors or omissions. Scoring was the total number of correct responses.

Transparency and Openness

This study's hypotheses and analysis plan were preregistered on the Open Science Framework (OSF; https://osf.io/zwbrd/). Data for this study were obtained from a larger project focused on the development of mathematical skills in Chilean students from kindergarten to Grade 3 (see OSF for a full list of prior publications). Details about recruitment and sample size decisions for the larger project can be found in Susperreguy et al. (2022). The project received ethics approval by the Scientific Ethics Committee of Social Sciences, Arts and Humanities of the Pontificia Universidad Católica de Chile. Due to ethical constraints (i.e., no data sharing policy), the data for this study and the larger project are not available.

We note two deviations from the preregistered analysis plan. First, regarding the statistical framework, we originally planned to use ANOVAs and hierarchical linear regressions. However, we received feedback that these approaches were methodologically limited because they failed to account for the clustering of students within schools. While multilevel modelling is standard for nested data, maximum likelihood estimation can be unstable with very few clusters (here, five schools), particularly for variance components. We therefore used a Bayesian framework, which is less reliant on large-sample assumptions.

To assess power under this constraint, we ran simulation-based analyses using 500 datasets reflecting the observed structure (students nested within 5 schools). School-level SES was modelled as binary, maternal education was simulated to be moderately correlated with SES ($r \approx .60$), and the outcome incorporated a target SES effect of $d = 0.40$ alongside a smaller maternal education effect. All models were estimated using four Markov chains with

2000 iterations per chain, including 1000 warm-up iterations, resulting in 4000 post-warmup posterior draws per model, utilizing weakly informative priors to ensure stable convergence. Power was defined as the proportion of simulations in which the lower bound of the credible interval (CrI) for the SES effect exceeded zero. Estimated power was low using 95% CrIs (~.22) but higher using 80% CrIs (~.77), reflecting the expected trade-off between interval width and sensitivity. Accordingly, we report both 80% and 95% CrIs, with 80% intervals used as the primary summary of posterior uncertainty and 95% intervals reported in Supplementary Materials for transparency and comparison (Kruschke, 2014; McElreath, 2018). Following recommended practices for Bayesian model reporting (Gelman et al., 2013), comprehensive convergence diagnostics, including trace plots, potential scale reduction factors, and effective sample sizes, along with posterior predictive checks were conducted for all models (see Supplementary Materials for full diagnostic reporting).

Second, we had planned to examine growth in number line estimation from Grade 2 to Grade 3. However, due to the range of the number line (0-1000), this task was quite challenging, with mean PAE values above 10%, minimal gains made over the one-year period, and significant skew. Based on the national curriculum (Ministerio de Educación, 2018) which states that comparing and ordering natural numbers up to 1000 is a learning goal for Grade 3, whereas it is only numbers up to 100 for Grade 2, this task likely required number knowledge that was beyond students' current capabilities. As such, we exclude number line estimation from the main analyses but present the analysis in Supplementary Materials.

The present study focused on a unique set of research questions that have not been addressed in previous publications. Data analysis and visualization were conducted in R Version 4.4.1 (R Core Team, 2024) using the *tidyr* (Wickham et al., 2024), *dplyr* (Wickham et al., 2024), *ggplot2* (Wickham, 2016), *cowplot* (Wilke, 2024), *car* (Fox & Weisberg, 2019), *emmeans* (Lenth, 2024), *rstanarm* (Goodrich et al., 2025), *bayesplot* (Gabry et al., 2019), and *lme4* (Bates et al., 2015) packages.

Analytic Strategy

The goal of the present study was to investigate how school SES is related to children's mathematical development. See Figure 1 for an overview of measures and time points for each research question. To investigate cognitive precursor skills and mathematics performance for children who attended low- versus high-SES schools (Hypotheses 1 and 2), we specified Bayesian linear mixed models predicting outcomes at Time 1. In these base models, school SES (low, high), grade level (kindergarten, Grade 1, Grade 2, Grade 3), their interaction, and maternal education (mean-centred) were entered as fixed effects, with random intercepts included for schools to account for the nesting of students within school clusters. Unless otherwise specified, kindergarten served as the reference group for grade-level comparisons. This approach allowed us to estimate the magnitude of the SES achievement gap in kindergarten above and beyond maternal education while accounting for uncertainty due to the small number of schools.

To determine whether children attending high-SES schools made greater gains from one school year to the next than children attending low-SES schools (Hypothesis 3), we analyzed the interaction between school SES and grade level on growth outcomes. Dependent variables were gain scores (i.e., Time 2 – Time 1) for mathematical and literacy outcomes. For mathematical outcomes, gains were assessed for kindergarten to Grade 1, Grade 1 to Grade 2, and Grade 2 to Grade 3. For letter-word identification and passage comprehension, gains were assessed from kindergarten to Grade 1, and Grade 2 to Grade 3, respectively. The predictors (i.e., school SES, maternal education, and cognitive precursors) were measured at Time 1.

Figure 1

Summary of Child Measures Used for Research Questions I, II, and III

Research Questions I & II				
	Grade at T1			
	K	G1	G2	G3
Measures				
Cognitive Precursors				
Receptive Vocabulary	✓	✓	✓	✓
Number Comparison	✓	✓	✓	✓
Number Ordering		✓	✓	✓
Mathematics Outcomes				
Calculation	✓	✓	✓	✓
Math Fluency	✓	✓	✓	✓
Applied Problems	✓	✓	✓	✓

Research Question III							
	Grade at T1				Grade at T2		
	K	G1	G2	G3	G1	G2	G3
Measures							
Cognitive Precursors							
Receptive Vocabulary	✓	✓	✓	✓			
Number Comparison	✓	✓	✓	✓			
Number Ordering		✓	✓	✓			
Mathematics Outcomes							
Calculation	✓	✓	✓	✓	✓	✓	✓
Math Fluency	✓	✓	✓	✓	✓	✓	✓
Applied Problems	✓	✓	✓	✓	✓	✓	✓
Literacy Outcomes							
Letter-Word Identification	✓				✓		
Passage Comprehension			✓				✓

Note. Research Questions I and II used data collected at Time 1 (T1). Research Question III used data collected at Time 1 (T1) and Time 2 (T2).

K = Kindergarten, G1 = Grade 1, G2 = Grade 2, G3 = Grade 3

To test whether school-level differences in growth were driven by individual student characteristics rather than the school context itself, we specified a series of robust models corresponding to the original analysis plan's hierarchical structure. In the base model, we included grade level, school SES, and their interaction. In the robust model, we added centred maternal education followed by Time 1 cognitive precursors to isolate the specific contribution of school SES to mathematical and literacy outcomes. All models were estimated using four Markov chains with weakly informative priors to ensure stable convergence.

For all Bayesian analyses, the posterior distributions of the estimated school-level SES gaps, along with their corresponding 80% and 95% CrIs, are visually presented in Figure S1 in Supplementary Materials. Full visual diagnostic histories, including Markov Chain Monte Carlo (MCMC) trace plots and posterior predictive check density overlays for all models are provided in Figures S2 and S3 in Supplementary Materials.

Missing Data

A series of Bayesian logistic regressions were conducted to determine whether children with incomplete longitudinal data (i.e., missing the second testing session) differed from those with complete data. Due to the cross-sequential design, this analysis was restricted to the kindergarten, Grade 1, and Grade 2 cohorts. Missingness was not reliably predicted by any cognitive or mathematical measures at Time 1, including receptive vocabulary (b = 0.05, 80% CrI [-0.21, 0.31], 95% CrI [-0.34, 0.45]), number comparison (b = -0.13, 80% CrI [-0.41, 0.13], 95% CrI [-0.55, 0.26]), number ordering (b = 0.07, 80% CrI [-0.23, 0.36], 95% CrI [-0.40, 0.52]), calculation (b = -0.03, 80% CrI [-0.29, 0.22], 95% CrI [-0.42, 0.35]), math fluency (b = -0.06, 80% CrI [-0.33, 0.20], 95% CrI [-0.49, 0.33]), and applied problems (b = 0.16, 80% CrI [-0.07, 0.41], 95% CrI [-0.21, 0.53]). Missingness was associated with maternal education at the 80% level (b = -0.26, 80% CrI [-0.49, -0.03], 95% CrI [-0.60, 0.09]). Children in low-SES schools were more likely to have incomplete data than those in high-SES schools (b = -0.96, 80% CrI [-1.48, -0.45], 95% CrI [-1.82, -0.19]). Overall, there was no consistent evidence that missingness was associated with baseline cognitive or mathematical performance, suggesting that attrition is not strongly related to prior skill levels. Accordingly, missing data were treated as conditionally ignorable given observed covariates.

Results

Descriptive Statistics

Descriptive statistics and correlations, collapsed across grade levels, are shown in Table 1. Descriptive statistics for each grade and time point can be found in Supplementary Materials (see Table S1). Means and standard deviations showed no evidence of floor or ceiling effects. A small number of extreme outliers ($|z\text{-scores}| > 3.29$) were identified: number comparison at Time 1 ($n = 4$), number ordering at Time 1 ($n = 1$), and passage comprehension at Time 1 ($n = 2$) and Time 2 ($n = 2$). These outliers were responsible for the significant skew (i.e., $|\text{skew}| > 1$) of some variables. However, sensitivity analyses with and without the inclusion of outliers revealed similar patterns of results and thus all data were included in the final analyses. All measures were significantly correlated with each other.

School Socioeconomic Status by Grade

To maintain readability in the main text while preserving full transparency, 95% credible intervals are reported in Supplementary Materials (see Table S2). Unless otherwise noted, all reported credible intervals are 80% CrIs.

Table 1

Descriptive Statistics and Correlations for All Measures

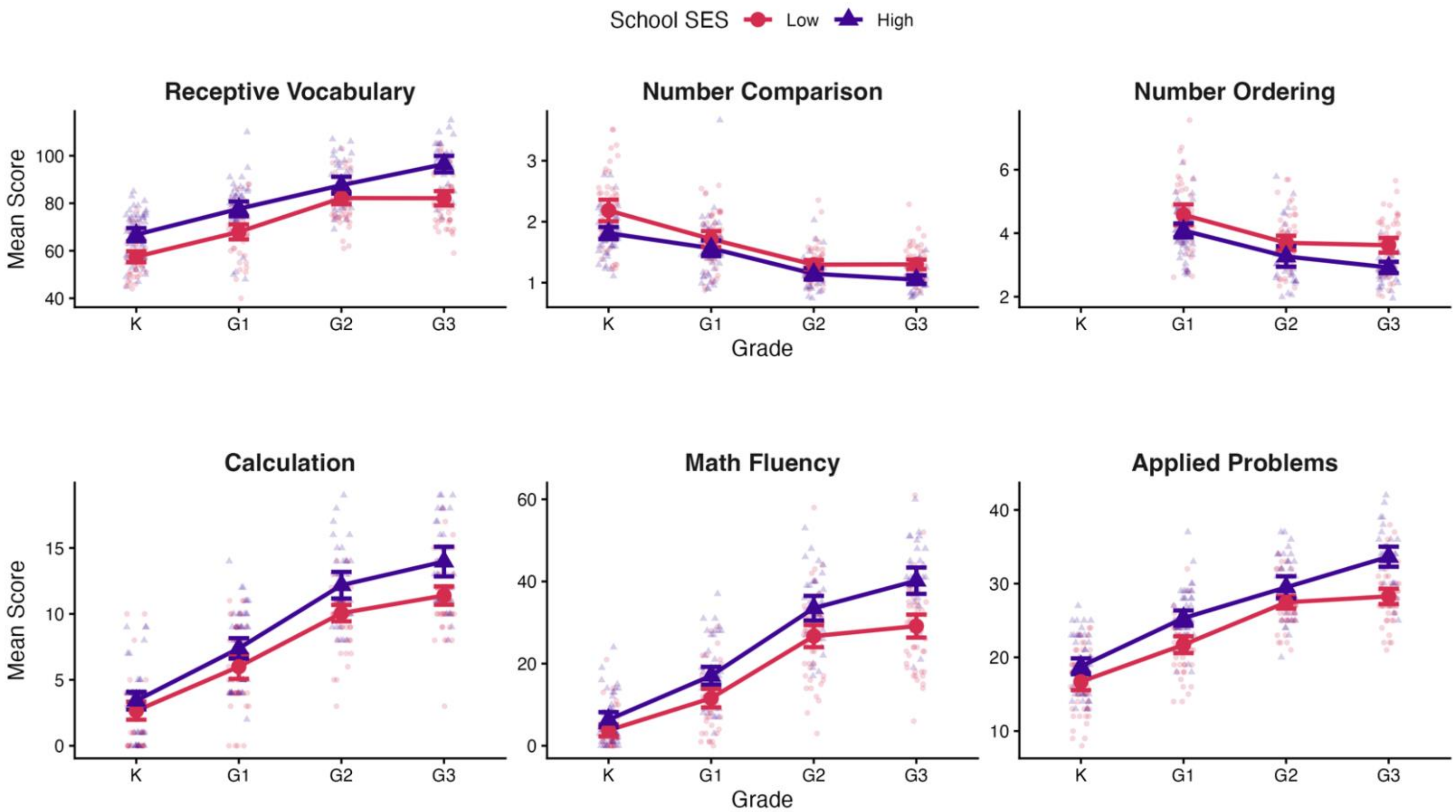
	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Receptive Vocabulary T1[a]	--	-.58	-.47	.53	.61	.68	.67	.77	.35	.59	.70	.67	.74
2. Number Comparison T1[b]		--	.62	-.36	-.27	-.68	-.68	-.65	-	-	-.58	-.61	-.59
3. Number Ordering T1[b]			--	-.24*	-	-.57	-.66	-.58	N/A	-.43	-.54	-.62	-.57
4. Letter-Word Identification T1[a]				--	N/A	.65	.62	.66	.48	.54	.67	.67	.71
5. Passage Comprehension T1[a]					--	.37	.39	.54	N/A	.43	.43	.45	.54
6. Calculation T1[a]						--	.84	.85	.33	.42	.78	.79	.82
7. Math Fluency T1[a]							--	.83	.36	.41	.77	.85	.82
8. Applied Problems T1[a]								--	.41	.51	.79	.81	.87
9. Letter-Word Identification T2[a]									--	N/A	.42	.50	.47
10. Passage Comprehension T2[a]										--	.45	.42	.57
11. Calculation T2[a]											--	.84	.93
12. Math Fluency T2[a]												--	.87
13. Applied Problems T2[a]													--
N per measure	360	357	260	191	169	363	342	363	94	157	253	253	253
Mean	76.2	1.5	3.8	31.1	26.2	8.0	20.6	24.6	51.1	26.2	10.1	26.7	37.7
SD	15.1	0.5	0.9	25.4	4.7	4.6	14.4	6.4	21.1	4.8	3.7	14.1	8.5
Skew	0.0	1.1	0.6	0.4	-1.0	0.7	0.4	-0.1	-0.8	-0.7	-0.2	0.4	0.1

Note. T1 = Time 1, T2 = Time 2. [a]Total correct; [b]Adjusted RT scores

* $p < .05$; ** $p < .01$; all other correlations significant at $p < .001$.

Figure 2

Cognitive Precursors and Mathematics Outcomes by School SES and Grade



Note. Error bars represent 95% Confidence Intervals. K = Kindergarten, G1 = Grade 1, G2 = Grade 2, G3 = Grade 3. Number comparison and number ordering scores are RT scores (LISAS) where lower scores indicate higher performance.

Cognitive Precursors

Receptive Vocabulary. The main effects of SES in kindergarten (*b* = 5.19, CrI [1.73, 8.66]) and maternal education (*b* = 0.94, CrI [0.63, 1.25]) were both reliable. Consistent with Hypothesis 1, children in high-SES schools generally outperformed children in low-SES schools on the receptive vocabulary task. The main effect of grade was reliable, with children in Grade 1 (*b* = 9.89, CrI [7.26, 12.52]), Grade 2 (*b* = 24.62, CrI [22.05, 27.16]), and Grade 3 (*b* = 25.22, CrI [22.64, 27.79]) outperforming children in kindergarten. Consistent with Hypothesis 2a, the interaction between school SES and grade was not reliable for Grade 1 (*b* = 1.42, CrI [-2.37, 5.15]) or Grade 2 (*b* = -3.42, CrI [-7.33, 0.50]), suggesting stable differences during these years. However, a reliable positive interaction emerged by Grade 3 (*b* = 4.49, CrI [0.57, 8.35]), indicating that the vocabulary gap may begin to widen in later grades. See Figure 2 (top left panel).

Number Comparison. The main effects of SES in kindergarten (*b* = -0.31, CrI [-0.45, -0.17]) and maternal education (*b* = -0.02, CrI [-0.03, -0.01]) were both reliable. Consistent with Hypothesis 1, children in high-SES schools outperformed children in low-SES schools on the number comparison task. The main effect of grade was reliable, with children in Grade 1 (*b* = -0.46, CrI [-0.56, -0.35]), Grade 2 (*b* = -0.89, CrI [-0.99, -0.79]), and Grade 3 (*b* = -0.90, CrI [-1.00, -0.80]) outperforming children in kindergarten. Partially consistent with Hypothesis 2a, while the interaction between school SES and grade was reliable for Grade 1 (*b* = 0.20, CrI [0.06, 0.35]) and Grade 2 (*b* = 0.22, CrI [0.07, 0.37]), the effect sizes were small in magnitude and the interaction was not reliable by Grade 3 (*b* = 0.12, CrI [-0.03, 0.28]). Overall, there is limited evidence for systematic widening of the SES gap; instead, the pattern is broadly consistent with relatively stable differences across grades, with only minor fluctuations. See Figure 2 (top middle panel).

Number Ordering. The main effect of SES in kindergarten was reliable (*b* = -0.42, CrI [-0.75, -0.09]). Consistent with Hypothesis 1, children in high-SES schools generally outperformed children in low-SES schools on the number ordering task. Maternal education was not a reliable predictor of performance (*b* = -0.02, CrI [-0.05, 0.01]). The main effect of grade was reliable, with children in Grade 2 (*b* = -0.83, CrI [-1.07, -0.59]) and Grade 3 (*b* = -0.95, CrI [-1.19, -0.72]) outperforming children in Grade 1 (reference group). Consistent with Hypothesis 2a, the interaction between school SES and grade was not reliable for Grade 2 (*b* = 0.02, CrI [-0.33, 0.36]) or Grade 3 (*b* = -0.21, CrI [-0.55, 0.14]). See Figure 2 (top right panel).

Mathematical Outcomes

Calculation. The main effect of SES in kindergarten (*b* = 0.56, CrI [-0.66, 1.82]) was not reliable, indicating that performance was comparable between children attending low- and high-SES schools in kindergarten. However, consistent with the general prediction of Hypothesis 1, a reliable advantage for children attending high-SES schools emerged in subsequent grades. The main effect of grade was reliable, with children in Grade 1 (*b* = 3.51, CrI [2.78, 4.22]), Grade 2 (*b* = 7.27, CrI [6.58, 7.97]), and Grade 3 (*b* = 8.83, CrI [8.14, 9.52]) outperforming children in kindergarten. Maternal education was not a reliable predictor (*b* = 0.07, CrI [-0.02, 0.15]). Consistent with Hypothesis 2b, the interaction between school SES and grade became reliable over time. While the interaction was not reliable in Grade 1 (*b* = 0.49, CrI [-0.50, 1.49]), it was reliable by Grade 2 (*b* = 1.53, CrI [0.51, 2.57]) and Grade 3 (*b* = 1.81, CrI [0.77, 2.84]). See Figure 2 (bottom left panel).

Math Fluency. The main effect of SES in kindergarten was not reliable, *b* = 2.11, CrI [-3.08, 7.34], indicating that performance was comparable between children attending low- and high-SES schools in kindergarten. However, consistent with the general prediction of Hypothesis 1, a reliable advantage for children attending high-SES schools emerged in subsequent grades. The main effect of grade was reliable, with children in Grade 1 (b = 8.98, CrI [6.62, 11.38]), Grade 2 (b = 22.60, CrI [20.35, 24.81]), and Grade 3 (b = 26.59, CrI [24.28, 28.89]) outperforming children in kindergarten. Maternal education was not a reliable predictor (b = 0.25, CrI [-0.01, 0.51]). Consistent with Hypothesis 2b, the interaction between school SES and grade became reliable over time. While the interaction was not reliable in Grade 1 (b = 2.05, CrI [-1.12, 5.24]), it was reliable by Grade 2 (b = 4.94, CrI [1.70, 8.19]) and Grade 3 (b = 8.20, CrI [4.72, 11.52]). See Figure 2 (bottom middle panel).

Applied Problems. The main effect of SES in kindergarten was not reliable, b = 1.72, CrI [-0.29, 3.77], indicating that performance was comparable between children attending low- and high-SES schools in kindergarten. Consistent with the general prediction of Hypothesis 1, a reliable advantage for children attending high-SES schools emerged in subsequent grades. The main effect of grade was reliable, with children in Grade 1 (b = 5.16, CrI [4.12, 6.20]), Grade 2 (b = 10.57, CrI [9.61, 11.53]), and Grade 3 (b = 11.87, CrI [10.88, 12.87]) outperforming children in kindergarten. Maternal education was a reliable predictor (b = 0.15, CrI [0.03, 0.27]). Results were partially consistent with Hypothesis 2b; while the interaction between school SES and grade changed over time, it did not show a linear widening. The interaction was reliable in Grade 1 (b = 1.50, CrI [0.06, 2.93]), but not in Grade 2 (b = 0.29, CrI [-1.16, 1.76]). However, the gap widened reliably by Grade 3 (b = 3.40, CrI [1.92, 4.87]). See Figure 2 (bottom right panel).

Gains in Mathematical and Literacy Outcomes

Mean scores at Time 1 and Time 2, as well as gain scores for mathematical and literacy outcomes, are displayed in Figure 3. To test whether school SES predicted children's one-year gains in mathematics and literacy outcomes (Hypothesis 3a), and whether these effects remained after accounting for maternal education (Hypothesis 3b) and cognitive precursors (Hypothesis 3c), we fit a series of Bayesian linear mixed models predicting gain scores (Time 2 - Time 1). These models included a random intercept for school to account for the nested structure of the data. Kindergarten served as the reference group for grade-level comparisons. Accordingly, the main effect of school SES reflects SES differences in gains during kindergarten, whereas SES by grade interactions reflect grade-specific deviations from this pattern in subsequent school years. Full model results, including 95% credible intervals, are reported in Table 2. Main text interpretations are based on 80% intervals for readability.

Before examining the unique effects of school SES on growth, we verified that school-level SES and individual maternal education represented distinct constructs. While there was a positive association between the two, the correlation was moderate-to-strong (r = .66). Variance Inflation Factors (VIF) for all models were well below conservative thresholds (all VIFs < 2.0), confirming that multicollinearity was not a concern. The inclusion of maternal education as a centred covariate allowed the school SES effects to reflect the unique contribution of the school environment, over and above individual-level familial educational background.

Table 2

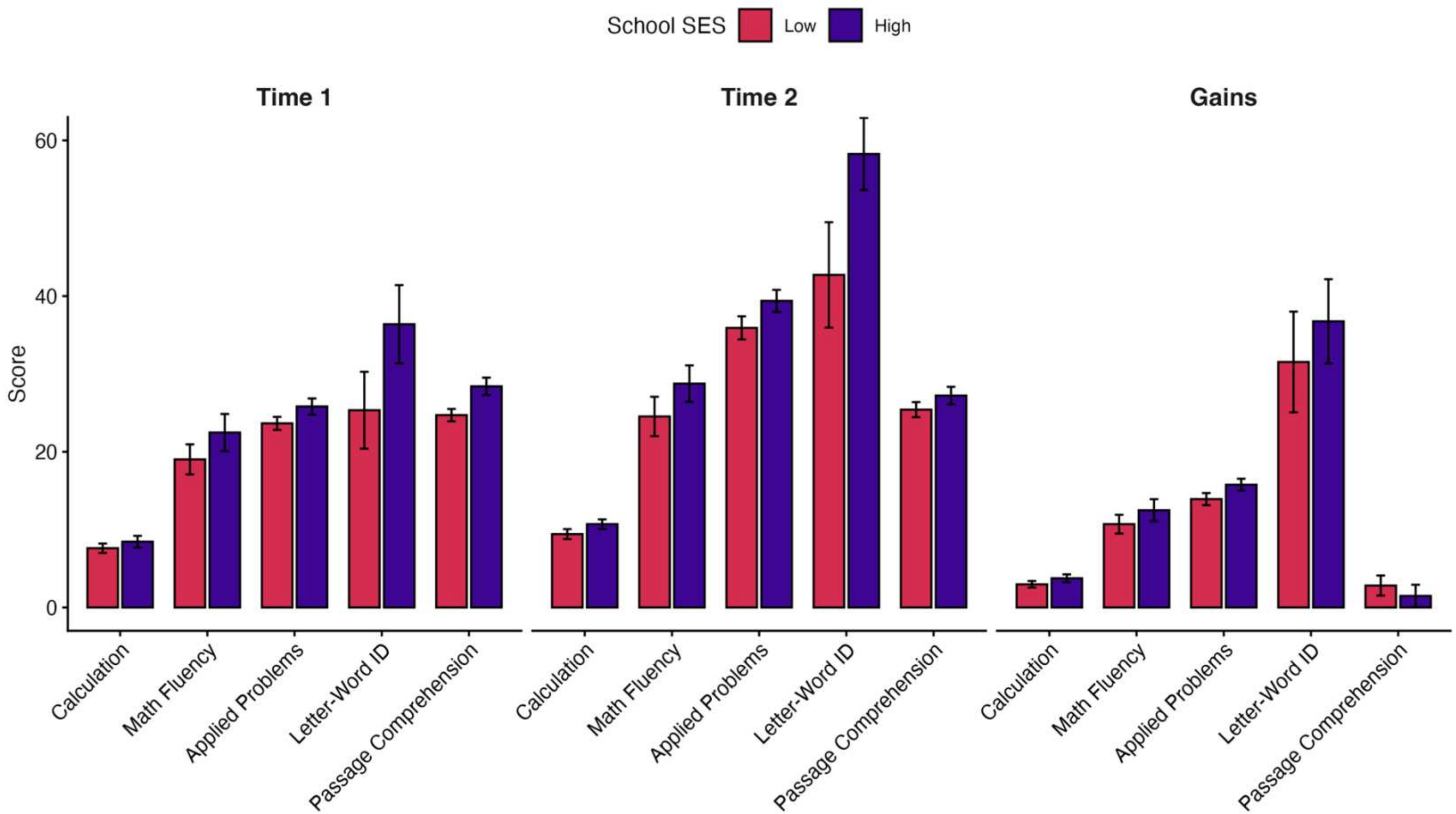
Bayesian Mixed-Effects Models Predicting Gains in Mathematics and Literacy Outcomes

Predictor	Calculation			Math Fluency			Applied Problems			Letter-Word Identification			Passage Comprehension		
	b	80% CrI	95% CrI	*b*	80% CrI	95% CrI	*b*	80% CrI	95% CrI	*b*	80% CrI	95% CrI	*b*	80% CrI	95% CrI
Base Model															
School SES	0.37	[-0.79, 1.54]	[-1.80, 2.49]	2.57	[-0.01, 5.11]	[-1.78, 6.68]	1.53	[-0.39, 3.46]	[-2.17, 4.99]	1.61	[-13.09, 15.66]	[-26.28, 27.62]	-0.45	[-3.10, 2.40]	[-5.32, 4.88]
School SES × Grade 1	1.08	**[0.09, 2.06]**	[-0.44, 2.57]	0.43	[-2.46, 3.28]	[-4.06, 4.87]	0.39	[-1.17, 1.96]	[-1.97, 2.83]	—	—	—	—	—	—
School SES × Grade 2	-0.82	[-1.83, 0.18]	[-2.39, 0.71]	-4.66	**[-7.59, -1.79]**	**[-9.17, -0.25]**	1.19	[-0.40, 2.78]	[-1.19, 3.58]	—	—	—	—	—	—
Robust Model															
School SES	0.44	[-0.81, 1.65]	[-1.75, 2.60]	3.08	**[0.27, 5.94]**	[-1.64, 7.76]	1.07	[-1.01, 3.14]	[-2.75, 4.68]	-2.36	[-18.36, 13.27]	[-31.13, 24.29]	-0.5	[-3.52, 2.65]	[-5.79, 5.01]
School SES × Grade 1	1.16	**[0.15, 2.16]**	[-0.39, 2.72]	0.68	[-2.25, 3.56]	[-3.80, 5.20]	0.63	[-0.95, 2.24]	[-1.80, 3.06]	—	—	—	—	—	—
School SES × Grade 2	-0.72	[-1.74, 0.31]	[-2.30, 0.90]	-4.31	**[-7.29, -1.37]**	[-8.90, 0.28]	1.29	[-0.30, 2.91]	[-1.14, 3.82]	—	—	—	—	—	—
Maternal Education	-0.04	[-0.13, 0.06]	[-0.18, 0.11]	-0.2	[-0.47, 0.08]	[-0.61, 0.21]	0.1	[-0.05, 0.25]	[-0.13, 0.32]	1.05	[-0.33, 2.39]	[-1.05, 3.11]	-0.06	[-0.36, 0.23]	[-0.51, 0.39]
Receptive Vocabulary	0.55	**[0.06, 1.06]**	[-0.21, 1.34]	1.98	**[0.58, 3.37]**	[-0.16, 4.11]	0.27	[-0.52, 1.07]	[-0.94, 1.48]	-12.01	[-49.47, 24.87]	[-69.72, 47.51]	3.93	[-4.34, 12.18]	[-8.71, 16.70]
Number Comparison	-0.2	[-0.51, 0.11]	[-0.67, 0.28]	-0.76	[-1.64, 0.12]	[-2.10, 0.57]	0.02	[-0.46, 0.50]	[-0.72, 0.77]	-0.59	[-3.70, 2.46]	[-5.30, 4.16]	0.6	[-0.31, 1.52]	[-0.79, 2.04]

Note. Kindergarten served as the reference group for grade-level comparisons. SES main effects reflect differences in kindergarten gains; SES × grade terms reflect grade-specific deviations from this pattern. Dashes indicate predictors not estimated because gains were only modelled for a single transition. Bolded coefficients indicate credible intervals excluding zero.

Figure 3

Mean Scores and One-Year Gains in Mathematical and Literacy Outcomes for Children Attending Low- and High-SES Schools



Note. Error bars represent 95% Confidence Intervals. T1 = Time 1, T2 = Time 2.

Mathematical Outcomes

Calculation. Supporting Hypothesis 3a, school SES predicted grade-specific differences in calculation gains. During kindergarten, gains were comparable for children attending high- and low-SES schools. However, a reliable positive interaction between school SES and Grade 1 emerged, indicating that children in high-SES schools made greater gains than their peers in low-SES schools during this year. No reliable SES-related differences in gains were observed for Grade 2. Critically, the Grade 1 SES effect remained reliable after accounting for maternal education and cognitive precursors, supporting Hypotheses 3b and 3c. Receptive vocabulary was a reliable positive predictor of growth, whereas number comparison and maternal education were not reliably associated with gains.

Math Fluency. Supporting Hypothesis 3a, school SES predicted grade-specific differences in math fluency gains. During kindergarten, gains were comparable for children attending high- and low-SES schools. A reliable negative interaction between school SES and Grade 2 was observed, reflecting a shift in growth rates. Children attending high-SES schools made their biggest gains early in schooling, whereas children attending low-SES schools showed a relative increase in their rate of gain by Grade 2. Despite this later shift, however, supporting Hypotheses 3b and 3c, the robust model showed that school SES reliably predicted gains, whereas number comparison and maternal education were not reliably associated with gains. Receptive vocabulary was also a reliable positive predictor of growth.

Applied Problems. Contrary to Hypothesis 3a, school SES was not a reliable predictor of gains in applied problems. SES differences in kindergarten gains were not reliable, and no reliable SES by grade interactions were observed for Grade 1 or Grade 2. Because no reliable SES effects were observed in the base model, Hypotheses 3b and 3c were not supported: School SES did not predict gains either before or after accounting for maternal education and cognitive precursors. Maternal education and cognitive predictors were likewise not reliably associated with growth in this domain.

Literacy Outcomes

Letter-Word Identification. Contrary to Hypothesis 3a, school SES was not a reliable predictor of gains in letter-word identification. Because no reliable SES effects were observed in the base model, Hypotheses 3b and 3c were not supported: School SES did not predict gains either before or after accounting for maternal education and cognitive precursors. Maternal education and cognitive predictors were likewise not reliably associated with growth in this domain.

Passage Comprehension. Contrary to Hypothesis 3a, school SES was not a reliable predictor of gains in passage comprehension. Because no reliable SES effects were observed in the base model, Hypotheses 3b and 3c were not supported: School SES did not predict gains either before or after accounting for maternal education and cognitive precursors. Maternal education and cognitive predictors were likewise not reliably associated with growth in this domain.

Discussion

In this preregistered study, we examined how school socioeconomic context contributes to changes in mathematical development during the early years of formal schooling. The findings are interpreted with respect to three developmental frameworks describing how SES differences may shape mathematics achievement over time: divergence, compensatory, and stability accounts. Together, these frameworks capture distinct expectations regarding whether SES-related differences amplify, diminish, or remain stable across schooling. Consistent with a divergence account, and previous research with Chilean children (Ayala et al., 2024; Cerda et al., 2014; Muñoz & Redondo, 2013), we found that in the early years of formal schooling, children attending high-SES schools generally outperformed their peers attending low-SES schools in mathematical outcomes and this gap widened over time (i.e., Matthew effects). For cognitive skills, children attending high-SES schools outperformed their peers from low-SES schools, but these differences generally remained stable with each additional school year. Similarly, for literacy, at the performance level there were differences for children attending high- versus low-SES schools, but school SES did not predict one-year literacy gains. We elaborate on these patterns below.

Children in High-SES Schools Exhibit Better Performance on Mathematics Outcomes Compared to Children in Low-SES Schools

Consistent with extensive evidence linking SES to academic achievement (Duncan & Magnuson, 2011; OECD, 2019; Sirin, 2005) and supporting our first hypothesis, we found that, for mathematical outcomes, from Grade 1 to Grade 3 children attending high-SES schools generally outperformed their peers attending low-SES schools. Exceptions were observed for all mathematics outcomes in kindergarten, where performance levels were comparable across SES groups, suggesting that SES-related differences in these outcomes emerge after school entry rather than reflecting pre-existing disparities. Supporting our second hypothesis, patterns consistent with widening SES-related differences emerged for the three mathematics outcomes even when controlling for maternal education, which did not explain these developmental differences except for applied problems. Specifically, for calculation and math fluency, SES-related divergence was reliably observed in Grades 2 and 3, consistent with the idea that the difference for children attending low- versus high-SES schools increased with each additional year of formal schooling. For applied problems, this widening was also reliable by Grade 3, with borderline evidence of divergence appearing as early as Grade 1. A cross-sectional examination of performance levels revealed a widening developmental divide; by Grade 3, the gap in applied problems reached 5.4 points, suggesting a cumulative divergence in mathematical reasoning.

Notably, across several measures, children attending low-SES schools showed minimal improvement between Grades 2 and 3, whereas children in high-SES schools continued to demonstrate measurable gains. Although these cohort-specific patterns did not always yield reliable SES by grade interactions in the conservative multilevel models, they suggest a systematic divergence in developmental trajectories visible at the level of performance means. These patterns are consistent with the view that curriculum-based mathematics outcomes are especially sensitive to cumulative inequalities in instructional quality and learning opportunities across schools. Within highly segregated educational systems, differences in school resources, teacher expertise, and academic environments may progressively amplify disparities in mathematics achievement over time (Ayala et al., 2024; Jordan et al., 1992; Laski et al., 2016; Short & McLean, 2023), whereas foundational cognitive skills that stabilize relatively early may be less affected by accumulating instructional differences. These findings contrast with literature suggesting that schools are equalizers (Von Hippel et al., 2018) or that academic achievement is relatively stable during childhood (Caro et al., 2009). Notably, researchers have suggested that stable inequalities might reflect similar learning opportunities for all students, regardless of background (Raudenbush & Eschmann, 2015). In Chile, however, inequality in educational experiences and resources, such as teacher guidelines, financial support, and student composition, might explain the growing gaps in mathematical performance observed in the present study (Ceron et al., 2022; OECD, 2019; Valenzuela et al., 2014).

School Socioeconomic Status as a Predictor of Mathematics Gains

In addition to cross-sectional patterns, we examined whether school SES predicted one-year learning gains. In support of our third hypothesis, children attending high-SES schools made greater gains in calculation and math fluency than children attending low-SES schools even when controlling for cognitive precursors. Specifically, children in high-SES schools made greater calculation gains from Grade 1 to Grade 2 and greater math fluency gains from kindergarten to Grade 1. Interestingly, a reliable negative interaction was observed for math fluency in Grade 2, suggesting that fluency development may not follow a linear trajectory. For applied problems, longitudinal models did not consistently indicate reliable SES-related differences in gains; however, mean-level trends still suggested greater cumulative progress in high-SES schools over time. Children in high-SES schools continued to demonstrate measurable gains in applied problems, whereas those in low-SES schools showed minimal improvement during the same period, suggesting that the strict nature of our multilevel models may have masked systematic differences in learning trajectories that were nonetheless apparent in the observed mean scores.

Moreover, school SES continued to predict longitudinal gains above and beyond maternal education, reinforcing the unique influence of school-level SES in children's mathematical development. These findings are consistent with other research, suggesting that policies should focus not only on familial SES but also on structural school inequalities (Chmielewski, 2019; Valenzuela et al., 2014). Socioeconomic disparities might reflect access to educational resources and teacher quality (Betts et al., 2000; Hanselman, 2018; Van Ewijk & Sleegers, 2010), with these school-level factors independently contributing to learning growth (Downey & Condron, 2016; Otto & Kistner, 2017).

School Socioeconomic Status in Relation to Performance and Gains in Cognitive Skills and Literacy Outcomes

To determine whether SES-related disparities showed different developmental patterns across domains and educational contexts, we examined cognitive skills and literacy outcomes in addition to mathematics outcomes. Consistent with our first hypothesis, children attending high-SES schools demonstrated stronger receptive vocabulary and quantitative skills at kindergarten entry, and these differences persisted in Grades 1, 2, and 3. Differences evident at kindergarten entry for cognitive precursors suggest that SES-related disparities in foundational skills are already present at the onset of formal schooling (Blakey et al., 2020; Liu et al., 2020). Consistent with this pattern, maternal education also predicted receptive vocabulary and number comparison, further indicating that early home environments contribute to the emergence of these foundational differences prior to and alongside school entry (Davis-Kean et al., 2021; Harding et al., 2015; Waters et al., 2021). The maintenance of these disparities in Grades 1, 2, and 3, highlight that early disparities persist during formal schooling.

The SES gaps for cognitive precursors followed a different pattern across the grade levels than those seen for the curriculum-based mathematics outcomes. Consistent with our second hypothesis, for number ordering, the gap remained stable across all grade levels. For number comparison, the gap widened in Grade 1 and Grade 2, though this divergence was no longer reliable by Grade 3, suggesting that differences in foundational numeracy may remain relatively stable or even narrow as children gain more experience with formal symbols (Jordan et al., 2006). Finally, regarding receptive vocabulary, the interaction was not reliable in the early years; however, contrary to our second hypothesis, a small but reliable widening of the gap emerged by Grade 3. This finding suggests that while schools may maintain or even reduce differences in some foundational cognitive precursors, they may unexpectedly exacerbate gaps in others, such as language-based skills, during the later years of early primary education (cf. Pace et al., 2017; Stanovich, 1986). More broadly, these findings are consistent with the possibility that foundational cognitive skills follow somewhat different developmental trajectories than curriculum based academic outcomes. Whereas mathematics achievement appears increasingly sensitive to cumulative instructional inequalities across schooling, cognitive skills showed comparatively stable SES differences across grades (Breit et al., 2024) suggesting that SES-related developmental patterns may vary systematically depending on the extent to which skills rely on cumulative instructional exposure versus earlier-emerging foundational competencies.

A somewhat similar pattern emerged for literacy outcomes. At the school level, controlling for familial SES, the gap between children attending vulnerable and non-vulnerable schools is particularly salient for higher order literacy skills, such as text quality and reading comprehension (Salas & Pascual, 2023). Although we did observe differences in performance levels for children attending low- versus high-SES schools at both Time 1 and Time 2, contrary to our third hypothesis, gains in letter-word identification and passage comprehension were not reliably predicted by school SES, maternal education, nor cognitive precursors. Our findings are consistent with other researchers who have found that SES differences in vocabulary and reading did not widen over time (Van Der Kleij et al., 2023) and that school SES ceased to exert significant influence on children's literacy skills once cognitive and linguistic skills were considered (Salas & Pascual, 2023). Moreover, we are not the first to find fan-spread effects in mathematics, but not in reading development (Baumert et al., 2012), suggesting that perhaps the effects of school SES are not consistent across these two fundamental domains. One possibility is that literacy interventions are more uniformly distributed across SES levels in some contexts (OECD, 2019) and as such there may be differential curriculum emphasis, with schools prioritising early literacy more evenly than mathematics. Another possibility is that the relatively transparent orthography in the Spanish language promotes high reading accuracy (Davies et al., 2007). Compared to languages with lower orthographic transparency, languages with high transparency, such as Spanish, facilitate more efficient literacy development, with learners reporting more confidence and motivation when learning to read and write (Tamelan, 2025). Nonetheless, overall passage comprehension levels in the present sample were relatively low, with students from both low- and high-SES schools making minimal gains from Grade 2 to Grade 3, suggesting that reading comprehension at this stage may rely more heavily on emerging decoding skills than higher-order comprehension processes, which could also limit detectable SES differences. More longitudinal research is needed to map the trajectories of these skills over the early years of formal education.

Across domains, the findings point to a differentiated pattern of SES-related development during early schooling. Mathematics outcomes showed the strongest evidence of divergence over time, consistent with cumulative instructional inequality shaping curriculum-based learning. In contrast, cognitive precursors exhibited more stable SES-related differences across grades, suggesting relative continuity in foundational skills and weaker sensitivity to school-level variation in instruction. Literacy outcomes showed the least evidence of SES-related differences in growth, with performance-level gaps present but no systematic divergence in gains once prior skills were considered. Overall, these domain-specific patterns indicate that the effect of school socioeconomic context is not uniform across development, but instead varies according to the extent to which skills depend on cumulative instructional exposure versus earlier-developing foundational competencies.

Limitations and Future Research

The present study is not without limitations. First, we could only examine effects from kindergarten to Grade 3 cross sectionally. Longitudinal research is necessary to determine the developmental trajectories of mathematics and literacy outcomes for children attending low- versus high-SES schools. Relatedly, due to the COVID-19 pandemic we were only able to collect two waves of data. As such, we could only longitudinally examine growth from one school year to the next for a subset of our sample. It is quite likely that children’s skills do not grow linearly.

Second, we had a limited sample size for the longitudinal analyses, particularly for the literacy tasks which were not administered for every grade level. Thus, future studies should follow a larger group of children from multiple schools for a longer period to capture the rate of change in mathematics and literacy outcomes while considering the nested nature of schools and classrooms. Relatedly, the study included a limited number of schools within each SES category, restricting the generalizability of our findings to the broader Chilean population. This was especially important given the multilevel structure of the data, where statistical power is influenced by the number of school clusters. Bayesian power analyses indicated adequate power when estimating 80% credible intervals, but substantially lower power at the more conservative 95% level. Although the overall pattern of findings was largely consistent across intervals, some effects were attenuated at the 95% level, suggesting greater uncertainty around weaker effects. It is therefore possible that some developmental differences visible in the observed mean trajectories were not reliably detected statistically because of limited cluster-level power. Future research should aim to recruit larger and more socioeconomically diverse sets of schools, including those representing middle-SES contexts, to better capture the full socioeconomic status range.

Third, school SES was derived from a vulnerability index that incorporates multiple factors and is closely related to parental education and language fluency. Examining the individual components of this index in future work, and conducting surveys with school principals and teachers, may help clarify which specific aspects of school SES most strongly influence children's learning outcomes. Future research would also benefit from incorporating broader measures of family-level SES to better distinguish school- and home-level socioeconomic influences.

Finally, the present study predominantly focused on domain-specific precursors of mathematics learning (i.e., number comparison, number ordering). Receptive vocabulary was included because language skills support early mathematics learning through comprehension of instruction and symbolic representations and have been shown to uniquely predict early numeracy and mathematics outcomes (Purpura et al., 2011; Slusser et al., 2019). Future work should also consider domain-general cognitive processes such as executive functions and working memory, which are associated with socioeconomic disadvantage and academic achievement (Spiegel et al., 2021). Future research integrating both domain-specific and domain-general predictors may help clarify the multiple cognitive pathways through which SES influences academic development.

Conclusion

In this preregistered study, we examined how school socioeconomic status (SES) relates to early mathematics development among Chilean children from kindergarten to Grade 3. Children attending high-SES schools generally outperformed those attending low-SES schools across mathematics, literacy, and cognitive assessments. Evidence of widening SES-related differences was outcome- and grade-specific, emerging most reliably for curriculum-based mathematics outcomes rather than uniformly across domains. Notably, school SES predicted specific one-year gains in calculation and math fluency even after controlling for maternal education and cognitive precursors. In contrast, growth in literacy outcomes and applied problems did not show the same reliable SES-driven divergence in gains, though a clear divide in observed mean scores was evident in the latter by the end of early primary school. Together, the findings point to persistent and compounding socioeconomic differences in mathematics learning and highlight the need for targeted school-level supports aimed at reducing the widening achievement gap during these formative years of formal education.

References

Agencia de Calidad de la Educación. (2015). *Metodología de construcción de grupos socioeconómicos Simce 2013 [Methodology for constructing SIMCE 2013 socieconomic groups].* http://archivos.agenciaeducacion.cl/estudios/Evolucion_brechas_socioeconomicas_de_rendimiento_en_pruebas_Simce.pdf

Aikens, N. L., & Barbarin, O. (2008). Socioeconomic differences in reading trajectories: The contribution of family, neighborhood, and school contexts. *Journal of Educational Psychology*, *100*(2), 235–251. https://doi.org/10.1037/0022-0663.100.2.235

Altindağ Kumaş, Ö. (2022). Early mathematical and receptive language skills of children from different socioeconomic levels: Letter knowledge a mediator. *Education 3-13*, *50*(6), 843–854. https://doi.org/10.1080/03004279.2021.2010785

Ayala, M. C., Strasser, K., Susperreguy, M. I., & Castillo, K. (2024). Socioeconomic gaps in specific mathematical skills at different ages in primary school. *Journal of Educational Psychology*, *116*(5), 762–784. https://doi.org/10.1037/edu0000892

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Baumert, J., Nagy, G., & Lehmann, R. (2012). Cumulative advantages and the emergence of social and ethnic inequality: Matthew effects in reading and mathematics development within elementary schools? *Child Development*, *83*(4), 1347–1367. https://doi.org/10.1111/j.1467-8624.2012.01779.x

Betts, J., Reuben, K. S., & Danenberg, A. (2000). *Equal resources, equal outcomes? The distribution of school resources and student achievement in California*. Public Policy Institute of California.

Blakey, E., Matthews, D., Cragg, L., Buck, J., Cameron, D., Higgins, B., Pepper, L., Ridley, E., Sullivan, E., & Carroll, D. J. (2020). The role of executive functions in socioeconomic attainment gaps: Results from a randomized controlled trial. *Child Development*, *91*(5), 1594–1614. https://doi.org/10.1111/cdev.13358

Breit, M., Scherrer, V., Tucker-Drob, E. M., & Preckel, F. (2024). The stability of cognitive abilities: A meta-analytic review of longitudinal studies. *Psychological Bulletin*, *150*(4), 399–439. https://doi.org/10.1037/bul0000425

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*(3), 273–293. https://doi.org/10.1207/S15326942DN1903_3

Cáceres-Serrano, P., & Alvarado-Izquierdo, J. M. (2017). The effect of contextual and socioeconomic factors on reading comprehension levels. *Modern Journal of Language Teaching Methods*, *7*(8), 76–85.

Caro, D. H., McDonald, J. T., & Wills, J. D. (2009). Socio-economic status and academic achievement trajectories from childhood to adolescence. *Canadian Journal of Education*, *32*(3), 558–590.

Cassen, R., & Kingdon, G. (2004). *Tackling low educational achievement*. Joseph Rowntree Foundation.

Cerda, G. A., Pérez, C., & Ortega, R. (2014). Relationship between early mathematical competence, gender and social background in chilean elementary school population. *Anales de Psicología*, *30*(3), 1006–1013. https://doi.org/10.6018/analesps.30.3.152891

Ceron, F. I., Bol, T., & Van De Werfhorst, H. G. (2022). The dynamics of achievement inequality: The role of performance and choice in Chile. *International Journal of*

Educational Development, *92*, 102628. https://doi.org/10.1016/j.ijedudev.2022.102628

Chmielewski, A. K. (2019). The global increase in the socioeconomic achievement gap, 1964 to 2015. *American Sociological Review*, *84*(3), 517–544. https://doi.org/10.1177/0003122419847165

Cremin, L. (1951). *The American Common School: A Historic Conception*. Teachers College Press.

D'Angiulli, A., Siegel, L. S., & Hertzman, C. (2004). Schooling, socioeconomic context and literacy development. *Educational Psychology*, *24*(6), 867–883. https://doi.org/10.1080/0144341042000271746

Davies, R., Cuetos, F., & Glez-Seijas, R. M. (2007). Reading development and dyslexia in a transparent orthography: A survey of Spanish children. *Annals of Dyslexia*, *57*(2), 179–198. https://doi.org/10.1007/s11881-007-0010-1

Davis-Kean, P. E., Tighe, L. A., & Waters, N. E. (2021). The role of parent educational attainment in parenting and children's development. *Current Directions in Psychological Science*, *30*(2), 186–192. https://doi.org/10.1177/0963721421993116

Denton, K., & West, J. (2002). *Children's reading and mathematics achievement in kindergarten and first grade*. National Center for Education Statistics, Office of Educational Research and Improvement, US Department of Education. https://doi.apa.org/doi/10.1037/e492182006-005

Dougherty, C. (2003). Numeracy, literacy and earnings: Evidence from the National Longitudinal Survey of Youth. *Economics of Education Review*, *22*(5), 511–521. https://doi.org/10.1016/S0272-7757(03)00040-2

Downey, D. B., & Condron, D. J. (2016). Fifty years since the Coleman report: Rethinking the relationship between schools and inequality. *Sociology of Education*, *89*(3), 207–220. https://doi.org/10.1177/0038040716651676

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, *43*(6), 1428–1446. https://doi.org/10.1037/0012-1649.43.6.1428

Duncan, G. J., & Magnuson, K. (2011). The nature and impact of early achievement skills, attention skills, and behavior problems. In G. J. Duncan & R. J. Murnane (Eds.), *Whither opportunity? Rising inequality, schools, and children's life chances* (pp. 47–69). Russell Sage Foundation.

Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: Moving from correlation to causation. *WIREs Cognitive Science*, *3*(3), 377–386. https://doi.org/10.1002/wcs.1176

Duncan, G. J., & Magnuson, K. A. (2003). Off with Hollingshead: Socioeconomic resources, parenting, and child development. In M. H. Bornstein & Bradley, *Socioeconomic status, parenting, and child development* (pp. 83–106). Erlbaum.

Dunn, L. M., Padilla, E. R., Lugo, D. E., & Dunn, L. M. (1986). *Test de Vocabulario en Imágenes Peabody. Adaptación Hispanoamericana [Peabody Picture Vocabulary Test. Hispanic-American adaptation]*. American Guidance Service.

Fox, J., & Weisberg, S. (2019). *An R Companion to Applied Regression* (Third). Sage. https://socialsciences.mcmaster.ca/jfox/Books/Companion/

Gabry, J., Simpson, D., Vehtari, A., Betancourt, M., & Gelman, A. (2019). Visualization in bayesian workflow. *Journal of the Royal Statistical Society Series A: Statistics in Society*, *182*(2), 389–402. https://doi.org/10.1111/rssa.12378

Gardner-Neblett, N., DeCoster, J., & Hamre, B. K. (2014). Linking preschool language and sustained attention with adolescent achievement through classroom self-reliance. *Journal of Applied Developmental Psychology*, *35*(6), 457–467. https://doi.org/10.1016/j.appdev.2014.09.003

Geary, D. C. (1995). Reflections of evolution and culture in children's cognition: Implications for mathematical development and instruction. *American Psychologist*, *50*(1), 24–37. https://doi.org/10.1037/0003-066X.50.1.24

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology*, *47*(6), 1539–1552. https://doi.org/10.1037/a0025510

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2013). *Bayesian data analysis* (0 ed.). Chapman and Hall/CRC. https://doi.org/10.1201/b16018

Goodrich, B., Gabry, J., Ali, I., & Brilleman, S. (2025). *rstanarm: Bayesian applied regression modeling via Stan.* https://mc-stan.org/rstanarm/

Grenwelge, C. H. (2009). Test review: Woodcock, R. W., Schrank, F. A., Mather, N., & McGrew, K. S. (2007). Woodcock-Johnson III Tests of Achievement, Form C/Brief Battery. Rolling Meadows, IL: Riverside. *Journal of Psychoeducational Assessment*, *27*(4), 345–350. https://doi.org/10.1177/0734282908327944

Griffin, S., Case, R., & Siegler, R. S. (1994). Classroom lessons: Integrating cognitive theory and classroom practice. In K. McGilly, *Rightstart: Providing the central conceptual prerequisites for first year formal learning of arithmetic to students at risk for school failure* (pp. 25–50). MIT Press.

Gutiérrez, G., & Carrasco, A. (2021). Chile's enduring educational segregation: A trend unchanged by different cycles of reform. *British Educational Research Journal*, *47*(6), 1611–1634. https://doi.org/10.1002/berj.3746

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: Developmental trajectories and mediation. *Developmental Science*, *18*(5), 686–702. https://doi.org/10.1111/desc.12246

Hanselman, P. (2018). Do school learning opportunities compound or compensate for background inequalities? Evidence from the case of assignment to effective teachers. *Sociology of Education*, *91*(2), 132–158. https://doi.org/10.1177/0038040718761127

Harding, J. F., Morris, P. A., & Hughes, D. (2015). The relationship between maternal education and children's academic outcomes: A theoretical framework. *Journal of Marriage and Family*, *77*(1), 60–76. https://doi.org/10.1111/jomf.12156

Holmes-Smith, P. (2006). *School socio-economic density and its effect on school performance*. Mceetya.

Hooper, S. R., Roberts, J., Sideris, J., Burchinal, M., & Zeisel, S. (2010). Longitudinal predictors of reading and math trajectories through middle school for African American versus Caucasian students across two samples. *Developmental Psychology*, *46*(5), 1018–1029. https://doi.org/10.1037/a0018877

Johnson, T., Burgoyne, A. P., Mix, K. S., Young, C. J., & Levine, S. C. (2022). Spatial and mathematics skills: Similarities and differences related to age, SES, and gender. *Cognition*, *218*, 104918. https://doi.org/10.1016/j.cognition.2021.104918

Jordan, N. C., Huttenlocher, J., & Levine, S. C. (1992). Differential calculation abilities in young children from middle- and low-income families. *Developmental Psychology*, *28*(4), 644–653. https://doi.org/10.1037/0012-1649.28.4.644

Jordan, N. C., Kaplan, D., Nabors Oláh, L., & Locuniak, M. N. (2006). Number sense growth in kindergarten: A longitudinal investigation of children at risk for mathematics difficulties. *Child Development*, *77*(1), 153–175. https://doi.org/10.1111/j.1467-8624.2006.00862.x

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology*, *45*(3), 850–867. https://doi.org/10.1037/a0014939

Kieffer, M. J. (2012). Before and after third grade: Longitudinal evidence for the shifting role of socioeconomic status in reading growth. *Reading and Writing*, *25*(7), 1725–1746. https://doi.org/10.1007/s11145-011-9339-2

Klein, A., Starkey, P., & DeFlorio, L. (2019). Improving the mathematical knowledge of at-risk preschool children: Two approaches to intensifying early math intervention. In *Cognitive Foundations for Improving Mathematical Learning* (pp. 215–245). Elsevier. https://doi.org/10.1016/B978-0-12-815952-1.00009-8

Korous, K. M., Causadias, J. M., Bradley, R. H., Luthar, S. S., & Levy, R. (2022). A systematic overview of meta-analyses on socioeconomic status, cognitive ability, and achievement: The need to focus on specific pathways. *Psychological Reports*, *125*(1), 55–97. https://doi.org/10.1177/0033294120984127

Kruschke, J. (2014). *Doing Bayesian data analysis: A tutorial with R, JAGS, and Stan*.

Laski, E. V., Schiffman, J., Vasilyeva, M., & Ermakova, A. (2016). Arithmetic accuracy in children from high- and low-income schools: What do strategies have to do with it? *AERA Open*, *2*(2), 2332858416644219. https://doi.org/10.1177/2332858416644219

Lenth, R. V. (2024). *emmeans: Estimated Marginal Means, aka Least-Squares Means*. https://CRAN.R-project.org/package=emmeans

Levine, S. C., Jordan, N. C., & Huttenlocher, J. (1992). Development of calculation abilities in young children. *Journal of Experimental Child Psychology*, *53*(1), 72–103. https://doi.org/10.1016/S0022-0965(05)80005-0

Liu, J., Peng, P., & Luo, L. (2020). The relation between family socioeconomic status and academic achievement in China: A meta-analysis. *Educational Psychology Review*, *32*(1), 49–76. https://doi.org/10.1007/s10648-019-09494-0

McElreath, R. (2018). *Statistical rethinking: A Bayesian course with examples in R and Stan*. Chapman and Hall/CRC.

Ministerio de Educación. (2018). *Bases Curriculares Primero a Sexto Básico*. https://www.curriculumnacional.cl/recursos/bases-curriculares-1-6-basico

Molina, A. (2021). *School segregation and social cohesion in santiago: Perspectives from the Chilean experience* (Vol. 3). Springer International Publishing. https://doi.org/10.1007/978-3-030-70534-3

Muñoz, P., & Redondo, A. (2013). *Inequality and academic achievement in Chile*. CEPAL Review no.109. https://ssrn.com/abstract=2812266

Muñoz-Sandoval, A. F., Woodcock, R. W., McGrew, K. S., & Mather, N. (2005). *Woodcock-Muñoz achievement battery III: Tests of achievement*. Riverside.

Nennstiel, R. (2023). No Matthew effects and stable SES gaps in math and language achievement growth throughout schooling: Evidence from Germany. *European Sociological Review*, *39*(5), 724–740. https://doi.org/10.1093/esr/jcac062

OECD. (2010). *PISA 2009 Results: Overcoming Social Background. Equity in Learning Opportunities and Outcomes. Volume II.* ERIC Clearinghouse.

OECD. (2019). *Society at a glance 2019: OECD social indicators*. OECD. https://doi.org/10.1787/soc_glance-2019-en

Otto, B., & Kistner, S. (2017). Is there a Matthew effect in self-regulated learning and mathematical strategy application? - Assessing the effects of a training program with standardized learning diaries. *Learning and Individual Differences*, *55*, 75–86. https://doi.org/10.1016/j.lindif.2017.03.005

Pace, A., Luo, R., Hirsh-Pasek, K., & Golinkoff, R. M. (2017). Identifying pathways between socioeconomic status and language development. *Annual Review of Linguistics*, *3*(1), 285–308. https://doi.org/10.1146/annurev-linguistics-011516-034226

Passolunghi, M. C., Mammarella, I. C., & Altoè, G. (2008). Cognitive abilities as precursors of the early acquisition of mathematical skills during first through second grades. *Developmental Neuropsychology*, *33*(3), 229–250. https://doi.org/10.1080/87565640801982320

Perry, L., & McConney, A. (2010). School socio-economic composition and student outcomes in Australia: Implications for educational policy. *Australian Journal of Education*, *54*(1), 72–85. https://doi.org/10.1177/000494411005400106

Purpura, D. J., Hume, L. E., Sims, D. M., & Lonigan, C. J. (2011). Early literacy and early numeracy: The value of including early literacy skills in the prediction of numeracy development. *Journal of Experimental Child Psychology*, *110*(4), 647–658. https://doi.org/10.1016/j.jecp.2011.07.004

R Core Team. (2024). *R* (Version Race for Your Life 4.4.1) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org

Raudenbush, S. W., & Eschmann, R. D. (2015). Does schooling increase or reduce social inequality? *Annual Review of Sociology*, *41*(1), 443–470. https://doi.org/10.1146/annurev-soc-071913-043406

Reardon, S. F. (2011). The widening academic achievement gap between the rich and the poor: New evidence and possible explanations. In G. J. Duncan & R. J. Murnane

(Eds.), *Whither opportunity? Rising inequality, schools, and children's life chances* (pp. 91–116). Russell Sage Foundation.

Rumberger, R. W., & Palardy, G. J. (2005). Does segregation still matter? The impact of student composition on academic achievement in high school. *Teachers College Record*, *107*(9), 1999–2045.

Salas, N., & Pascual, M. (2023). Impact of school SES on literacy development. *PLOS ONE*, *18*(12), e0295606. https://doi.org/10.1371/journal.pone.0295606

Short, D. S., & McLean, J. F. (2023). The relationship between numerical mapping abilities, maths achievement and socioeconomic status in 4- and 5-year-old children. *British Journal of Educational Psychology*, *93*(3), 641–657. https://doi.org/10.1111/bjep.12582

Sirin, S. R. (2005). Socioeconomic status and academic achievement: A meta-analytic review of research. *Review of Educational Research*, *75*(3), 417–453. https://doi.org/10.3102/00346543075003417

Skopek, J., & Passaretta, G. (2021). Socioeconomic inequality in children's achievement from infancy to adolescence: The case of Germany. *Social Forces*, *100*(1), 86–112. https://doi.org/10.1093/sf/soaa093

Slavin, R. E. (1987). Ability grouping and student achievement in elementary schools: A best-evidence synthesis. *Review of Educational Research*, *57*(3), 293–336. https://doi.org/10.3102/00346543057003293

Slusser, E., Ribner, A., & Shusterman, A. (2019). Language counts: Early language mediates the relationship between parent education and children's math ability. *Developmental Science*, *22*(3), e12773. https://doi.org/10.1111/desc.12773

Sontag, C., & Stoeger, H. (2015). Can highly intelligent and high-achieving students benefit from training in self-regulated learning in a regular classroom context? *Learning and Individual Differences*, *41*, 43–53. https://doi.org/10.1016/j.lindif.2015.07.008

Spiegel, J. A., Goodrich, J. M., Morris, B. M., Osborne, C. M., & Lonigan, C. J. (2021). Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. *Psychological Bulletin*, *147*(4), 329–351. https://doi.org/10.1037/bul0000322

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly*, *21*(4), 360–407. https://doi.org/10.1598/RRQ.21.4.1

Susperreguy, M. I., Di Lonardo Burr, S., Douglas, H., Xu, C., LeFevre, J.-A., Del Río, M. F., & Salinas, V. (2022). Home mathematics environment and math performance of Chilean students in kindergarten and Grades 1 to 3. *Early Childhood Research Quarterly*, *59*, 84–95. https://doi.org/10.1016/j.ecresq.2021.11.004

Tamelan, T. M. (2025). Exploring orthographic transparency: Implications for language learning. In N. N. Benu & M. Jonathans (Eds.), *Innovations in language learning: Pedagogical strategies and linguistic insights*. Artha Wacana Press.

Treviño, E., Valenzuela, J. P., & Villalobos, C. (2019). Segregation of indigenous students in the Chilean educational system and its relation to socioeconomic segregation. In A. Gaete & V. Gómez, *Education and poverty* (pp. 321–347). Cambridge Scholars Publishing.

Valenzuela, J. P., & Allende, C. (2023). School segregation in Chile. In V. Dupriez, J. P. Valenzuela, M. Verhoeven, & J. Corvalán (Eds.), *Educational Markets and Segregation* (pp. 167–187). Springer International Publishing. https://doi.org/10.1007/978-3-031-36147-0_9

Valenzuela, J. P., Bellei, C., & Ríos, D. D. L. (2014). Socioeconomic school segregation in a market-oriented educational system. The case of Chile. *Journal of Education Policy*, *29*(2), 217–241. https://doi.org/10.1080/02680939.2013.806995

Van Der Kleij, S. W., Burgess, A. P., Ricketts, J., & Shapiro, L. R. (2023). Tracking vocabulary and reading growth in children from lower and higher socioeconomic backgrounds during the transition from primary to secondary education. *Child Development*, *94*(1). https://doi.org/10.1111/cdev.13862

Van Ewijk, R., & Sleegers, P. (2010). The effect of peer socioeconomic status on student achievement: A meta-analysis. *Educational Research Review*, *5*(2), 134–150. https://doi.org/10.1016/j.edurev.2010.02.001

Vandierendonck, A. (2017). A comparison of methods to combine speed and accuracy measures of performance: A rejoinder on the binning procedure. *Behavior Research Methods*, *49*(2), 653–673. https://doi.org/10.3758/s13428-016-0721-5

Von Hippel, P., & Hamrock, C. (2019). Do test score gaps grow before, during, or between the school years? Measurement artifacts and what we can know in spite of them. *Sociological Science*, *6*, 43–80. https://doi.org/10.15195/v6.a3

Von Hippel, P. T., Workman, J., & Downey, D. B. (2018). Inequality in reading and math skills forms mainly before kindergarten: A replication, and partial correction, of "are schools the great equalizer?" *Sociology of Education*, *91*(4), 323–357. https://doi.org/10.1177/0038040718801760

Von Stumm, S., Cave, S. N., & Wakeling, P. (2022). Persistent association between family socioeconomic status and primary school performance in Britain over 95 years. *Npj Science of Learning*, *7*(1), 4. https://doi.org/10.1038/s41539-022-00120-3

Waters, N. E., Ahmed, S. F., Tang, S., Morrison, F. J., & Davis-Kean, P. E. (2021). Pathways from socioeconomic status to early academic achievement: The role of specific executive functions. *Early Childhood Research Quarterly*, *54*, 321–331. https://doi.org/10.1016/j.ecresq.2020.09.008

Watts, T. W., Duncan, G. J., Siegler, R. S., & Davis-Kean, P. E. (2014). What's past is prologue: Relations between early mathematics knowledge and high school achievement. *Educational Researcher*, *43*(7), 352–360. https://doi.org/10.3102/0013189X14553660

Wickham, H. (2016). *Ggplot2*. Springer International Publishing. https://doi.org/10.1007/978-3-319-24277-4

Wickham, H., Vaughan, D., & Girlich, M. (2024). *Tidyr: Tidy Messy Data. R package.* (Version 1.3.1) [Computer software]. https://CRAN.R-project.org/package=tidyr

Wilke, C. (2024). *Cowplot: Streamlined plot theme and plot annotations for "ggplot2"* (Version 1.1.3) [Computer software]. https://CRAN.R-project.org/package=cowplot

Zhu, X., Tang, Y., Wang, S., Ma, X., Lin, J., Chai, Q., Yang, X., & Zhao, X. (2025). Underlying mechanisms in the relationship between family socioeconomic status and mathematical abilities: A longitudinal investigation. *Cognitive Development*, *75*, 101591. https://doi.org/10.1016/j.cogdev.2025.101591

Supplementary Materials

Table S1

Descriptive Statistics for All Measures by Grade and Time Point

	Kindergarten			Grade 1			Grade 2			Grade 3		
	N	*M* (SD)	Skew	*N*	*M* (SD)	Skew	*N*	*M* (SD)	Skew	*N*	*M* (SD)	Skew
Time 1												
Receptive Vocabulary[a]	98	62.2 (10.3)	0.1	93	73.1 (11.9)	-0.3	86	84.3 (10.2)	0.1	83	87.7 (12.7)	0.0
Number Comparison[b]	96	2.0 (0.5)	0.5	93	1.6 (0.5)	1.0	85	1.2 (0.3)	1.4	83	1.2 (0.3)	1.0
Number Ordering[b]	--	--	--	93	4.3 (1.0)	0.6	84	3.5 (0.9)	0.6	83	3.4 (0.8)	0.5
Letter-Word Identification[a]	98	16.5 (18.7)	1.8	93	46.4 (22.4)	-0.5	--	--	--	--	--	--
Passage Comprehension[a]	--	--	--	--	--	--	86	25.5 (4.5)	-1.1	83	26.9 (4.8)	-0.9
Calculation[a]	100	3.0 (2.5)	0.7	94	6.7 (3.0)	-0.1	86	10.9 (2.8)	0.2	83	12.4 (3.1)	0.3
Math Fluency[a]	81	5.1 (5.6)	1.3	92	14.5 (8.1)	0.4	86	29.4 (10.0)	0.1	83	33.4 (11.2)	0.1
Applied Problems[a]	100	17.7 (4.1)	-0.0	94	23.6 (4.2)	0.1	86	28.3 (3.8)	0.3	83	30.3 (4.6)	0.3
Time 2												
Letter-Word Identification[a]	--	--	--	94	51.1 (21.1)	-0.8	--	--	--	--	--	--
Passage Comprehension[a]	--	--	--	--	--	--	81	24.8 (5.1)	-0.8	76	27.9 (4.0)	-0.0
Calculation[a]	--	--	--	94	6.9 (2.5)	-0.3	82	10.7 (2.7)	-0.5	77	13.2 (2.4)	-0.3
Math Fluency[a]	--	--	--	94	14.7 (8.0)	0.4	82	28.4 (9.5)	-0.4	77	39.5 (11.8)	0.6
Applied Problems[a]	--	--	--	94	30.5 (5.3)	-0.6	82	38.6 (6.2)	0.0	77	45.5 (6.0)	0.3

Note. [a]Total correct; [b]Adjusted RT scores

Table S2

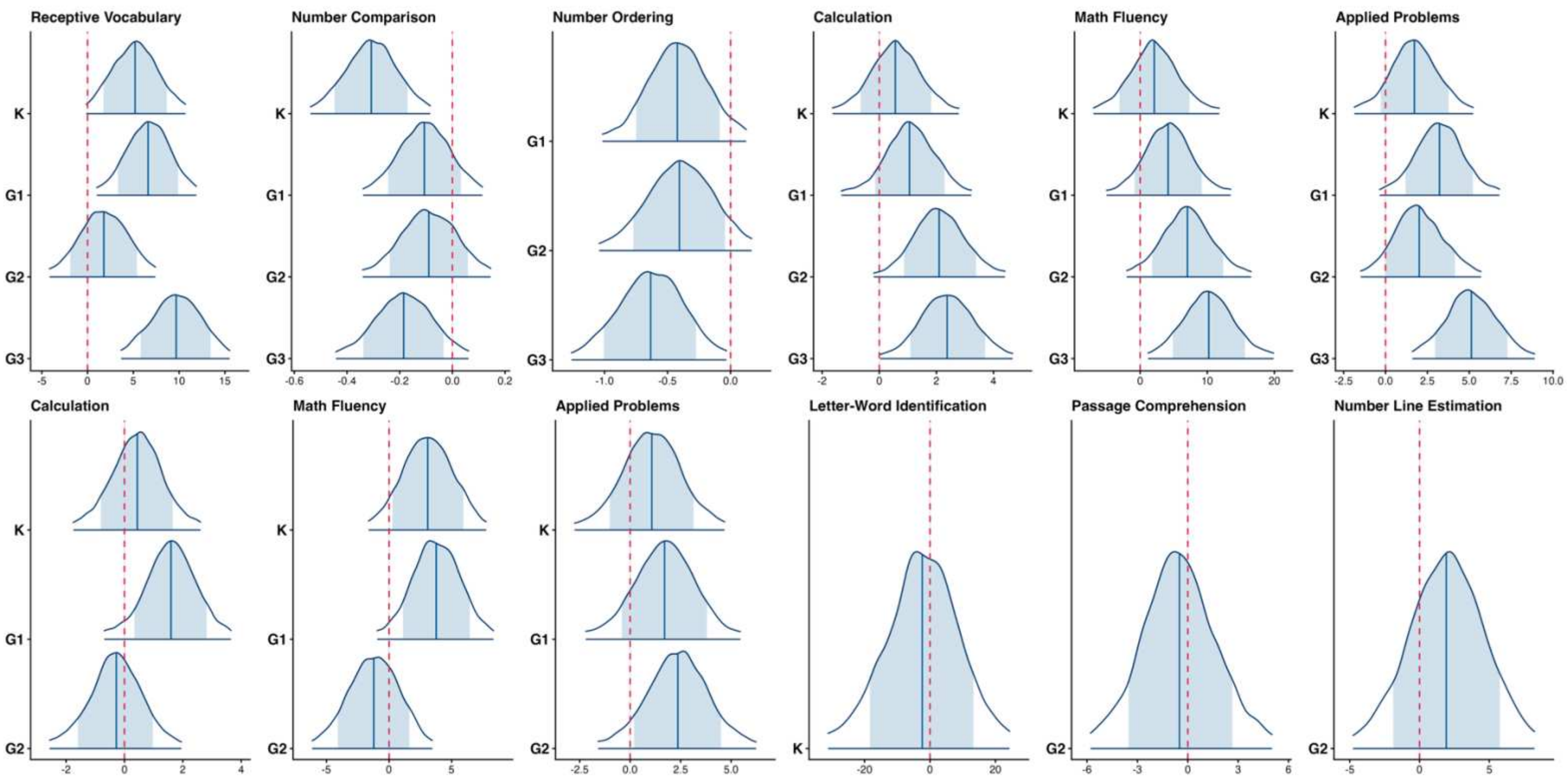
Bayesian Estimates (95% CrIs) for School SES Effects by Grade

	Cognitive Precursors						Mathematics Outcomes					
	Receptive Vocabulary		Number Comparison		Number Ordering		Calculation		Math Fluency		Applied Problems	
Predictors	b	95% CrI	b	95% CrI	b	95% CrI	b	95% CrI	b	95% CrI	b	95% CrI
School SES	5.19	[-0.14, 10.70]	**-0.31**	**[-0.54, -0.08]**	-0.42	[-1.02, 0.12]	0.56	[-1.64, 2.78]	2.11	[-6.96, 11.78]	1.72	[-1.86, 5.23]
Maternal Education	**0.94**	**[0.46, 1.41]**	-0.02	[-0.04, 0.00]	-0.02	[-0.06, 0.03]	0.07	[-0.06, 0.19]	0.25	[-0.15, 0.65]	**0.15**	**[-0.03, 0.33]**
Grade 1	**9.89**	**[5.87, 13.99]**	**-0.46**	**[-0.62, -0.30]**	--	--	**3.51**	**[2.41, 4.64]**	**8.98**	**[5.30, 12.60]**	**5.16**	**[3.58, 6.72]**
Grade 2	**24.62**	**[20.78, 28.65]**	**-0.89**	**[-1.05, -0.74]**	**-0.83**	**[-1.20, -0.46]**	**7.27**	**[6.22, 8.33]**	**22.6**	**[19.26, 26.01]**	**10.57**	**[9.08, 12.02]**
Grade 3	**25.22**	**[21.32, 29.23]**	**-0.9**	**[-1.06, -0.74]**	**-0.95**	**[-1.32, -0.59]**	**8.83**	**[7.76, 9.86]**	**26.59**	**[23.16, 30.04]**	**11.87**	**[10.33, 13.43]**
School SES × Grade 1	1.42	[-4.43, 7.07]	0.20	[-0.02, 0.42]	--	--	0.49	[-1.05, 2.02]	2.05	[-2.95, 7.05]	1.5	[-0.69, 3.75]
School SES × Grade 2	-3.42	[-9.32, 2.60]	0.22	[-0.02, 0.45]	0.02	[-0.52, 0.55]	1.53	[-0.02, 3.10]	4.94	[-0.07, 9.83]	0.29	[-1.92, 2.56]
School SES × Grade 3	4.49	[-1.54, 10.29]	0.12	[-0.12, 0.36]	-0.21	[-0.76, 0.33]	**1.81**	**[0.19, 3.37]**	**8.2**	**[3.00, 13.37]**	**3.4**	**[1.11, 5.71]**

Note. Bolded coefficients indicate credible intervals excluding zero.

Figure S1

Posterior Distributions of School SES Gaps Across Cognitive and Mathematics Trajectories and Longitudinal Gains Models



Note. Continuous probability density curves represent the posterior distributions of the school-level SES effect. The inner shaded regions denote the 80% highest posterior density credible intervals, and the outer whiskers denote the 95% highest posterior density credible intervals. The dashed line represents the null hypothesis of zero SES differences; with the exception of number comparison, number ordering, and number line estimation, posterior mass distributed to the right of 0 indicates a high-SES performance advantage. For models tracking simple trajectories across multiple grades (Top Row and Bottom Row: *Calculation, Math Fluency, Applied Problems*), outcomes are partitioned by grade baseline. For single-grade targeted gain models, baseline timepoints are explicitly designated.

Bayesian Model Convergence and Diagnostics

All statistical models were estimated within a fully Bayesian framework using Markov Chain Monte Carlo (MCMC) simulation via the *rstanarm* package in R. For each of the twelve focal models, estimation used four parallel chains with 2,000 iterations per chain, including 1,000 warm-up iterations, resulting in 4,000 post-warmup posterior draws per model. Following recommended practices for Bayesian model reporting (Gelman et al., 2013), convergence diagnostics and posterior predictive checks were conducted for all models.

Convergence was evaluated using both visual inspection and quantitative diagnostics. Trace plots for the primary parameter of interest (school SES) across all twelve models are presented in Figure S2. Across models, chains showed good mixing and stable overlap, indicating adequate exploration of the posterior distributions and convergence across independent chains. Quantitatively, convergence was assessed using the potential scale reduction factor ($\hat{R}$) and effective sample size (ESS). Across all models, $\hat{R}$ values ranged from 1.000 to 1.003, remaining well below the commonly recommended threshold of 1.05, indicating satisfactory convergence. Effective sample sizes ranged from 1,951 to 4,067 posterior draws across focal parameters, suggesting adequate sampling efficiency and stable posterior estimation. Posterior predictive checks were conducted to evaluate model fit. For each model, 100 replicated datasets were generated from the posterior distributions and compared with the observed outcome distributions. Density overlays for all models are presented in Figure S3. Across models, the observed data distributions aligned closely with the simulated posterior predictive distributions, suggesting that the models adequately captured the major distributional characteristics of the observed data without substantial evidence of systematic misfit.

Figure S2

Markov Chain Monte Carlo (MCMC) Trace Plots

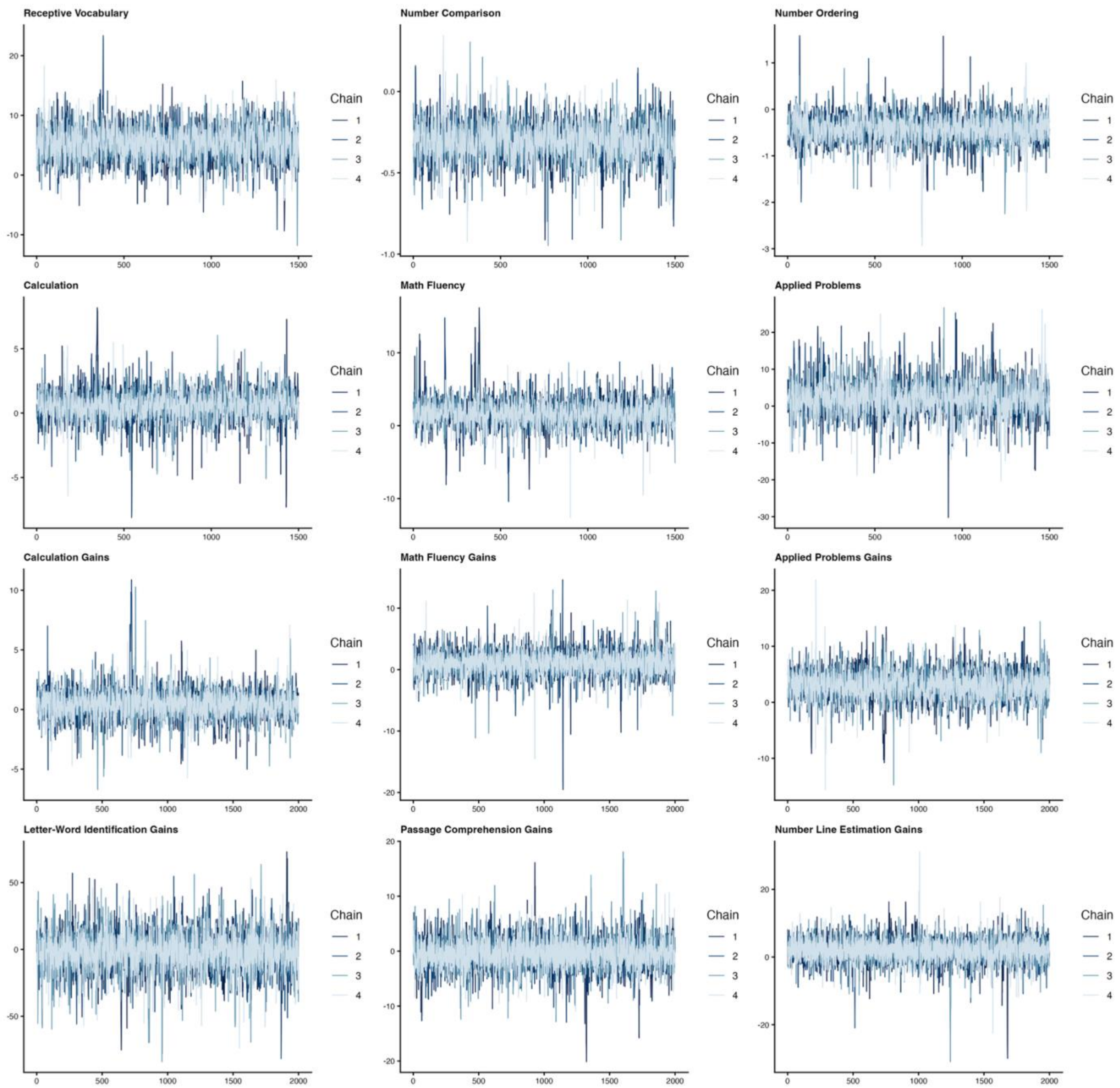
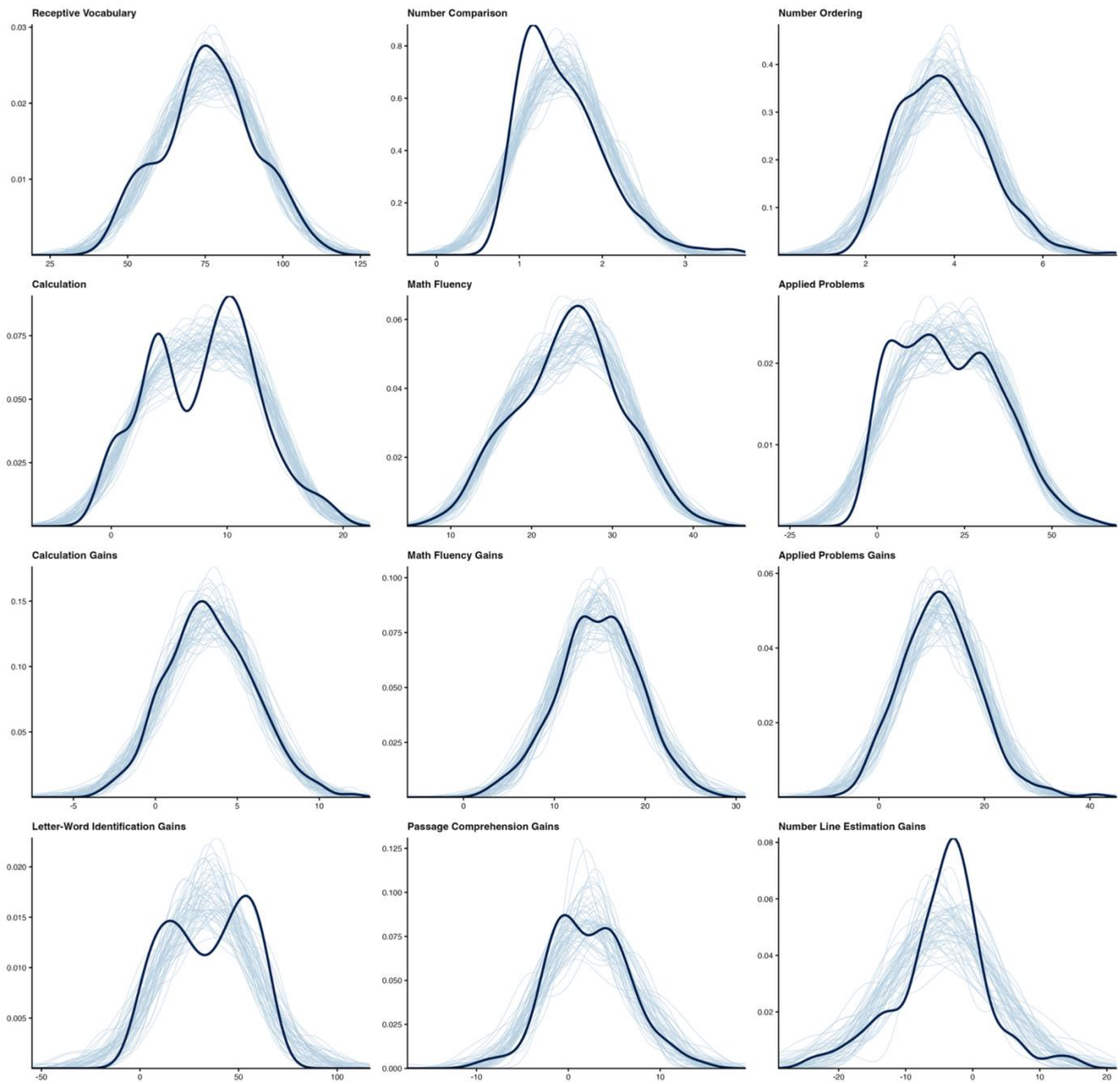


Figure S3

Posterior Predictive Checks



Number Line Estimation

In this task children are presented a number line with the endpoints 0 and 1000 on an iPad (“EstimationLine”; https://hume.ca/ix/estimationline/). A target number is shown on the screen, and children need to tap a spot on the line where they think the target number should be placed. After tapping the line, a red vertical mark is displayed to show their estimate. The line remains on the screen until the child presses the ‘Done’ button to advance to the next trial. Children complete two calibration trials where they are asked to tap a green target on the number line. The experimental trials, which include 24 target numbers (12 below the midpoint, 12 above the midpoint), are presented one at a time in random order. For each trial, the percentage absolute error (PAE) is calculated using the following formula: $PAE = \left[\frac{|Estimated\ Number - Target\ Number|}{1000}\right] \times 100$. Scoring was the mean PAE across all trials. Internal reliability was .90. For RQ3, gain scores were calculated as Time 1 - Time 2 because lower PAE is associated with more accurate estimation performance. This decision was made for ease of interpretation (i.e., positive gains associated with positive performance). Number line estimation was only measured in Grade 2 at Time 1 (and subsequently Grade 3 at Time 2), and thus we also included number ordering as a precursor.

Number line estimation at Time 1 (M_{PAE} = 14.0, SD = 8.5, Skew = 1.3) was significantly correlated (ps < .001) with all Time 1 measures (receptive vocabulary r = -.40; number comparison r = .43; number ordering r = .47; passage comprehension r = -.35; calculation r = -.42; math fluency r = -.45; applied problems r = -.55) and all Time 2 measures (passage comprehension r = -.25, p < .05; number line estimation r = .57; calculation r = -.45; math fluency r = -.50; applied problems r = -.47). In total, at Time 1 81 students completed the number line task in Grade 2 (M_{PAE} = 15.1, SD = 8.5, Skew = 1.3) and 82 children completed the number line task in Grade 3 (M_{PAE} = 12.9, SD = 8.9, Skew = 1.7). Number line estimation at Time 2 (M_{PAE} = 12.6, SD = 7.6, Skew = 1.2) was significantly correlated (*ps* < .001) with all Time 1 measures (receptive vocabulary $r = -.30$; number comparison $r = .31$; number ordering $r = .39$; letter-word identification $r = -.25$, $p < .05$; passage comprehension $r = -.34$; calculation $r = -.47$; math fluency $r = -.49$; applied problems $r = -.51$) and all Time 2 measures (passage comprehension $r = -.43$; calculation $r = -.41$; math fluency $r = -.50$; applied problems $r = -.51$). In total, at Time 2 79 students completed the number line task in Grade 2 ($M_{PAE} = 15.0$, $SD = 8.2$, Skew = 0.7) and 76 children completed the number line task in Grade 3 ($M_{PAE} = 10.1$, $SD = 6.1$, Skew = 2.2).

Contrary to Hypothesis 3a, school SES was not a reliable predictor of gains in number line estimation ($b = 1.92$, 80% CrI [-2.38, 6.22], 95% CrI [-4.77, 8.24]). Because no reliable SES effects were observed in the base model, Hypotheses 3b and 3c were not supported: School SES did not predict gains either before or after accounting for maternal education and cognitive precursors. Neither ($b = -0.15$, 80% CrI [-0.63, 0.33], 95% CrI [-0.89, 0.60]) nor receptive vocabulary ($b = -12.74$, 80% CrI [-26.33, 0.85], 95% CrI [-34.13, 8.07]) reliably predicted growth. However, number comparison skill at Time 1 was a reliable predictor of improvement at the 80% level ($b = -884.34$, 80% CrI [-1582.50, -174.80], 95% CrI [-1984.15, 215.67]), indicating that children with initially poorer number comparison skills showed greater reductions in number line estimation error over the year.